A Research on FRP: Development and Use in Construction

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ABSTRACT *Various traditional materials and methods are in use for new construction and retrofitting. Construction and retrofitting using FRP (Fiber Reinforced Polymer) is a novel approach which is advantageous over traditional methods and materials due to wonderful properties of composites. This research throws light on very development of FRP and its use in construction; in the end its wonderful properties have been discussed. The purpose here is to introduce a wonder material FRP to our society. Disseminating this knowledge is of great importance, as the wonder material is still considered relatively new in this part of the world.*

Keywords: *FRP (Fiber Reinforced Polymer), Retrofitting, Strengthening*

1. Introduction-

Various traditional materials are in use for new construction like timber, stones, bricks, steel, Aluminium and RCC etc. Again Retrofitting of structures has a powerful impact on economy and it is as important and technical as the design and construction of new structures. Various retrofitting materials and methods like cement grout, shotcrete/guniting, steel or concrete jackets, externally bonded steel plates etc. However a novel composite material FRP is available now-a-days for new construction and retrofitting, and is being adopted all over the world. FRP has advantageous wonderful properties like extremely light weight, extremely high strength and non-corrosiveness etc. over traditional materials and methods.

2. Retrofitting: Requirement, Traditional Methods and its Drawbacks-

There are various factors due to which retrofitting is required. Deterioration of structural strength of existing infrastructure (due to age and environmental attacks), up-gradation of various design codes (due to better understanding of various design concepts in due course of time) and higher load carrying capacity demand (due to present day increased service needs) warrant retrofitting. There are other reasons also which call for retrofitting of structures like-over loading, poor quality of constructions or design, up-grading of seismic zones. Individual members need to be upgraded to accommodate structural modification or changes in the use of structure etc. Structures may also need retrofitting due to an accident-man made including vandalism and pollution; or natural disasters, such as, earthquakes, floods, cyclones and Tsunami etc. Fire and explosive blasts can adversely affect the performance of even a new structural element and retrofitting is required.[1]

Structures have been retrofitted by traditional methods like- cement grout, stitching and grout injection, ferrocement cover, shotcrete/guniting, polymer modified concrete filling, section enlargement, post-tensioning/ external prestressing, 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.[2]

The method and nature of retrofitting depends on funds available, type of construction, level of strength desired, type and state of damage etc. However, the methods of retrofitting mentioned above have been used successfully for many applications but they have their own disadvantages and limitations. While these conventional methods can effectively enhance the elements load carrying capacity, they are often susceptible to corrosion damage requiring regular maintenance, else leading to failure of the strengthening system. Bonded steel plates, steel jackets, external posts tensioning involving steel are exposed to environmental attacks vulnerable to corrosion limiting their life. These methods require heavy lifting equipments so heavy working loads during installation, need for pressure on the adhesive during hardening, more curing time. It is also impossible to visually examine the condition of a retrofitted concrete member following a seismic event.[3] Again, high electric conductivity and magnetic interferences are coupled with these methods.

As Steel plates longer than 2–3m cannot be handled easily so the need of overlap joints arises, which involves installation skill, extra cost and time. Again joints are more prone to corrosion. As far as welding is concerned, it is not a desired solution in several cases, due to fatigue problems associated with weld defects. Bolted connections on the other hand have better fatigue life but are time intensive and expensive.[4]

Methods involving concrete are laborious, dusty and adding substantial mass to the structure. Long implementation and curing time hence longer period of evacuation and downtime, shrinkage and creep problems are some of the other drawbacks. Quality of strengthening depends heavily upon the skill of the personnel it is difficult to strengthen complex areas such as beam column connection.[5] All of these methods add considerably more dead load to the structure and are time consuming hence requiring more downtime. These methods are also liable to disturb the architecture of the structure.

This has drawn attention towards an innovative method, using FRP composite as retrofitting material. Method of retrofitting using FRP offers numerous advantages over these methods, and has attracted considerable attention in recent years. FRP composites applications apart from new construction, include retrofitting of reinforced concrete, steel, masonry, cast iron, aluminum and timber structures. It is also being used as replacement of steel in the form of FRP bars, pre-stressing tendons etc.[6]

3. FRP Development-

FRP materials were developed primarily for aerospace and defense industries in the 1940s and are widely used in many industries including construction industry today.[7,8] The very basis of strengthening existing structures using bonding technique are polymer adhesives such as epoxies and polyesters, known as synthetic adhesives. These adhesives are widely used for structural bonding today, and were first used in Germany at the beginning of 1930s. Natural adhesives such as starch, animal glues and plant resins have been used for centuries and are still used widely today for packing and for joining wood. However, these adhesives are not very good for structural bonding.[9] The method of strengthening existing concrete structures with the use of epoxy adhesives originated in France in the 1960s, where tests on concrete beams with epoxy bonded steel plates were conducted. There is also reported use of this strengthening method in South Africa in 1964. Since then, the application of epoxy bonded steel plates has been used to strengthen bridges and building in several countries over the world.[9] The first ideas on strengthening of concrete with epoxy bonded steel plates were presented in the 1960's by L'Hermite et al and Bresson. The first applications on a highway bridge and in a building followed in 1966-67.[10] Within 20 years since 1967, when L'Hermite and Bresson proposed the external bonding of steel plates with epoxy resins for the post-strengthening of structures, the partial substitution of steel plates (as there are many disadvantages associated with retrofitting using steel plates) with carbon fiber reinforced polymer (CFRP) strips was discussed at EMPA laboratories, Switzerland in 1982; and in 1987 it was shown that this is feasible.[11] FRP products were first used to RC structures in the mid 1950s.[12] Experimental work using FRP for retrofitting concrete structures was reported as early as 1978 in Germany.[13] The first known use of FRPs as reinforcement occurred in 1975 in Russia. There, glass fiber reinforced polymer (GFRP) prestressing tendons were used to reinforce a 30 ft. (9 m) long, glued timber bridge.[14] In Switzerland, one of the first applications with the use of carbon FRP (CFRP) was carried out at the end of the 1980s, and since then several thousand applications have been carried out worldwide.[9] FRP reinforcements gained significant support during the 1990s from research of magnetically levitated (maglev) train support structures in Japan. The Japanese in 1996 were the first to introduce design guidelines for FRP reinforced concrete. Since then, the use of FRP as structural reinforcement has increased exponentially and design guidance has been authored by organizations from around the world.[14] Nowadays, the strengthening of concrete by Fiber Reinforced Polymer is a state-of-the art technique.

4. FRP-A composite-

FRP- fiber reinforced polymer (also fiber reinforced plastics, as polymer based material is often known as plastic when used in commercial and industrial products) are normally made of two components, first-immensely strong high performance fibers (such as carbon, glass or aramid) and second-polymer resin matrix (such as polyester, vinylester or epoxy resin).[15] Composite materials are made by combining at least two different physically distinct and mechanically separable component materials with one or more materials as reinforcements, and one or more materials as the matrix. There are distinct, recognizable regions of each material. The materials are intermingled. There is an interface between the materials.[16] These are combined together to form a new material which posses properties that are remarkably different from those of its individual components. FRP composites are formed by embedding continous fibers in a resin matrix which binds the fibers together The fiber is primary load carrying component, while the matrix acts as binder, as environmental protector and stress distribution phase of the composite. 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. [17] However, FRP products produced for use in structural engineering can include significantly more ingredients than just the primary constituents: fiber and polymer resins. Fibers are produced with surface coatings called 'sizing'. Resins can contain filters, catalysts, accelerators, hardeners, curing agents, pigments, ultraviolet stabilizers, fire retardants, mold release agents and other additives. These constituents have different functions from causing the resin to polymerize to helping the processing to modifying the final properties of the FRP part.[15]

5. Classification of FRP and their specific use-

Depending on the fibers used, FRP composites are classified into three types: Glass Fiber Reinforced Polymer(GFRP), Carbon Fiber Reinforced Polymer(CFRP); and Aramid Fiber Reinforced Polymer(AFRP),[18] Basalt fiber reinforced polymer (BFRP), Recently Steel Fiber Reinforced Polymer is also introduced. FRP composites are available in various forms to fulfill various purposes. For new concrete structural members- FRP bars or grids, FRP tendons, and stay-in-place FRP formwork, FRP pultruded profile shapes for new structures; for existing structural members- rigid FRP strips, FRP fabric and sheets are available.[19]

They have different properties. The choice depends purpose of strengthening and environmental exposure. For example The low-tensile modulus of glass fiber composites (GFRP), ranging between 72 GPa, and 87GPa, makes them less desirable for retrofitting steel structures.[20]E-glass fiber reinforced polymer (GFRP) has the lowest cost of all structural FRPs and is therefore the most utilized. CFRP is most suited for flexural strengthening, they are most chemically inert also. Carbon fiber reinforced polymer (CFRP) has the highest strength of FRP materials and also the greatest range of strengths. The range is due to the carbon source and manufacturing methods. CFRP is most resistant to creep rupture and fatigue failure than the other FRPs. Its higher cost is offset by its high strength and high resistance to cyclic and fatigue failures. Aramid fiber reinforced polymer (AFRP) is not as common a structural reinforcement due to the fibers' low compressive strength perpendicular to the fiber direction and higher cost. It is this feature, though, that makes aramid fiber the choice of ballistic resistant textiles because the fibers absorb impact very well. Basalt fiber reinforced polymer (BFRP) has a higher cost due to a lack of manufacturer capacity, but with somewhat better strengths than GFRP, resistance to alkalies, and a nearly unlimited resource, its cost is sure to go down. [14]

6. Methods of Retrofitting using FRP-

FRP is being used in retrofitting of timber, iron, steel and RC structures for enhancing axial compressive strength and ductility, flexural strength, and shear strength etc. FRP plate bonding / wrapping /jacketing method generally known as Externally Bonded (EB) method. EB-FRP is the most popular method for retrofitting. EB-FRP systems come in various forms, and can be classified based on how they are delivered to the site and installed as Prepreg systems, Precured systems, Wet lay up system and other forms include cured FRP rigid rod and flexible strand or cables. However, in recent years a new variant of the retrofitting method called Near Surface Mounted (NSM) has been developed. Other methods using FRP, in which Power Actuated Fastners (PAF) and Mechanical Fastners (MF) are applied, are also there. Sprayed FRP is also one of the methods.

6. Advantages and Limitations-

FRP has many advantages over conventional materials and methods of retrofitting of RC structures. The increase in the use of FRP for retrofitting of RC structure may be credited to their advantageous wonderful properties at one hand such as – high corrosion resistance, outstanding tensile strength, extremely high strength to weight ratio, light weight, high specific stiffness, significant chemical adhesion, good fatigue, non electrical and non magnetic conductance, , low thermal conductivity, non metallic nature, high degree of formability and tailorability, ability to shield electromagnetic interference. On the other hand, ease of handling and installation, lesser time and cost required for installation, minimum service disruption hence less down time, low labour and equipment cost, easy and prompt manipulation on site, rot and termite proof, little maintenance and long life, no transportation problem as available in rolls, no unnecessary joint as endless tapes available; and on top of all, if one compares the life cycle cost, use of FRP can be cost effective in various cases.

However, use of FRP is a better alternative to traditional materials and methods for retrofitting of RC structures, there are factors which are limiting its everyday use. Very high material cost and ignorance of a large segment of construction community in the field of FRP are to mention in this perspective. In many countries, apart from lack of any guidelines or codes, absence of formal method of design of up-gradation, the unwillingness to accept existing reports, guidelines etc. that are presently being used worldwide is an obstacle to wider use of these material and techniques. Procuring and difficulty in using FRP, in small quantities at one end and uncertain supply of imported material at other also contribute in this direction.[21] Proper disposal of FRP waste is also its one of the limitations.

7. Concluding Remarks-

FRP proves to be a wonder material as it has many advantageous properties as compared to traditional/ conventional materials. However, despite a considerable number of field applications and laboratory research on FRP, the research results have not yet been fully getting its place into teaching curricula. There are not sufficient engineers who are knowledgeable enough to design structures with composite materials or to specify them for construction projects. FRP really is still a specialty item at many countries. Providing sufficient training on unique features of FRPs so that engineers could design or specify them in construction will improve the scenario. There is a need of Government-Industry-Institute partnership to take advantage of full potential of FRP. The increase in use of FRP for retrofitting is inevitable because of its potential. At last but not the least, works of researchers and authors are hereby duly acknowledged, using which this paper could get this form.

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