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USE OF FRP SHEETS TO STRENGTHEN THE EXISTING BEAMS

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ABSTRACT

The rehabilitation of existing reinforced concrete (RC) bridges and building becomes necessary due to ageing, corrosion of steel reinforcement, defects in construction/design, demand in the increased service loads, and damage in case of seismic events and improvement in the design guidelines. Fiber-reinforced polymers (FRP) have emerged as promising material for rehabilitation of existing reinforced concrete structures. The rehabilitation of structures can be in the form of strengthening, repairing or retrofitting for any type of deficiencies. RC rectangular-section is the most common shape of beams and girders in buildings and bridges.
A repair mechanism for the concrete beams with a particular percentage of damage has been attempted. CFRP which is a well-accepted & efficient material for repair & rehabilitation is used in this study. The reinforced concrete beams has been tested and performance under single point loading setup. CFRP sheet were bounded to the beams with different configuration with the main objective of increasing the service life load capacity.
In a set of experiments, all beams were subjected to a certain level of loading to create damage and then repaired with CFRP sheet with different configuration except one beam i.e. control beam and another one beam was repaired under sustain loading condition.
The overall objective of this study is to investigate the performance and failure modes of RC beams strengthened with externally bonded CFRP sheets. In order to achieve these objectives, an extensive experimental program consisting of testing five full scale RC beams will be carried out.

1. Introduction

Reinforced concrete (RC) is an extremely popular construction material. It has proven to be successful in terms of both structural performance and durability. Because of the nature and role of concrete in the creation, rehabilitation and regeneration of the infrastructure system of any country, Reinforced concrete plays a very important part in a nation's economic development. Lack of durability of Reinforced concrete structures has thus not only massive economic implications to a nation's well-being, but it is also one of the greatest threats to sustainable growth of concrete and construction industries.
Many natural disasters, earthquake being the most affecting of all, have produced a need to increase the present safety levels in buildings. The knowledge of understanding of the earthquakes is increasing day by day and therefore the seismic demands imposed on the structures need to be revised. The design methodologies are also changing with the growing research in the area of seismic engineering. So the existing structures may not qualify to the current requirements. As the complete replacement of such deficient structures leads to

incurring a huge amount of public money and time, retrofitting has become the acceptable way of improving their load carrying capacity and extending their service lives.

Deterioration in concrete structures is a major challenge faced by the infrastructure and bridge industries worldwide. The deterioration is 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 ultra-violet radiations. This problem, coupled with revisions in structural codes needed to account for the natural phenomena like earthquakes or environmental deteriorating forces, demands development of successful structural retrofit technologies. The structural retrofit problem has two options, repair/retrofit or demolition/reconstruction.

The following are some reasons that may need retrofitting:-

- Building which are designed considering gravity loads only.
- Development activities in the field of Earthquake Resistant Design (EQRD) of buildings and other structures result into change in design concepts.
- Lack of timely revisions of codes of practice and standards.
- Lack of revisions in seismic zone map of country.
- In cases of alterations in buildings in seismic prone area i.e. increase in number of story, increase in loading class etc.
- In cases of deterioration of Earthquake (EQ) forces resistant level of building e.g. decrease in strength of construction material due to decay, fire damage, and settlement of foundations.
- The quality of construction actually achieved may be lower than what was originally planned.
- Lack of understanding by the designer.
- Improper planning and mass distribution on floors.

Traditionally, the trend within the construction industries has been towards the latter option. This solution has become increasingly unacceptable due to changing economic and social attitudes concerning existing structures. This fact leads to the necessity for development of appropriate structural retrofit/repair systems. Traditionally, the retrofitting of reinforced concrete structures, such as columns, beams and other structural elements, involved a time consuming and disruptive process of removing and replacing the low quality or damaged concrete or/and steel reinforcements with new and stronger material. However, with the introduction of new advanced composite materials such as fiber reinforced polymer (FRP) composites, concrete members can now be easily and effectively strengthened using externally bonded FRP composites.

Retrofitting of concrete structures with wrapping FRP sheets provide a more economical and technically superior alternative to the traditional techniques in many situations because it offers high strength, low weight, corrosion resistance, high fatigue resistance, easy and rapid installation and minimal change in structural geometry. In addition, FRP manufacturing offers a unique opportunity for the development of shapes and forms that would be difficult or impossible with the conventional steel materials. Although the fibers and resins used in FRP systems are relatively expensive compared with traditional strengthening materials, labor 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 impractical. However, the use of these materials for retrofitting the existing concrete structures cannot reach up to the expectation due to lack of the proper knowledge on structural behavior of concrete structures retrofitted by fiber reinforced polymers (FRP) composites. Successful retrofitting of concrete structures with FRP needs a thorough knowledge on the subject and available user-friendly technologies/ unique guidelines. Beams are the critical structural members subjected to bending, torsion and shear in all type of structures. Similarly, columns are also used as various important elements subjected to axial load combined with/without bending and are used in all type of structures considering from building to bridge as piers or abutments. Therefore, extensive research works are being carried out throughout world on retrofitting of concrete beams and columns with externally bonded FRP composites. Several investigators took up concrete beams and columns retrofitted with carbon fiber reinforced polymer (CFRP)/ glass fiber reinforced polymer (GFRP) composites in order to study the enhancement of strength and ductility, durability, effect of confinement, preparation of design guidelines and experimental investigations of these members. The results obtained from different investigations regarding enhancement in basic parameters like strength/stiffness, ductility and durability of structural members retrofitted with externally bonded FRP composites, though quite encouraging, still suffers from many limitations. This needs further study in order to arrive at recognizing FRP composites as a potential full proof structural additive. FRP repair is a simple way to increase both the strength and design life of a structure. Because of its high strength to weight ratio and resistance to corrosion, this repair method is ideal for deteriorated concrete structure due to exposure to de-icing salts and other environmental factors by encasing concrete members .FRP protects from existing salts and other environmental factors .It is noted that in many bridges the majority of corrosive damage occurred on exterior girders. This indicates that deleterious effects may be direct results of surface exposure, to spray of water, de-icing agents and environmental effects. Encasement of these girders not only increases design life, but also protects the members from surface attacks. FRP is a versatile material.

1.2 FRP AND RETTROFITTING

1.2.1 INTRODUCTION

Retrofitting of existing infrastructure is bound to increase all over the world. This is because of deterioration of structural strength of existing infrastructure (due to age and environmental attacks),up-grading 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) etc. For years, civil engineers have been in search for alternatives to steels and alloys to combat the high costs of repair and maintenance of structures damaged by corrosion and heavy use. Since 1940s, composite materials, formed by the combination of two or more distinct materials in a microscopic scale, have gained increasing popularity in the engineering field. Fiber Reinforced Polymer (FRP) is a relatively new class of composite material manufactured from fibers and resins and has proven efficient and economical for the development and repair of new and deteriorating structures in civil engineering. Wide spread utilization of FRP's in construction is hampered by lack of long-term durability and performance data in tropical environment.

FRP (Fiber-reinforced polymer)

Fiber-reinforced polymer commonly known as FRPs represents a class of materials that falls into a category referred to as composite materials. Composite materials consist of two or more materials that retain their respective chemical and physical characteristics when combined together. FRPs are commonly used in the aerospace, automotive, marine, and construction industries. Fiber-reinforced polymer is a composite material made of a polymer matrix reinforced with fibers. The fibers are usually glass, carbon, or aramid, while the polymer is usually an epoxy, vinyl ester or polyester thermosetting plastic.

Fibers can be formed from a wide range of amorphous and crystalline materials but in the construction industry the three fibers which are generally used in structural systems are

- The glass fiber (the E-glass fiber, the S-glass fiber and the Z-glass fiber),
- The aramid fiber (the aromatic polyamides, Kevlar 49 fiber) and
- The carbon fiber (the ultra-high-modulus fiber, the high-modulus fiber and the high-strength fiber).

1.3 OBJECTIVE

- To study the contribution of externally bonded Fiber Reinforced Polymer (FRP) sheets on the behavior of RC beams.
- To know the contribution of FRP sheet composites as repair materials under sustain loading condition.
  - **Ghazi et al. (1994)** studied the behaviour of reinforced concrete (RC) beams strengthened in shear with fiber glass plate bonding (FGPB) for structural and non-structural cracking behaviour due to a variety of reasons. Results from a study on strengthening of RC beams having deficient shear strength and showing major diagonal tension cracks have been presented. The beams with deficient shear strength were damaged to a predetermined level (the appearance of the first shear crack) and then repaired by fiber glass plate bonding (FGPB) techniques. Different shear repair schemes using FGPB to upgrade the beams shear capacity were used, i.e., FGPB repair by shear strips, by shear wings, and by U-jackets in the shear span of the beams and the results show that the increase in shear capacity by FGPB was almost identical for both strip and wing shear repairs. However, this increase was not adequate to cause beams repaired by these two schemes to fail in flexure.

  - **Chajes et al. (1995)** worked on shear strengthening of reinforced concrete beams using externally composite fabrics. Here, a series of 12 under-reinforced concrete T-beams was tested to study the effectiveness of beams using externally applied composite fabrics as a method of increasing beam shear capacity. Oven composite fabrics made of aramid, E-glass, and graphite fibers were bonded to the web of the T-beams using a two-component epoxy. The three different fabrics were chosen to allow various fabric stiffness's and strengths to be studied. The beams were tested in flexure, and the performance of eight beams with external shear reinforcement was compared to results of four control beams without external reinforcement. All the beams failed in shear and those with composite reinforcement displayed excellent bond characteristics. For the beams with external reinforcement, 60 to 150 % of increase in ultimate strength was achieved.
  - **Norris et al. (1997)** examine the behavior of damaged or under strength concrete beams retrofitted with thin carbon fiber reinforced plastic (CFRP) sheets, epoxy bonded to the tension face and web of the concrete beams to enhance their flexural and shear

strengths. The effect of CFRP sheets on strength and stiffness of the beams is considered for various orientations of the fibers with respect to the axis of the beam. The beams were fabricated, loaded beyond concrete cracking strength, and retrofitted with different CFRP systems. The beams were subsequently loaded to failure. Finally, they concluded that there is increase in strength and stiffness of the existing concrete structures after providing CFRP sheets in the tension face and web of the concrete beam depending upon the different orientation of fiber.

- **Khalifa et al. (2000)** studied the shear performance and the modes of failure of reinforced concrete (RC) beams strengthened with externally bonded carbon fiber reinforced polymer (CFRP) wraps experimentally. The experimental program consisted of testing twenty-seven, full-scale, RC beams. The variables investigated in this research study included steel stirrups (i.e., beams with and without steel stirrups), shear span-to depth ratio (i.e., a/d ratio 3 versus 4), CFRP amount and distribution (i.e., Continuous wrap versus strips), bonded surface (i.e., lateral sides versus U-wrap), fiber orientation (i.e., 90°/0° fiber combination versus 90° direction), and end anchor (i.e., U-wrap with and without end anchor). As part of the research program, they examined the effectiveness of CFRP reinforcement in enhancing the shear capacity of RC beams in negative and positive moment regions, and for beams with rectangular and T-cross section. The experimental results indicated that the contribution of externally bonded CFRP to the shear capacity is significant and dependent upon the variable investigated. For all beams, results show that an increase in shear strength of 22 to 145% was achieved.
- **Khalifa and Antonio (2002)** examined experimentally the shear performance and modes of failure of the rectangular simply supported reinforced concrete (RC) beams designed with shear deficiencies. These members were strengthened with externally bonded carbon fiber reinforced polymer (CFRP) sheets and evaluated in the laboratory. The experimental program consisted of twelve full-scale RC beams tested to fail in shear. The variables investigated within this program included steel stirrups, and the shear span-to-effective depth ratio as well as amount and distribution of CFRP. The experimental results indicated that the contribution of externally bonded CFRP to the shear capacity was significant. They concluded that, the beams tested in this program, increases in shear strength up to 40 to 138%. The contribution of externally CFRP reinforcement to the shear capacity is influenced by the a/d ratio. The test results indicated that contribution of CFRP benefits the shear capacity at a greater degree for beams without shear reinforcement than for beams with adequate shear reinforcement.
- **Hadi (2003)** examined the strength and load carrying capacity enhancement of reinforced concrete (RC) beams; those had been tested and failed in shear. A total of sixteen sheared beam specimens with a length of 1.2m and cross-sectional area of 100 x 150 mm were retrofitted by using various types of fiber reinforced polymer (FRP) and then retested. The retrofitted beam specimens wrapped with different amounts and types of FRP were subjected to four-point static loading. Load, deflection and strain data were collected during testing the beam specimens to failure. Results of the experimental program indicate that there were several parameters that affect the

strength of the beams. The results also show that the use of FRP composites for shear strengthening provides significant static capacity increase.

Experimental Observations:

BEAM - 1

CONTROL BEAM (CB)

The control beam (CB) was not strengthened with CFRP sheet. It was an un-cracked beam. It was checked for its ultimate load bearing capacity under single point loading setup.

2. BEAM – 2

STRENGTHENED BEAM 1 (SB1)

The beam SB1 was a pre-cracked beam. It was strengthened with one layer of CFRP sheet having U-wrap on bottom and web portions and then checked it to its ultimate load capacity under single point loading setup.

2. 1 BEAM – 3

STRENGTHENED BEAM 2 (SB2)

The beam SB2 was a pre-cracked beam. It was strengthened with one layer of CFRP sheet having fully-wrap on bottom, top and web portions and then checked it to its ultimate load capacity under single point loading setup.

2.2 BEAM – 4

STRENGTHENED BEAM 3 (SB3)

The beam SB3 was a pre-cracked beam. It was strengthened with one layer of CFRP sheet under sustain loading having U-wrap on bottom and web portions and then checked it to its ultimate load capacity under single point loading setup.

2.3 BEAM – 5

STRENGTHENED BEAM 4 (SB4)

The beam SB4 was a pre-cracked beam. It was strengthened with one layer of CFRP sheet having CFRP sheet on bottom portions and then checked it to its ultimate load capacity under single point loading setup.

2.4 SUMMARY

One control beam and four beams strengthened with CFRP sheet tested in this experimental investigation. The detail descriptions of above mentioned beams are presented in **Table 3.10**.

Table 1. Beam Test Parameters and Material Properties

Beam ID	***Fc (MPa)***	**Tension Reinforcement**	**Material Type**	**Sheet Thickness (mm)**	**Strengthening system with FRP sheets**
CB	**25.93**	2 φ 16mm, 1 φ 12mm	-------------	----------	Control Beam (No sheets)
SB1	**26.02**	2 φ 16mm, 1 φ 12mm	CFRP	1	One layer bonded to the bottom and sides of beam (U-shape)
SB2	**26.90**	2 φ 16mm, 1 φ 12mm	CFRP	1	One layer bonded to the bottom, top and sides of beam (fully wrap)

SB3	**26.77**	2 φ 16mm, 1 φ 12mm	CFRP	1	One layer bonded to the bottom and sides of beam (U-shape)
SB4	**25.20**	2 φ 16mm, 1 φ 12mm	CFRP	1	One layer bonded to the bottom sides of beam

Test Results and Discussions

The CFRP strengthened beam and the control beams were tested to find out their ultimate load carrying capacity. Beam-CB failed in flexural and shear. Beam-SB1 failed due to fracture of CFRP sheet and then flexural failure of the beam took place. Beam-SB2 failed due to debonding of the CFRP sheet and then shear failure and flexural failure of the beam took place. Beam-SB3 failed due to fracture of CFRP at the center followed by debonding and finally flexural failure of the beam occurred. Beam-SB4 failed in the debonding of CFRP sheet and then flexural failure took place.

Table 2. Ultimate Load and Nature of Failure

Sr. No.	**Type Of Beam**	**Beam Designation**	**Ultimate Load (KN)**	**Nature Of Failure**	**λ=(strengthened beam/control beam)**
1	Control Beam	CB	130	Flexural Failure + Shear Failure	-
2	Strengthened Beam	SB1	170	Fracture of CFRP + Flexural-Shear Failure + Crushing of Concrete	1.31
3	Strengthened Beam	SB2	180	Debonding of CFRP + Shear-Flexural Failure	1.38
4	Strengthened Beam	SB3	156	Debonding of CFRP + Shear-Flexural Failure + Crushing Of Concrete	1.2
5	Strengthened Beam	SB4	165	Debonding + Flexural Failure	1.30

3. LOAD DEFLECTION HISTORY

Load deflection history of all the beams was recorded. The mid-span deflection of the control and strengthened beams were measured at different load steps and the deflections under the point loads were also recorded. The load-deflection histories are illustrated in figures-4.11 to 4.20. As figures shows, the deflection curve is initially straight, showing the linear relationship between the load and deflection and became non-linear with further increase in load.

Beam CB was the control beam. Single point loading was done on the beam and at each increment of the load; deflection at the middle of the beam was recorded. Using this load deflection data, load vs. deflection curve is plotted. At the load of 70 KN initial cracks started coming on the beam. Further with increase in loading propagation of the cracks took place. The beam CB failed completely in flexural.

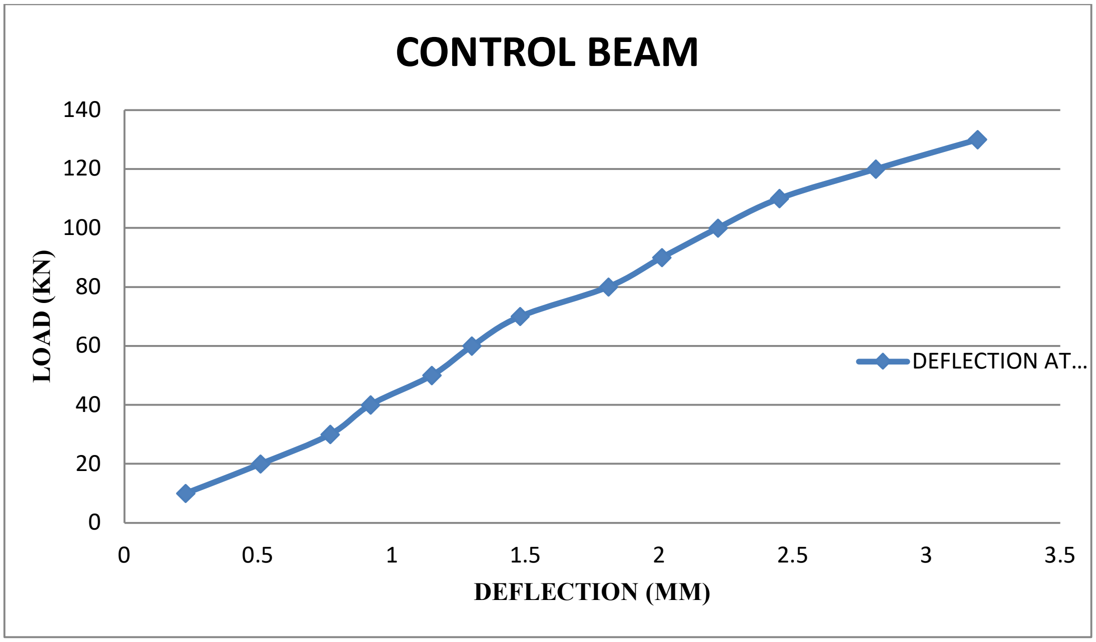

FIGURE 1. LOAD VS. DEFLECTION CURVE FOR CB

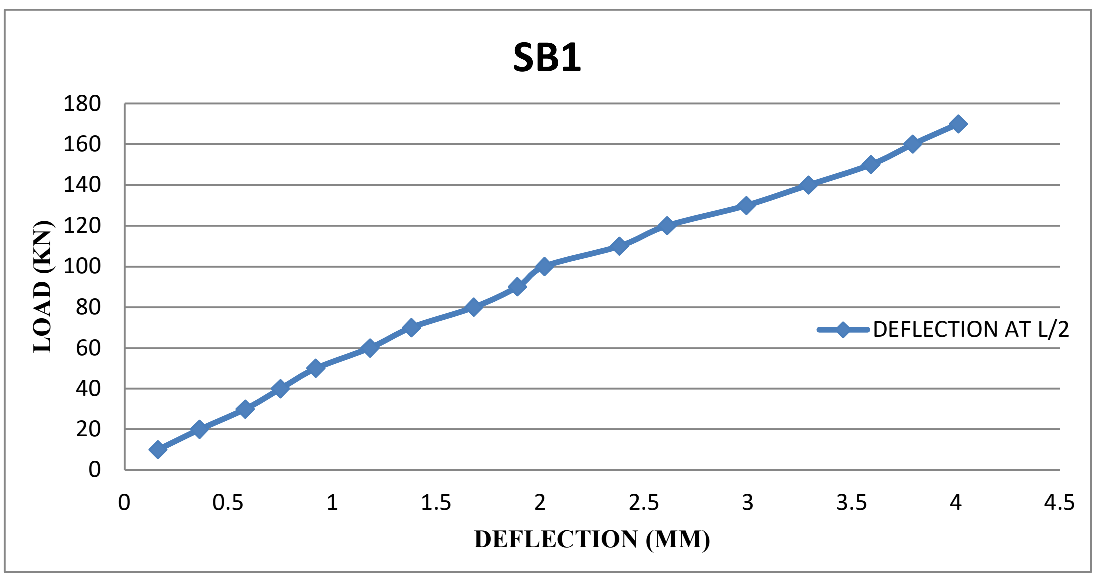

FIGURE 2. LOAD VS. DEFLECTION CURVE FOR SB-1

In beam SB-1 strengthening is done by application of CFRP sheet having U-wrap i.e. on three sides of the beam. Single point loading was done on the beam and at each increment of the load; deflection at the middle of the beam was recorded. Using this load deflection data, load vs deflection curve is plotted. The beam SB-1 failed completely in flexural.

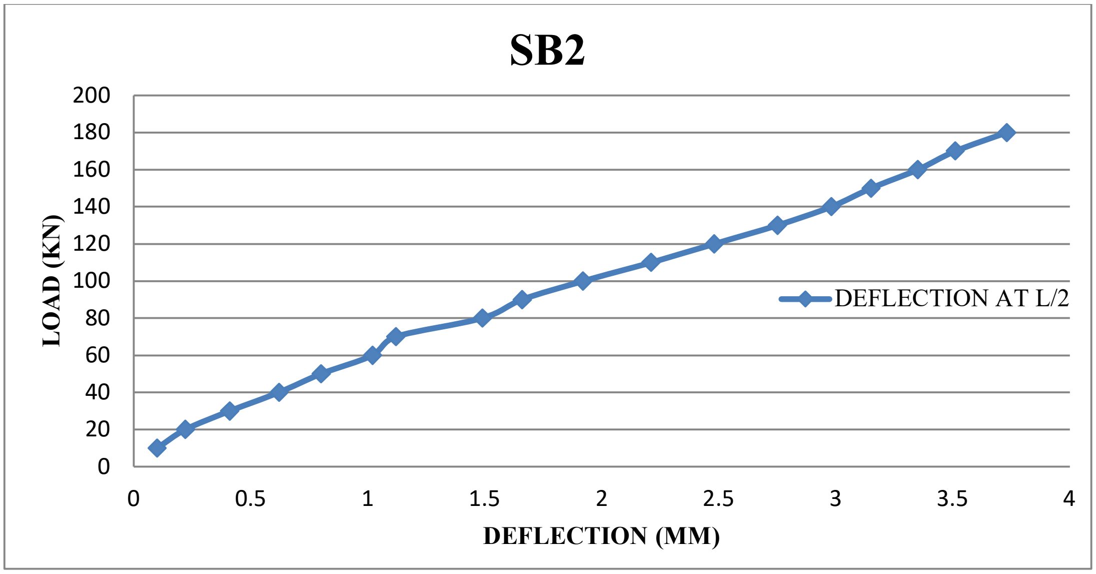

FIGURE 3. LOAD VS. DEFLECTION CURVE FOR SB-2

In beam SB-2 strengthening is done by application of CFRP sheet having fully wrap on beam. Single point loading was done on the beam and at each increment of the load; deflection at the middle of the beam was recorded. Using this load deflection data, load vs deflection curve is plotted. The beam SB-2 failed completely in flexural.

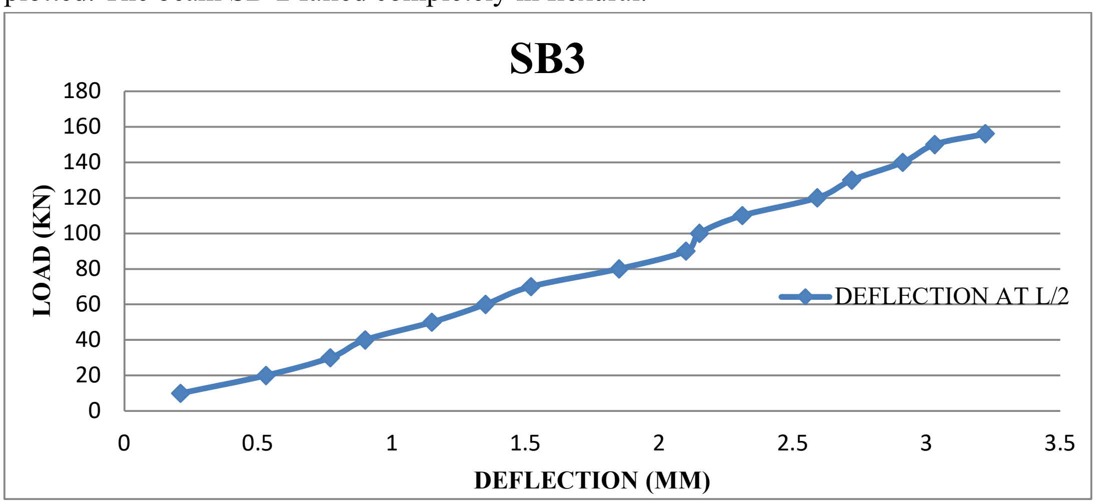

FIGURE 4. LOAD VS. DEFLECTION CURVE FOR SB-3

In beam SB-3 strengthening is done by application of CFRP sheet having U-wrap i.e. on three sides of the beam. Single point loading was done on the beam and at each increment of the load; deflection at the middle of the beam was recorded. Using this load deflection data, load vs deflection curve is plotted. The beam SB-3 failed completely in flexural.

4. Conclusion

The load carrying capacity of the strengthened Beam 2 was found to be maximum of all the beams. It increased up to 38.46 % more than the control beam CB, 7.69% more than strengthened beam SB-1, 18.46 % more than strengthened beam SB-3 Beam SB-3 which was retrofitted under sustained load in the web and sides only shows higher deflection values on same loads as compared to other strengthened beams and lower deflection value as compared to control beam. Strengthened beam SB-3 which was strengthened under sustained load shows less ultimate load carrying capacity as compared to strengthened beam SB-1 which is strengthened normally.

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