USE OF FIBRE REINFORCED POLYMERS (FRP) IN STRENGTHENING OF HIGH PERFORMANCE CONCRETE BEAM COLUMN JOINT

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Abstract - *Due to lot of cost involved in infrastructure and civil works, there is an urgent need for development of novel, long lasting and cost effective method for new construction, repair, strengthening, retrofitting and rehabilitation. Promising way of resolving such problems is to selectively develop techniques using advanced composites like FRP for such purposes. FRP's have been used in the past for strengthening normal grade concrete structures. Infrastructure constructions nowadays consist of use of high performance high strength concrete very often. The components like Beam-column, beam-column-slab and slab-column junctions of such construction have been identified as vulnerable locations which are subjected to highly horizontal and vertical forces during seismic excitation and may fail because of inadequate steel reinforcement, inadequate detailing and poor quality control during construction. Experimental study conducted on strengthening of high performance high strength concrete beam column joints using Fibre Reinforced Polymer of which results are presented.*

***Key Words*: FRP, Fibre Reinforced Polymer, HPC, High Performance Concrete, Strengthening, Beam Column Joint**

1. INTRODUCTION

Fibre Reinforced Polymer materials are now finding wide applications in the field of construction especially repairing, retrofitting and strengthening. The beam column joints are the crucial regions in framed structures. Some of the deficiencies in beam column joints such as inadequate reinforcement, poor detailing, and inadequate design are being overcome by use of High Performance concrete. Fibre Reinforced Polymer materials can find applications in such situations to overcome the deficiencies.

1.1Fibre reinforced polymers (FRP)

FRP composite materials are very attractive for applications in concrete structures due to their characteristics such as high strength to weight ratio, light weight and potentially high durability. Most important applications are in the renewal of constructed infrastructures such as buildings, bridges and pipelines etc. Recently it has been increasingly applied for the rehabilitation of concrete structures mainly due to fulfilling desired requirements of performance characteristics, ease of application and low maintenance cost during life cycle. These characteristics and the successful rehabilitation measures led to development of FRPsystems.

In recent days, civil engineering and the construction industry have begun to witnessing the potential of fibre reinforced polymers (FRP) composites as strengthening material for many problems associated with the deterioration of buildings and infrastructures. Over the last decade, an increase in the application of FRPCs has been seen in construction industry because of their good engineering properties. Further, these are being considered as a replacement to the conventional steel in reinforced concrete structures due to continuing drop in the cost of FRP materials.

FRP can be applied to strengthen the beams, columns, and slabs of buildings and bridges [7]. It is possible to increase the strength of structural members even after they have been severely damaged due to loading conditions. In the case of damaged reinforced concrete members, this would first require the repair of the member by removing loose debris and filling in cavities and cracks with mortar or epoxy resin. Once the member is repaired, strengthening can be achieved through wet, hand lay-up of fibre sheets impregnated with epoxy resin, applied to the cleaned and prepared surfaces of the member. Test on rehabbed specimen suggests that FRP not only restores its original strength but there is considerable enhancement in its yield load, initial stiffness and energy dissipation capacity. [8] Evaluation of the environmental impact of FRP composites in infrastructure applications shows direct and indirect benefits that are more competitive than conventional materials. The selection of FRP materials should be subject to its ability to reduce the overall life-cycle costs. It is now an established fact that composites enable concrete infrastructure to achieve long service life without costly repairs and maintenance.

1.2 High performance concrete (HPC)

High performance concrete being a specialized series of concrete has been designed to provide several benefits in the construction of concrete structures. Performance benefits that can be derived are long term mechanical properties such as early high strength, toughness, volume stability, longer life in severe environments etc. Several strength and durability criteria were used in evaluation of high performance concrete design. American Concrete Institute

(ACI) defines high performance concrete as concrete meeting a special combination of performance and uniformity requirements that cannot be always achieved routinely using conventional constituents and normal mixing, placing and curing practices.[2] It demands much higher performance from concrete as compared to performance expected from routine concrete. United States Federal Highway Administration (USFHWA) [9] defines HPC mixtures essentially composed of same material as conventional concrete mixtures but the proportions are designed to provide strength and durability required for the structural and environmental requirements.

HPC can also be defined more precisely that "concrete that attains mechanical, durability or constructability properties exceeding those of normal concrete." The term HPC is used to describe concretes that are made with carefully selected high quality Ingredients, optimized mixture designs, and which are batched, mixed, placed, consolidated and cured to the highest industry standards. High-performance concrete (HPC) exceeds the properties and constructability of normal concrete, Typically, HPC will have a water-cement ratio (w/c) of 0.20 to 0.40. Plasticizers are usually used to make these concretes fluid and workable. Achievement of these low w/cm concretes often depends on the effective use of admixtures to achieve high workability, another common characteristic of HPC mixes.

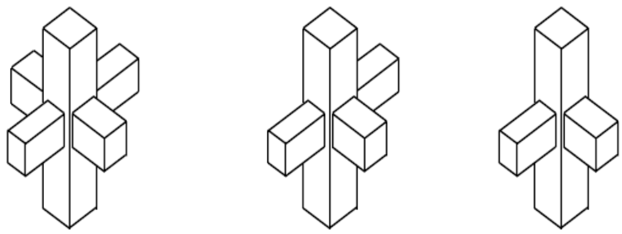
High-performance concrete characteristics are developed for particular applications and environments. The properties are High strength, High early strength, High modulus of elasticity, High abrasion resistance, High durability and long life in severe environments, Low permeability and diffusion, Resistance to chemical attack, High resistance to frost and deicer scaling damage, Toughness and impact resistance, Volume stability, Ease of placement, Compaction without segregation, Inhibition of bacterial and mold growth [4] Durability is of utmost importance for structures exposed to the environment. [6]

High-performance concrete almost always has a higher strength than normal concrete. High-strength concrete (HSC) to have a strength significantly beyond what is used in normal practice. Design strength of at least 70 MPa or above is considered as high strength concrete. However, strength is not always the primary required property.

1.3 Beam Column Joint

Beam column and slabs are considered as structural elements in any framed structures. Whenever these members meet together in a frame structure they form a structural system. Beam column joints in a reinforced concrete moment resisting frame are crucial zones for transfer of loads effectively between the connecting elements i.e., beams and columns in the structure. The beam column joint is the crucial zone in a reinforced concrete moment resisting frame. It is subjected to large forces during severe ground shaking. The basic requirement of a joint is to enable the adjoining members to develop and sustain their ultimate capacity. The demand on this finite size element is always severe under seismic loading and therefore beam column joints should have an acceptable strength and stiffness to withstand internal forces developed by the adjoining members.

A joint is considered as the portion of the column within the depth of deepest beam that frames into the column. In a moment resisting frame, three types of joints are identified these are categorized as interior, exterior and corner joints. Beam column joints are generally classified with respect to geometrical configuration and identified as interior, exterior and corner joints as shown in Figure1. [3] Whenever four beams frame into the vertical faces of the column, the joint is regarded as an interior joint or an interior beam-column joint consists of two beams on either side of the column. An exterior beam-column joint has a beam terminating on one face of the column. When beams frame into two adjacent vertical faces of a column the joint is considered as a corner joint.



(a) Interior (b) Exterior (c) Corner

Fig -1: (a) to (c) Types of Joints in a Frame

2. MECHANISM OF FAILURES OF BEAM - COLUMN JOINTS

The complex state of stress in beam-column joints, leading to building collapse, has been recognized as a major cause in past earthquakes. This may be attributed to inadequate joint confinement. The inadequacy of building joint designed according to earlier standards has been observed to be major cause of severe damage or collapse since beam-column and slab-column-beam joints are vulnerable locations. This type of damage has been observed in many earthquakes as also shown in Photograph 1 and Photograph 1 respectively. Shear failure or bond failure are considered undesirable since they lead to degradation of strength and stiffness of the frame [5]. The failure of interior beam-column joints can also be initiated by pull out of the beam bottom steel reinforcement at the joint typically embedded for short and insufficient length into the column.

3. STRENGTHENING USING FRP

FRP are usually applied to concrete either in the form rigid plates or flexible fabrics. The most common fibres that are used in FRP are carbon fibres, E-glass (or Fibre Glass) and Aramid (or Kevlar). The application of FRP in construction may be justified in the construction industry in terms of cost benefit ratio in the light of the fact that the use of FRP materials for strengthening is considered the most economical option of strengthening due to much lower installation cost. The FRP's are mainly used for flexural strengthening and shear strengthening concrete structural elements such as beam, column and slabs.

Photograph -1: Damaged beam-column joint during earthquake (Kocaeli, Turkey 1999) [5]

Photograph -2: Beam-column connection failure, Izmit, Turkey, 1999 earthquake [5]

4. THE EXPERIMENTATION PROGRAMME

The experimentation programme consist of determining effect on performance of High Performance Concrete beam-column joint strengthened with different types of Fibre Reinforced Polymers and different types of strengthening patterns. The experimental program was divided into 3 separated phases including the testing of bare or virgin specimen that is damaging phase, the repairing phase consisting of surface treatment and FRP strengthening and the retesting phase of strengthened specimen.

4.1 The High Performance Concrete Mix

The High Performance Concrete having high strength of 70 Mpa for which concrete mix design carried out by testing properties of constituents materials. HPC concrete mix was designed by using part of the cement replaced by micro fillers like silica fumes, fine aggregates, and water binder ratio, high range of water reducing agent or super plasticizer. Ordinary Portland Cement of 43 Grade was used. Fine aggregate used are mixture of two types of sand in proportion of 1:1.5. One portion is conforming to Zone III and second portion conforming to Zone II. The crushed stone aggregate of 10mm size obtained were used. Silica fume is a Supplementary cementitious material is used. For designing HPC–High Performance High Strength concrete mix, American Concrete Institute method ACI 211.4-08 [1] for HPC have been used. Concrete Mix Proportion for M70 grade of concrete corresponding to 1 : 0.112 : 2.22 : 1.473 : 0.28 : 1.2 representing cement, silica fume, coarse aggregate (10mm), fine aggregate, water cement ratio and HRWR has been used in casting of beam column joints core. Only core portion of beam column joint was casted with M70 grade of concrete while outer portion of beam column joints other than core portion was cast with normal M20 grade of concrete.

4.2 Steel reinforcement

Steel reinforcement used in the beams and column consisted of 10mm diameter bars and stirrups were of 6mm diameter of high yield strength deformed Fe 500 grade bars to take care of handling stresses in the Beam Column joint specimens.

4.3 Dimensions of the specimen

The dimensions of the beam column joints cast are shown in Fig. 2 and 3.

4.4 Surface Preparation

For surface preparation, Sikadur-31 is 2 part thixotropic adhesive is used to seal the wide cracks. Sikadur-52 is a low viscosity injection resin is used as an grouting epoxy to fill and seal voids and cracks.

4.5 FRP materials used

Glass Fibre Reinforced Polymer Wrap GFRP – SIKAWRAP – 430 G a woven unidirectional glass fiber fabric, Carbon Fibre Reinforced Polymer Wrap Type 1– CFRP1- SIKAWRAP – 230 C a woven unidirectional carbon fiber fabric and Carbon Fibre Reinforced Polymer Wrap Type 2 –CFRP2 – SIKAWRAP – 450 C a Stitched carbon fiber fabric used for wrapping. Sikadur – 330 – Adhesive – 2-part epoxy primer impregnation resins is used as impregnation resin for SikaWrap fabric reinforcement for the dry application and structural adhesive for bonding Sika CarboDur plates. Properties of materials are given in Table1

4.6 Testing of Specimens

A fully digital loading frame of 2000kN capacity has been used for applying the load. Linear Variable Differential

Transducers (LVDTs) were used to measure the deformations. The data acquisition system was fixed with the loading frame attached with the LVDT wires. The testing of virgin beam column joints was done in loading frame. A hydraulic jack was used to apply the load at the free end of the beam by the load cell. The beam column joints were tested by applying monotonically increasing load through load cell.

The beam column joint specimens get damaged during testing in loading frame needed proper surface preparation to apply the FRP wrap over it as it is difficult to apply the FRP with adhesive on concrete surfaces due to cracks, dust and uneven surfaces. Dirt, dust and other foreign materials are removed to make it open textured surface. After sealing and grouting, the sharp corners of joint have to be made rounded to make them smooth so that FRP sheet would be wrapped easily. The specimens are strengthened with single layer of FRP fabric on front full face, back full face and sides in the form of overlays. The fabric is glued to the surfaces in specified manner.

The testing of strengthened beam column joint specimen has been carried out in similar fashion as of virgin beam column joints. The experimental observations pertaining to virgin and strengthened beam column joints specimens were recorded.

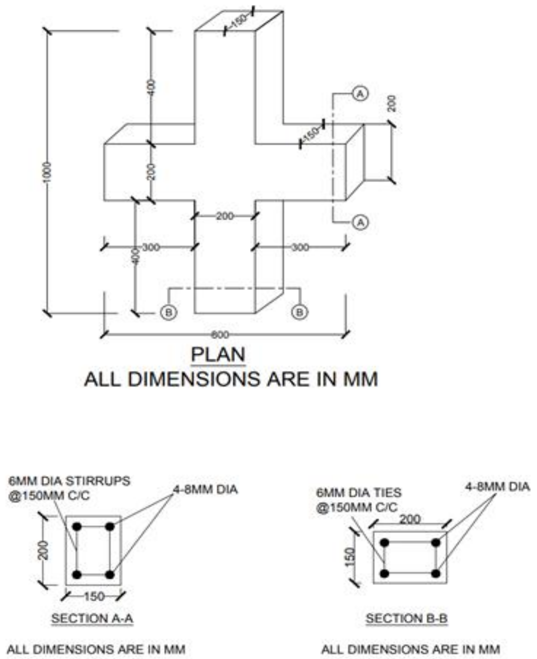


Fig -2: Development of beam-column joints

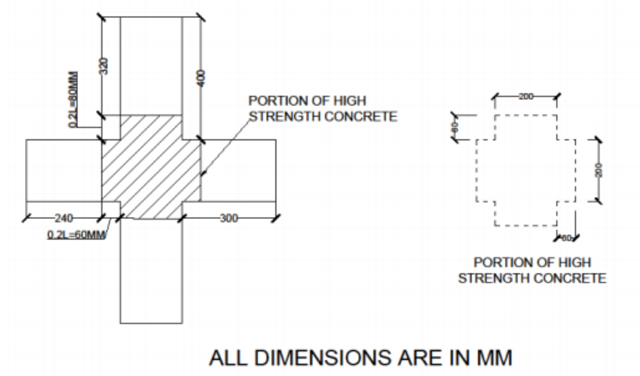


Fig -3: Dimensions of beam-column joints

5. STRENGTHENING SYSTEM

The strengthening pattern adopted and results are discussed.

5.1 Specimen Details

The three beam column joints have been cast. They are designated as below shown in Table 2

Table -1: Properties of materials

Material	Description	Effective Thickness (mm)	Tensile Strength (Mpa)	Tensile Modulus (Mpa)
GFRP SikaWrap - 430G	unidirectional woven glass fiber fabric	0.172	1334	76000
CFRP Type 1 SikaWrap - 230C	unidirectional woven carbon fiber fabric with mid-range strengths	0.129	3200	220000
CFRP Type2 SikaWrap - 450C	unidirectional woven carbon fiber fabric	0.255	3200	220000

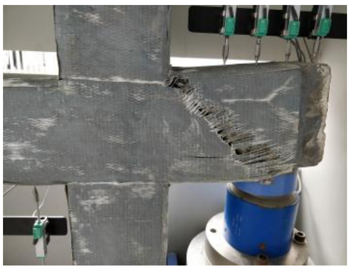
Table -2: Properties of materials

Sr. No.	Designation	Description
X1	GPSFBS	Glass Fibre Reinforced Polymer Single Layer Front, Back and Sides
X2	CP1SFBS	Carbon Fibre Reinforced Polymer Type 1 Single Layer Front, Back and Sides
X3	CP2SFBS	Carbon Fibre Reinforced Polymer Type 2 Single Layer Front, Back and Sides

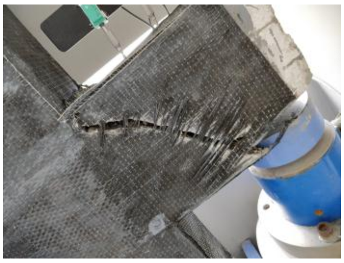
Photograph -3: Experimental set up with locations of LVDT

Photograph -4: Front face, Back face and Side face pattern of FRP fabric

5.2 Results and Discussion

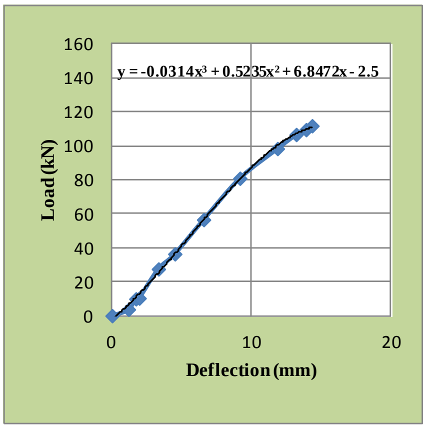


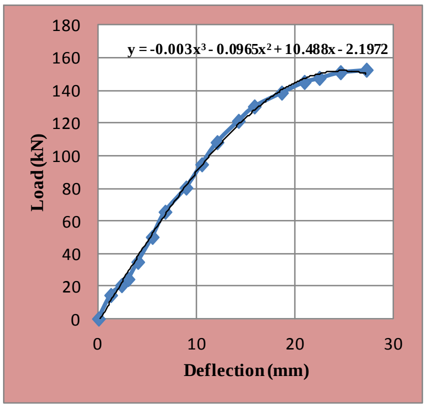
Photograph -5: Failure pattern observed in case of GFRP specimen



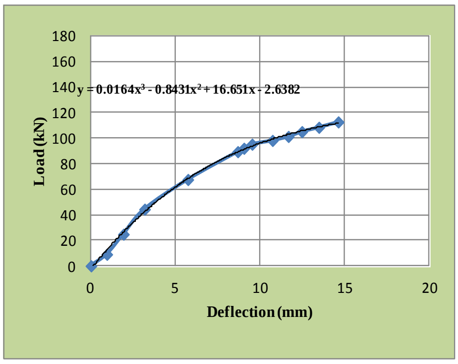
Photograph -6: Failure pattern observed in case of CFRP1 specimen

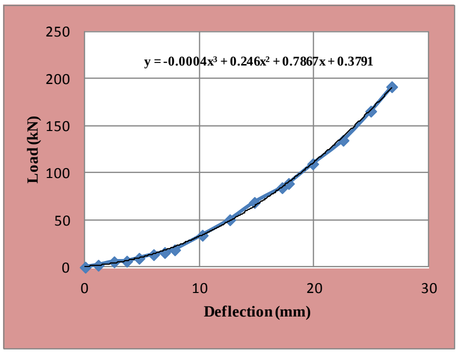
Photograph -7: Failure pattern observed in case of CFRP2 specimen



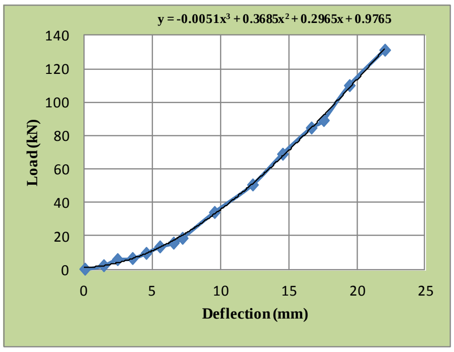


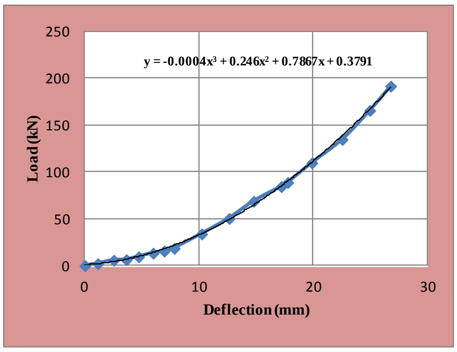
(a) GPSFBS Specimen





(a) CP1SFBS Specimen





(a) CP2SFBS Specimen

Fig -4: Pre strengthening and post strengthening Load versus Deflection curve for specimen (a) GPSFBS (b) CP1SFBS (c) CP2SFBS specimen respectively.

Failure Pattern- The beam column joints cast with high strength concrete were tested by applying monotonically increasing concentrated load and it was observed that the failure occurred in less ductile but more brittle nature. The same beam column joint when strengthened with different FRP materials, the failure pattern was observed to be ductile with increased energy absorption capacity. After strengthening, FRP fabrics have been yield of and pull out of it observed in case of CFRP 2.

Load carrying capacity- Load carrying capacity has been significantly increased in all three types of FRP while it was highest in case of CFRP2 i.e. 55.22 %.

Table 3 shows the summary of results.

Sr. No.	Designation	Ultimate load before strengthening kN	Ultimate load After strengthening kN	% increase in ultimate load
X1	GPSFBS	111.81	145.65	30.26
X2	CP1SFBS	112.48	149.47	32.89
X3	CP2SFBS	124.25	192. 87	55.22

6. CONCLUSIONS

Both glass and carbon fibre reinforced polymer materials can be efficiently used for strengthening and retrofitting of reinforced concrete joints. Joints exhibit enhanced strength. Specimens strengthened with CFRP2 show highest increase in joint strength while GFRP and CFRP1 show nearly equal increase. CFRP1 has marginally higher increase than GFRP strengthened specimen. Test on strengthened specimen shows that FRP not only restores its original strength but there is considerable enhancement in its load carrying capacity.

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BIOGRAPHIES

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