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Flexural Strengthening of Rc Beam using Glass Fibre Reinforced Polymer

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Abstract:- **In the last few decades there has been rapid increase in the glass fiber reinforced polymer (GFRP). For this study, Advantage Glass Fiber Reinforced Polymer (GFRP) sheet was used during the tests, the FRP sheets are used for shear strengthening. Throughout this study, Advantage glass fiber was used manufactured by Owens corning. In this study M20 grade concrete was used and steel reinforcement Fe415 and cement used ordinary Portland cement. Totally Four reinforcement beam were cast of size 1800mmX100150mm. Out of three one beam was kept as control beam which is tested up to ultimate level. The remaining beams were strengthened using GFRP. Finally after the tests of the beams flexural strengthening study will be conducted and thus compared with experimental results.**

I. INTRODUCTION

The deterioration of Civil Engineering infrastructures such as buildings, bridge decks, girders, offshore structures, parking structures are mainly due to ageing, poor maintenance, corrosion, exposure to harmful environments. These deteriorated structures cannot take the load for which they are designed. A large number of structures constructed in the past using the older design codes in different parts of the globe are structurally unsafe according to the new design codes and hence need up gradation.

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.

II. OBJECTIVE

The main objectives of the present work are:

- To study the structural behaviour of reinforced concrete (RC) beams under static loading condition.
- To study the contribution of externally bonded (EB) Fiber Reinforced Polymer (FRP) sheets on the shear behaviour of RC beams.
- To examine the effect of different fiber orientations, number of layers etc. on the response of beam in terms of failure modes, enhancement of load carrying capacity and load deflection behaviour.

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DESCRIPTION OF THE METHODOLOGY

- Literature review is nothing but the collection of works carried out by some of the earlier investigators on reinforced concrete beams with FRP.
- Cement, Fine aggregate & Coarse aggregate are the materials used for casting of beams. Before the Mix design, various property tests should be conducted to ingredient materials.
- Specific gravity of fine aggregate and coarse aggregate, finess modulus of the fine aggregate, initial and final setting time of cement are the important tests conducted. Mix proportion for M20 grade of concrete is based on IS 10262: 2009.
- The reinforcement was placed inside the mould on the cover blocks. The fresh concrete was pouring the mould in convenient layers and was compacted by tamping rod and the surface was made smooth by trowelling.
- The beam was lifted manually and erected in position on the supporting system. Loading frame of 500kN capacity was used for testing. Load was applied gradually at the L/3 and 2L/3 of the

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 2, Issue 6, June 2017

beam. Deflectometer reading were taken at every increment of 5kN of load cell. The first crack load was carefully noted and the loading was carried out until the collapse of the beam.

- The design approach for computing the shear capacity of RC beams strengthened with externally bonded GFRP sheets is presented in this chapter. The design approach is expressed in American Concrete Institute (ACI) design code format. The main factors affecting the additional strength that may be achieved by the externally bonded GFRP reinforcement have been considered.
- In this experimental investigation the shear behaviour of RC beams strengthened by GFRP sheets are studied. The test results illustrated in the present study showed that the external strengthening with GFRP composites can be used to increase the shear capacity of RC beams, but the efficiency varies depending on the test variables such as fiber orientations, wrapping schemes and number of layers. Compare to the experimental and theoretical results.

MATERIALS

Cement

- Bharathi cement (Ordinary Portland cement), purchased from Tiruchengode and stored in the lab and were stacked over a wooden platform free from moisture and covered with a polythene sheet to avoid the influence of atmospheric moisture. Its specific gravity was found to be 3.15.

Fine Aggregate

- The fine aggregate used in this investigation was clean river sand brought from Karur. It was sieved through 4.75 mm sieve, care was taken to see that they were uniformly dry and clean. The specific gravity and the fineness modulus of the sand were 2.67 and 3.05 respectively. As per IS code specification the fine aggregate falls in the Zone III grading.

Coarse Aggregate

- The coarse aggregate used was broken granite stones drawn from an approved quarry, crushed granite metal of size 20mm was used. The specific gravity of coarse aggregate was 2.85

Test results for the materials

S.No	DESCRIPTION OF TEST	RESULT
1	Specific gravity of cement	3.15
2	Standard consistency of cement	34%
3	Initial setting time of cement	30 min
4	Specific gravity of fine aggregate	2.67
5	Specific gravity of coarse aggregate	2.85

Water

- Bore well water available in the structural engineering laboratory was used for casting all specimens of this investigation. The quality of water was found to satisfy the requirements of IS 456 – 2000.

Reinforcing Steel

- High-Yield Strength Deformed (HYSD) bars confirming to IS 1786:1985. The reinforcements used were 12 mm and 10 mm diameters are used for the longitudinal reinforcement. The yield strength of steel reinforcements used in this experimental program is determined by performing the standard tensile test on the three specimens of each bar. The modulus of elasticity of steel bars was 2×10^5 MPa.

Glass Fibre Reinforced Polymer (GFRP)

- Continuous fiber reinforced materials with polymeric matrix (FRP) can be considered as composite, heterogeneous, and anisotropic materials with a prevalent linear elastic behaviour up to failure. Normally, Glass and Carbon fibers are used as reinforcing material for FRP. Isophthalic resin is used as the binding material between fiber layers.

- For this study, Advantex Glass Fibre Reinforced Polymer (GFRP) sheet was used during the tests, the FRP sheets are used for shear strengthening. Throughout this study, Advantex glass fibre was used manufactured by Owens Corning.

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Vol 2, Issue 6, June 2017

Advantex® Glass Fibre properties

Properties	Test Method	Unit	Advantex® Glass	E-Glass
Chemical Composition	-	-	No added Boron / Fluorides	Added Boron / Fluorides
Softening point	ASTM C338	°C	916	830-860
Refractive Index	-	-	1.56-1.57	1.54-1.56
Fibre weight loss in 10% H_2SO_4(100 hours @ 96°C)	-	-	5.5%	> 40%
Tensile Strength	ISO 527-1-10	MPa	255-260	240-245
Elastic Modulus	ISO 527-1-10	GPa	16.8-17.1	15.5-16

4.2.7. Isophthalic Resin

- Iso resin for high temperature moulding applications like DMC / SMC / Pultrusion etc. The properties are checked in accordance with the methods indicated in IS 6746 – 1994 and the values can vary within the tolerances mentioned therein.
  - Table 4.3. Properties of Isophthalic Resin

ECMALON Grade	Colour and Apperance	Sp. gr. @ 27°c	Viscosity @ 25°c (cps)	Acid No. (mg. KOH/g.)	Elongation (%)	7 days water absorption (mgs)
8841	Light yellow to yellow clear liqid	1.1	1200	16	1.5	60

Mix Design

- The concrete mix has been designed for M20 grade as per IS 10262-2009. Proportion of concrete should be selected to make the most economical use of available materials to produce concrete of required quality. The mix ratio for casting the specimen used is 1:1.44:2.78 and water cement ratio is 0.5. Materials required for one cubic meter of concrete given in Table 4.4.

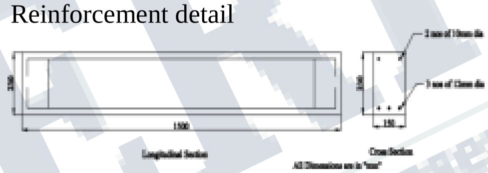
Materials required for one cubic meter of concrete

Water (lit)	Cement (kg)	Fine aggregate (kg)	Coarse aggregate (kg)
0.45	1	1.44	2.78
186	413	594	1148

REINFORCEMENT DETAILS

All the beams were casted with the following reinforcement details. 2 numbers of 10mm dia at top used as hanger reinforcement and 3 numbers of 12mm dia at bottom used as main reinforcement. Fig. 4.3 shows that details of beam reinforcement.

Reinforcement detail



mix design for M20 grade of concrete.

Wooden mould for five straight beams. For casting the various specimen, the following moulds were used.

- For reinforced concrete straight beam, 1500 x 230 x 150 mm wooden mould.
- For concrete cubes, 150 x 150 x150 mm steel mould.

During casting of beam

After Casting Of Beam

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Vol 2, Issue 6, June 2017

Casting of Companion specimens

The inner surface of the moulds was cleaned thoroughly just before casting and a thin coat of oil was applied to this surface to prevent the adhesion of cement mortar. For casting the standard specimens, moulds were filled with concrete in three layers. Each layer was well compacted by standard tamping rod. The size of the companion specimens cast are:

Cubes of 150 x 150 x 150mm size : 3 Nos

These specimens were removed from moulds 24 hours after casting.

During casting of cubes

CURING OF SPECIMENS

Curing of beams

Twenty four hours after casting, the beams were demoulded and the cured under wet gunny bags for 28 days. The gunny bags were watered thrice a day, taking special care to see that all parts were watered uniformly.

curing of specimens

Curing Of Specimens

Curing of Companion specimens

Twenty four hours after casting, the companion specimens were demoulded and all the specimens were kept near the beam were cured under wet gunny bags watered along with beams. Thus, same curing conditions were adopted for both beams and their companion specimens.

Table 5.1 Details of companion specimen test

S.NO	BEAM CODE	COMPANION SPECIMENS	
		CUBE (Nos)	1
1	CB	3	1
2	SB1	3	1
3	SB2	3	1
4	SB3	3	1
5	SB4	3	1

TESTING THE COMPANION SPECIMENS

Cube Compression Test

Cubes of size 150 x 150 x 150mm that had been casted along with beams were tested on the same day on which the beam was tested to ascertain the compressive strength of concrete used in the beams, the cube tests were carried out in the compressive testing machine of 1000 kN capacity and the tests were carried out as per the procedure recommended by IS: 516-1959.

Testing setup of cube

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International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 2, Issue 6, June 2017

Table 5.2 Compressive strength of cube

S.NO	BEAM CODE	CUBE COMPRESSIVE STRENGTH (N/mm^2)
1	CB	25
2	SB1	25.76
3	SB2	24.12
4	SB3	23.97
5	SB4	25.42

STRENGTHENING OF BEAMS WITH GFRP SHEETS

All the loose particles of concrete surface at the bottom sides of the beam were chiseled out by using a chisel. Then the required region of concrete surface was made rough using a coarse sand paper texture and cleaned with an air blower to remove all dirt and debris particles. Once the surface was prepared to the required standard, the isophthalic resin was mixed in accordance with manufacturer's instructions. The mixing is carried out in a plastic container (Catalyst and gobalt) and was continued until the mixture was in uniform. After their uniform mixing, the fabrics are cut according to the size then the isophthalic resin is applied to the concrete surface. Then the GFRP sheet is placed on top of isophthalic resin coating and the resin is squeezed through the roving of the fabric with the roller. Then the second layer of the isophthalic resin was applied and GFRP sheet was then placed on top of isophthalic resin coating and the resin was squeezed through the roving of the fabric with the roller and the above process was repeated.

strengthening of beams with GFRP sheets

EXPERIMENTAL SETUP

Totally five beams were casted.One is conventionally reinforced concrete beam without stirrups. Remaining four beams were casted with concrete strengthened by different layers of GFRP. All the beams were tested for flexure under a Loading Frame of capacity 500kN. These beams were tested on an effective span of 1300mm with simply supported conditions under two point loading.The load measurements were taken from Data Acquisition System. Deflections were measured under the mid span using LVDT. The crack patterns are also recorded at every 5kN load increment.The shear strength of concrete beam was determined based on IS: 516 –1959.

Experimental setup for testing of beams

SUMMARY

Five beams were tested in this experimental investigation. One is control beams was tested, four beams were strengthened with isophthalic resin bonded different orientations of GFRP.

Table 5.3 Beam test parameters

BEAM ID	MATERIAL TYPE	SHEET THICKNESS (mm)	STRENGTHING SYSTEM WITH GFRP SHEETS
CB	-	-	Control beam (No sheets)
SB 1	GFRP	1	One layer U- Shape of shear span of beam & another layer U-strip of shear span of beam.
SB 2	GFRP	1	One layer U- Shape of shear span of beam & another layer inclined U- strip (+45) of shear span of beam.
SB 3	GFRP	1	One layer inclined U-Shape (+45)of shear span of beam & another layer U- strip of shear span of beam.
SB 4	GFRP	1	One layer inclined U-Shape (+45)of shear span of beam & another layer inclined U- strip (+45)of shear span of beam.

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International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 2, Issue 6, June 2017

Control Beam (CB)

The control beam (CB) was casted with a reinforcement of 3 numbers of 12 mm bar on tension face. The stirrups were not provided in the beam to make it shear deficient. The beam was tested by applying the point loads gradually. Fig. 6.1 shows the experimental test setup of control beam under four point loading. The first hair crack was visible in the shear span at a load of 51 kN. This crack appeared at the mid-height zone of the web of the beam. As the load increased beyond the first crack load, many inclined cracks were also developed and the first visible crack started widening. With further increase in load, the beam finally failed in shear at a load of 133.3 kN exhibiting a wider diagonal shear crack as shown in Picture. The first shear crack became the critical crack for the ultimate failure of the control beam.

Test setup of control beam

Ultimate failure of control beam

Strengthened Beam 1 (SB1)

The beam SB1 was strengthened with one layer U- Shape GFRP of shear span of beam & another layer U- strip of shear span of beam GFRP sheets having U-wrap on shear spans. (0 to L/3 and 2L/3 to L distance from left support) with three equal strips on both sides of the beam, each strip of width 75mm and the spacing between the strips is 75mm. The test setup of the beam is shown in Fig. 6.3. The initial crack in concrete as appeared in case of control beam could not be traced out because the shear zones were fully wrapped with GFRP sheets. The failure was initiated by the flexural zone. As the load was enhanced, the ultimate failure was followed by a flexural failure at an ultimate load of 202.7 kN as shown in Fig. 6.4. The strengthening of beam SB1 with GFRP U-wraps resulted in a 34.23% of increase in shear capacity when compared to the control beam.

Test setup of strengthened beam 1

Ultimate failure of strengthened beam 1

Strengthened Beam 2 (SB2)

The beam SB2 was strengthened with one layer U-Shape GFRP in the shear span of beam & another layer inclined U- strip (+45°)on shear span. (0 to L/3 and 2L/3 to L distance from left support) with two equal inclined strips on both sides of the beam, each strip of width 75mm and the spacing between the strips is 75mm.The test setup of thebeam is shown in Fig. 6.5. The initial crack in concrete as appeared in SB2 could not be observed because the shear zones were fully wrapped with GFRP sheets. The failure was initiated by the flexural zone. The failure of beam followed by flexural failure and the beam finally failed at load of 195 kN as shown in Fig. 6.6. There is no noticeable increase in shear capacity compared to beam SB1. However, there is a 31.64% of increase in shear capacity when compare to the control beam.

Test setup strengthened beam 2

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 2, Issue 6, June 2017

Ultimate failure of strengthened beam 2

Strengthened Beam 3 (SB3)

The beam SB 3 was strengthened with One layer inclined U- Shape (+45̊)GFRP in the shear span of beam & another layer U- strip of shear span of beam. (0 to L/3 and 2L/3 to L distance from left support) with three equal strips on both sides of the beam, each strip of width 75mm and the spacing between the strips is 75mm. The test setup of the beam is shown in Fig. 6.7. The initial crack started at a load of 70 kN only on the concrete surface. The load carrying capacity of beam SB3 with GFRP strips is relatively close to that of beam SB1 with continuous sheets. Sudden failure of beam SB3 occurred at an ultimate load of 167.7kN as shown in Fig. 6.8. The strengthening of beam SB3 with resulted in a 20.5% of increase in the shear capacity when compared to the control beam.

Test setup of strengthened beam 3

Ultimate failure of strengthened beam 3

Strengthened Beam 4 (SB4)

The beam SB4 was strengthened with One layer inclined U- Shape (+45̊)GFRP in the shear span of beam & another layer inclined U - strip (+45̊) of shear span of beam. (0 to L/3 and 2L/3 to L distance from left support) with two equal inclined strips on both sides of the beam, each strip of width 75mm and the spacing between the strips is 75mm. The test setup of the beam is shown in Fig. 6.9. The initial crack started at a load of 85 kN only on the concrete surface. The load carrying capacity of beam SB4 with GFRP strips is relatively close to that of beam SB1 with continuous sheets. Sudden failure of beam SB3 occurred at an ultimate load of 204kN as shown in Fig. 6.10. The strengthening of beam SB4 with resulted in a 34.65% increase in the shear capacity over the control beam.

Test setup of strengthened beam 4

Ultimate failure of strengthened beam 4

TEST RESULTS

First Crack Load

The crack patterns of the beams were observed with the progress of the load. The load at initial crack of the beams was recorded and presented in Fig. 6.11. It is observed that the initial cracks in the strengthen RC beams are developed at a higher load than the control beam.

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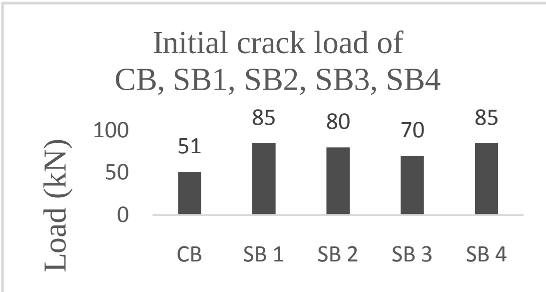
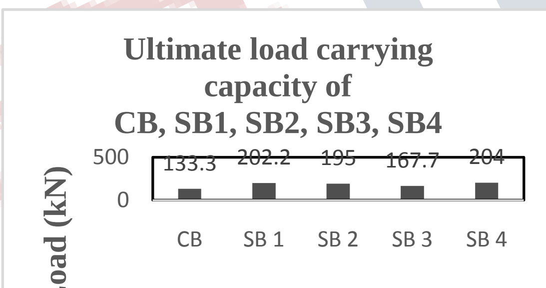
International Journal of Engineering Research in Mechanical and Civil Engineering
(IJERMCE)
Vol 2, Issue 6, June 2017



Initial crack load of Beams CB, SB1, SB2, SB3, and SB4

Ultimate load carrying capacity

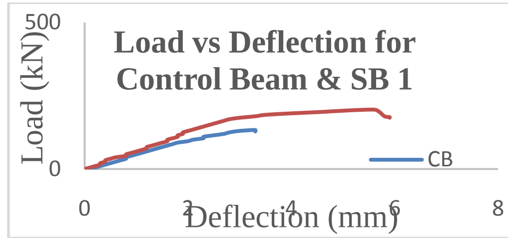
The ultimate load carrying capacity of the control beam CB and beams SB1 (strengthened with one layer continues U- wrap GFRP of shear span of beam & another layer U- strip of shear span of beam .), SB2 (strengthened with one layer U - Shape of shear span of beam & another layer inclined U- strip (+45̊) of shear span of beam.), SB3 (Strengthened with one layer inclined U - Shape (+45̊) of shear span of beam & another layer U- strip of shear span of beam), SB4 (Strengthened with One layer inclined U - Shape (+45̊) of shear span of beam & another layer inclined U - strip (+45̊) of shear span of beam) are presented in picture.



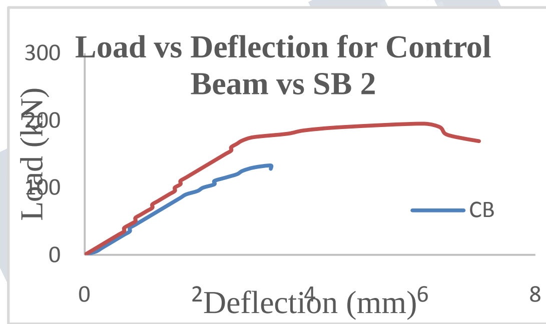
Ultimate load carrying capacity of beams CB, SB1, SB2. SB3 and SB4

Load vs Deflection

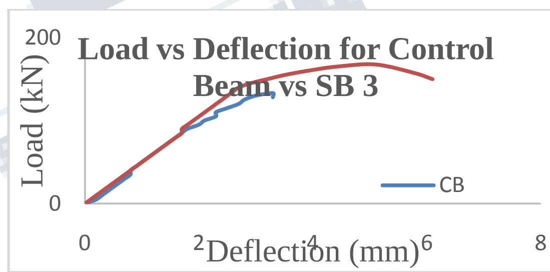
The load deflection history for all beams was recorded. From the load vs. deflection curves, which are shown graphically in Fig. 6.13, Fig. 6.14, Fig. 6.15, Fig. 6.16 & Fig. 6.17. It was noted that the flexural and shear behaviour of beams strengthened with GFRP sheets behaves in a superior way when compared with the control specimen. From an overall assessment i.e. considering maximum load carrying, deflection best results was obtained when GFRP sheet to apply the beams. The mid-span deflection of the control and strengthened beams were measured at different load increments and the deflections under the point loads were also recorded.



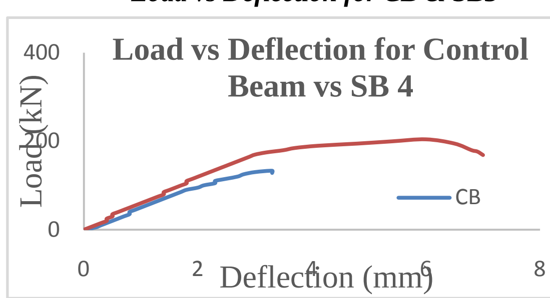
Load vs Deflection for CB & SB1



Load vs Deflection for CB & SB2



Load vs Deflection for CB & SB3



Load vs Deflection for CB & SB4

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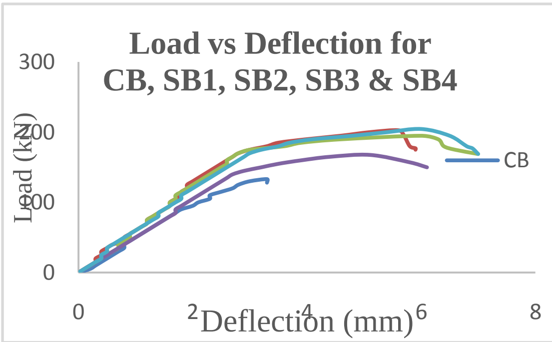
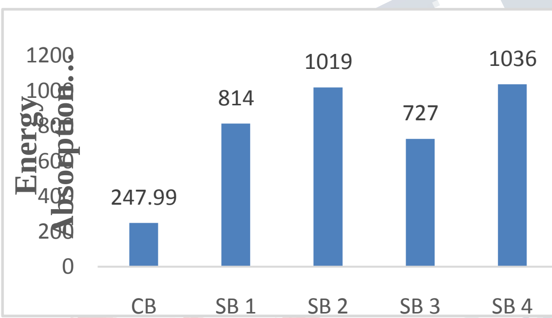
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 2, Issue 6, June 2017



Load vs Deflection for CB, SB1, SB2, SB3 & SB4

Energy Absorption Capacity

Energy absorption capacity is calculated from the load-deflection curve. Energy absorption capacity calculated from the obtained graphs has been given in the figure 6.18 respectively. The energy absorption capacity of GFRP wrapped beams is 814kN-mm, 1019kN-mm, 727kN-mm and 1036kN-mm which are 69.53%, 75.66%, 65.88 % and 76.06% higher than that of control beam.

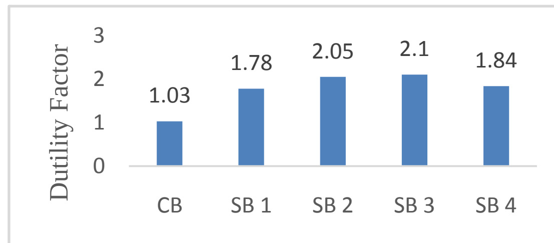


Energy Absorption Capacity of Beams

Ductility Factor

Ductility is one of the important parameters to be considered in the design of structures subjected to large amount of inelastic deformations due to various loading conditions such as wind, seismic or impact load. It is defined as the ability of a member to undergo inelastic deformation beyond the yield deformation without significance loss in its load carrying capacity.

The ratio of ultimate deflection to the deflection at first yield is known as ductility factor which is shown in Figure respectively.



Ductility Factor of Beam

III. CONCLUSION

In this experimental investigation the shear behaviour of RC beams strengthened by GFRP sheets are studied. The test results illustrated in the present study showed that the external strengthening with GFRP composites can be used to increase the shear capacity of RC beams, but the efficiency varies depending on the test variables such as fiber orientations, wrapping schemes and number of layers.

Based on the experimental and theoretical results, the following conclusions are drawn:

- ➢ Externally bonded GFRP reinforcement can be used to enhance the shear capacity of RC beams.
- ➢ The test results confirm that the strengthening technique of FRP system can increase the shear capacity of RC beams.
- ➢ The initial cracks in the strengthened beams are formed at a higher load compared to the control beam.
- ➢ Strengthening of the webs with GFRP is most vulnerable due to debonding with premature failure.
- ➢ Among all the GFRP configurations (i.e. vertical strips, strips inclined at 45º and inclined at 45ºcontinue wrap, vertical continue U- wrap), the First layer inclined U- Shape 45ºof shear span of beam & second layer inclined U- strip 45ºof shear span of beam is more effective than the others.

- The load-deflection behaviour was better for beams retrofitted with GFRP inclined continue U- wrap & inclined U- shape strips.
- A proportional increase in shear capacity with increasing GFRP amount can not be achieved when debonding is not prevented.
- The ultimate load carrying capacity of the strengthen beams were found to be greater than that of the control beams.
- Finally, the use of GFRP sheets as an external reinforcement is recommended to enhance the shear capacity of RC Beams with GFRP (90º continue U-wrap + 90º U-shape strips)& (45º continue U-wrap + 45º U-shape strips).

RECOMMENDATIONS FOR FUTUREWORK

- Based on the finding and conclusions of the current study the following recommendations are made for future research in FRP shear strengthening:
- Study of the bond mechanism between CFRP, AFRP and BFRP.
- FRP strengthening of RC T-beams with different types of fibers such as carbon, aramid & basalt.
- Strengthening of RC L-beams with FRP composite.
- Strengthening of RC L-section beams with web opening.
- Effects of web openings of different shape and size on the shear behaviour of T & L-beams.
- Effects of shear span to depth ratio on shear strengthening of beams.
- Numerical modelling of RC T & L-beams strengthened with FRP sheets anchored at the end.

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