EXPERIMENTAL INVESTIGATION OF UNREINFORCED CONCRETE BEAMS EXTERNALLY BONDED WITH FRP

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ABSTRACT

Many of the existing reinforced concrete structures throughout the world are in urgent need of rehabilitation, repair or reconstruction because of deterioration due to various factors like corrosion, lack of detailing, failure of bonding between beam-column joints, increase in service loads etc, leading to cracking, spalling, loss of strength, deflection etc. The recent developments in the application of the advanced composites in the construction industry for concrete rehabilitation and strengthening are increasing based on specific requirements, national needs and industry participation. The need for efficient rehabilitation and strengthening techniques of existing concrete structures has resulted in research and development of composite strengthening systems. Fibre Reinforced Polymer (FRP) composite has been accepted in the construction industry as a promising substitute for repairing and in incrementing the strength of RCC structure. FRP composites possess some outstanding properties such as resistance to corrosion, good fatigue and damping resistance, high strength to weight ratio and electromagnetic transparency. FRPs over the years have gained respect in terms of its superior performance and versatility and now are being used not only in housing industry but its potentials are being continuously explored for its use in retro-fitting and strengthening of damaged structural members.

INTRODUCTION

The strengthening or retrofitting of existing concrete structures to resist higher design loads, correct deterioration related damage, or increase ductility has traditionally been accomplished using conventional materials and construction techniques. Externally bonded steel plates, steel or concrete jackets and external post-tensioning are just some of the many traditional techniques available.

Composite materials made of fibres in a polymeric resin, also known as fibre-reinforced polymers (FRP), have emerged as an alternative to traditional materials and techniques. An FRP system is defined as all the fibres and resins used to create the composite laminate, all applicable resins used to bond it to the concrete substrate, and all applied coatings used to protect the constituent materials. Coatings used exclusively for aesthetic reasons are not considered part of an FRP system.

FRP materials are lightweight, non-corrosive, and exhibit high tensile strength. Additionally, these materials are readily available in several forms ranging from factory-made laminates to dry fibre sheets that can be wrapped to conform to the geometry of a structure before adding the polymer resin. The relatively thin profile of cured FRP systems is often desirable in applications where aesthetics or access is a concern.

The growing interest in FRP systems for strengthening and retrofitting can be attributed to many factors. Although the fibres and resins used in FRP systems are relatively expensive compared to traditional strengthening materials like concrete and steel, labour and equipment costs to install FRP systems are often lower. FRP systems can also be used in areas with limited access where traditional techniques would be difficult to implement: for example, a slab shielded by pipe and conduit.

OBJECTIVES OF STUDY

The main objective of the experimentation was to study the effect of completely confinedunreinforced concrete beams of size 700x150x150mm with varying thicknesses of GFRP fabrics ranging from 3mm to 9mm and to analyze their increase in failure and flexural strength with respect to a control beam of similar dimension.

METHODOLOGY

Two different types of FRP fabrics were used for the experiment:

(a) Bi-directional FRP fabric with orientation of fibres in plus/minus 45 degrees having a thickness of 0.5mm.

(b) Bi-directional FRP fabric with orientation of fibres in 0/90 degrees with a layer of chopped strands (Also called BDCSM or Bi-directional chopped strand mat) with a thickness of 1mm.

The FRP fabrics were pasted on the beams in multiple layers using epoxy as per manufacturer's specifications. Air bubbles were eliminated using hand roller, in order to ensure a perfect bonding.

Figure 1: Bi-directional with chopped strand mat (BDCSM)

Figure 2: Bi-directional FRP fabric

The beams were grouped into four series labeled A to D. Each series had different layer thickness of GFRP. All beams were cast with the same geometrical dimensions of 700x150x150 mm using M-25 grade concrete. These beams were tested up to failure by applying two points loading from top in a flexural testing machine/ universal testing machine (UTM) in order to evaluate the enhancement of failure and flexural strength due to external strengthening.The beams were tested in concrete laboratory. to obtain the failure load and flexural strength.

ANALYTICAL CALCULATION OF FAILURE LOAD

Existing research suggests that the ultimate flexural strength of FRP strengthened RC beams can be predicted using existing design approaches with modifications to account for the brittle nature of FRPs. The beam is deemed to have reached failure when either the concrete compressive strain attains the maximum usable strain 0.0035 according to BS 8110-1997 and/or the FRP reaches the rupture strain.

The ultimate moment capacity of the reinforced beam (M_u) is given by the expression:

$$Mu = k1\frac{fcu}{\gamma c}bx\left(\frac{h}{2}-k2x\right)+\sum_{i=1}^{n}\sigma si.Asi\left(\frac{h}{2}-dsi\right)+\sigma frp.Afrp\left(\frac{h}{2}-dfrp\right)\_\_(1)$$

The depth of neutral axis (x) can be calculated using the expression:

$$k1\frac{fcu}{\gamma c}bx+\sigma si.Asi+\sigma frp.Afrp=0 \quad \_\,(2)$$

Where,

x= Depth of neutral axis
d_{si}= Centroid of steel bars in layer 'i' from the extreme concrete compression fiber
d_{frp}= Centroid of FRP from the extreme concrete compression fiber
h= Depth of beam
f_{cu}=Compressive strength of concrete
b= Beam width
k_1=Mean stress factor
k_2=Centroid factor of the compressive force
σ_{frp}= Stress in FRP
A_{frp}=Area of FRP
σ_{si}=Stress in steel bars
A_{si}= Area of tension reinforcement in layer 'i'
Y_c=Partial safety factor of concrete in flexure

Calculation of failure strength (cracking load) of beam with 3 mm thickness of FRP layer:
Substituting the values in the above equation (ignoring the values of σ_{si} and A_{si} since no steel reinforcement was used), the value of ultimate moment capacity of the beam (Mu) is calculated from eqn (1) as:

Mu= (-) 16.96 KNm

Ignoring the negative symbol and using the expression:

$$Mu=\frac{wl^2}{8}\_\_(3)$$

The failure load (w) is calculated from eqn (3) as:
W=277.04 KN

(Factor of safety considered is unity for all material strength)

EXPERIMENTAL RESULTS

The loading was done in a Universal Testing Machine (UTM) of 1000KN capacity. One dial gauge was placed below the beam at mid span to measure the deflection. The dial gauge was taken out, when it showed rapid deflection indicating imminent approach towards peak/failure load to avoid damage.
The following results were obtained after the beams were subjected to two point loading:

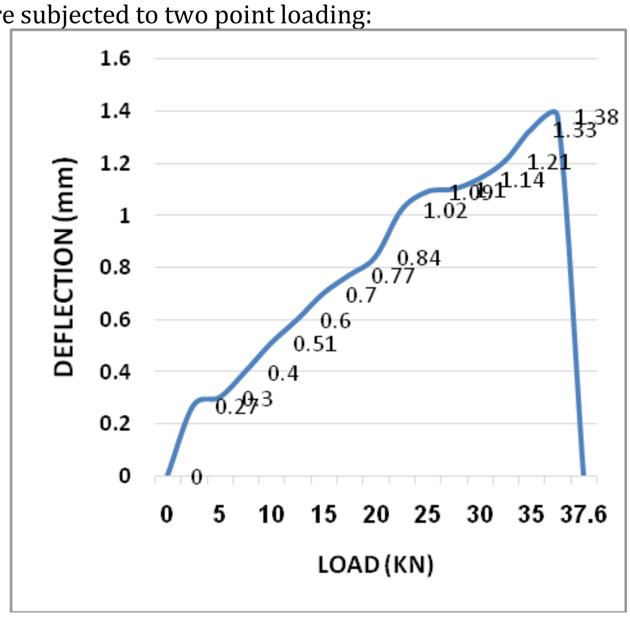

Figure 3: Load- Deflection diagram: Control beam

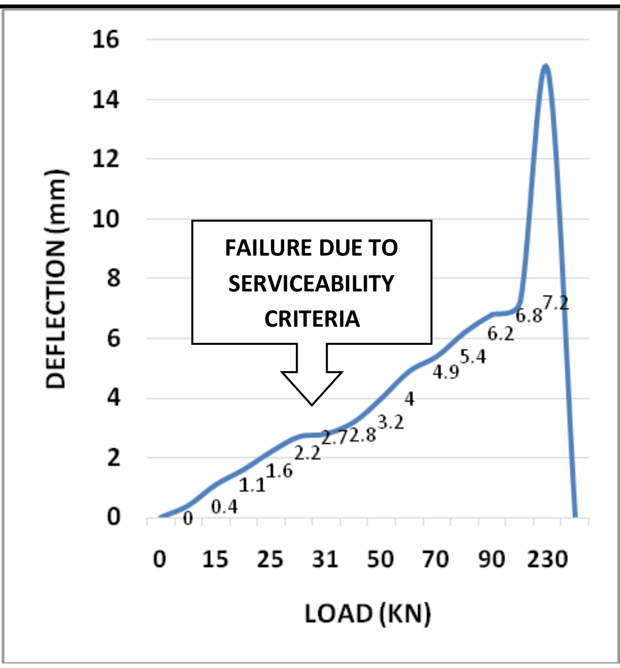

Figure 4: Load- Deflection diagram: Beam with 3mm FRP layer

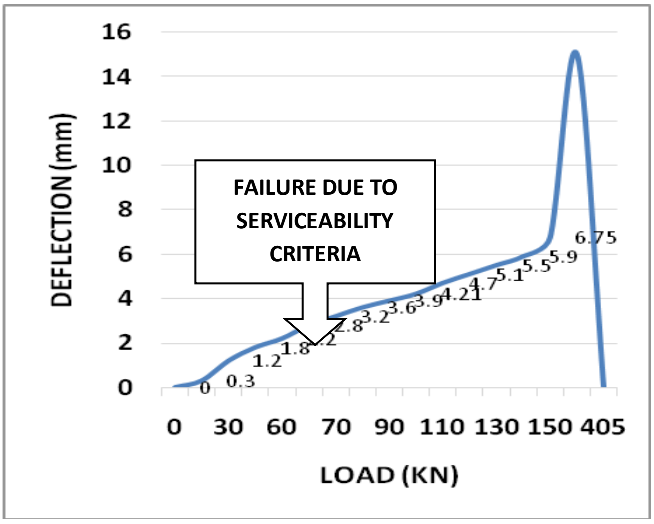

Figure 5: Load- Deflection diagram: Beam with 5mm FRP layer

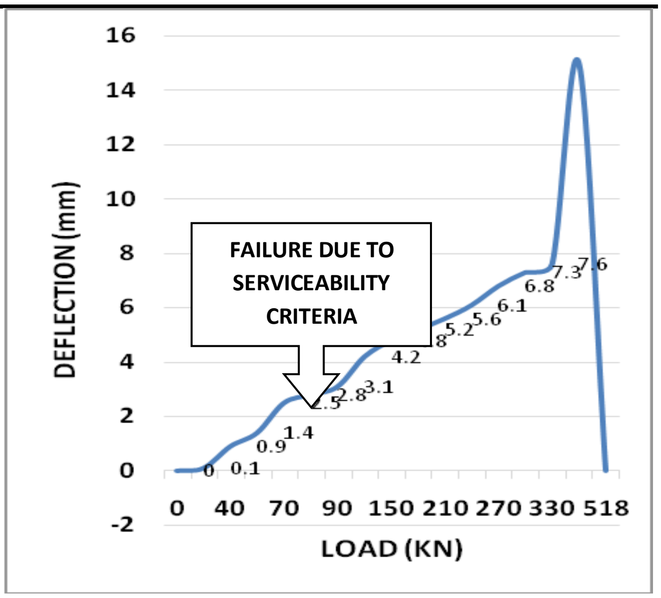

Figure 6: Load- Deflection diagram: Beam with 7mm FRP layer

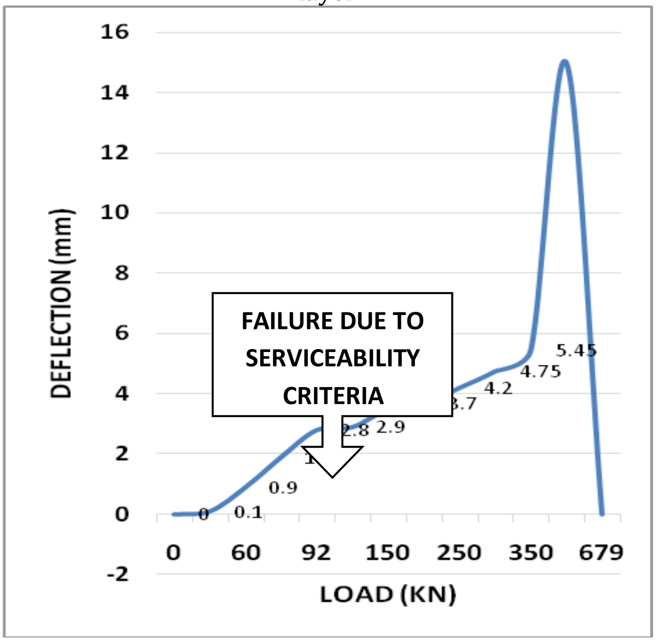

Figure 7: Load- Deflection diagram: Beam with 9mm FRP layer

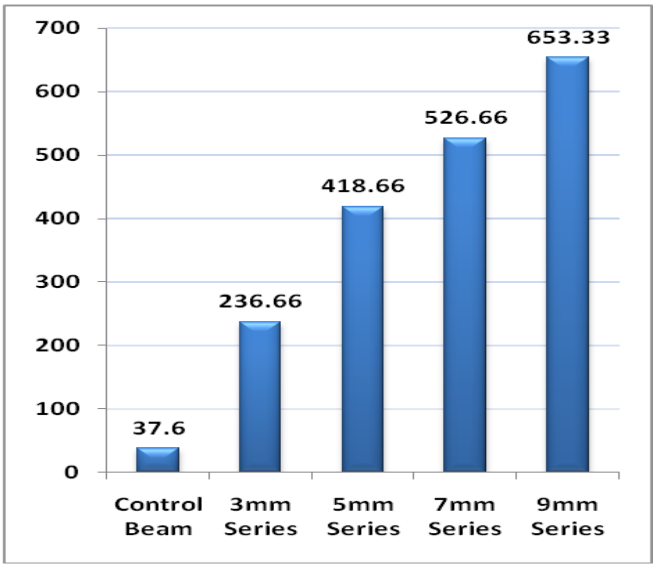

Figure 8: Average failure loads (KN)

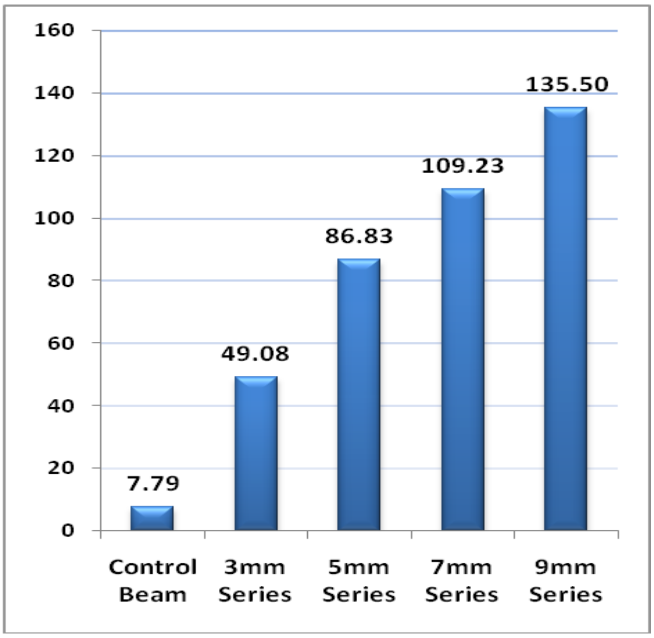

Figure 9: Average flexural strength (N/mm²)

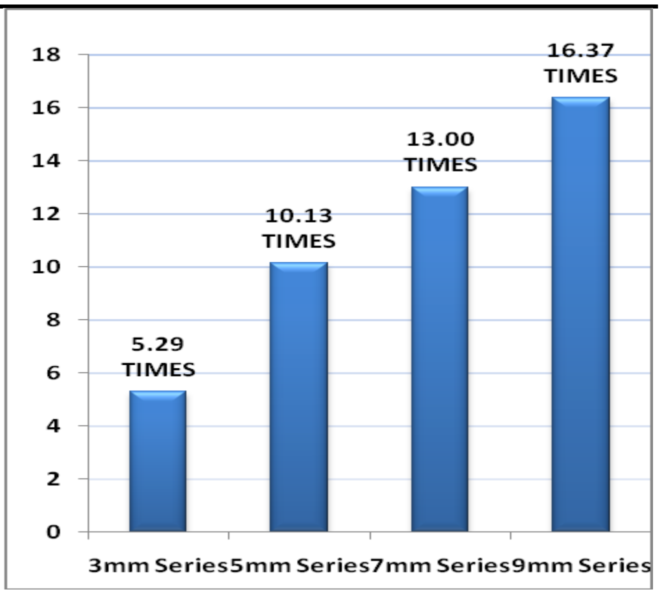

Figure 10: Increase in flexural strength with respect to control beams

DISCUSSION ON RESULTS

From the outcome of the experimental results, it is seen that increase in thickness of laminate, increases the fracture load of a structure.Though the samples failed in serviceability criteria at an early stage, they possessed a much greater strength to withstand failure.Confinement of structures with FRP results in exponential enhancement in strength. Likely applications of total confinement of structures may be precast slabs for culverts or short span crossings or any other pre cast structures for bridges.

CONCLUSIONS

FRP systems have been successfully used to strengthen bridges, buildings, tanks, tunnels and underground pipes. The higher cost of FRP is compensated by reduced cost of labour, use of equipment, downtime during installation, making them more cost effective than traditional strengthening techniques.

FRP systems can be effectively used for rehabilitation of structures affected by deterioration due to ageing, lack of maintenance, accidental events such as earthquakes and tsunamis, increase in service loads, large crack widths, large deformations and degradation of structures due to corrosion of steel.

Applications of FRP include flexural strengthening of slabs, flexural strengthening of beams, shear strengthening of beams, shear strengthening and confinement of columns, wrapping of concrete tanks, and shear strengthening of beam-column joints.

While strengthening with FRP can involve complex processes, this system offers number of advantages compared to conventional strengthening methods.

Understanding the properties and limitations of FRP is an important step in developing the right design solution and utilizing it for the right application.

RFERENCES

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