STUDY ON TORSIONAL BEHAVIOUR OF RETROFITTED RECTANDULAR RC BEAMS WITH WEB OPENINGS

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710CE2016
M.TECH (DUAL DEGREE) IN STRUCTURAL ENGINEERING

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CERTIFICATE

This is to certify that the thesis report entitled "STUDY ON TORSIONAL BEHAVIOUR OF RECTANGULAR RC BEAMS WITH WEB OPENINGS AND STRENGTHENED WITH GFRP", submitted by **Mr. SAI RAM REDDY SARIPALLI** bearing Roll number **: 710ce2016** in partial fulfilment of the requirements for the award of **Master of Technology (Dual degree) in Civil Engineering** with specialization in "**Structural Engineering**" during session 2010-2015 at National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other university/institute for the award of any Degree or Diploma.

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ABSTRACT:

In modern building construction web openings become necessary to provide utility ducts like water supply lines, air conditioning ducts etc. These ducts cause potential weakness in any construction hence affecting strength, serviceability and stability of the structure. There will be more adverse impact on structures if web opening has to pass through the beams or columns. Sometime in unavoidable situations openings are essential to pass through existing load bearing elements of structure hence required to strengthen externally to restore the strength. External jacketing by glass, carbon, basalt fibre fabrics provides a popular, simple and effective method for restoring the strength capacity of such elements.

Many research works have been published on behaviour of retrofitted RCC beams with opening of different size and shapes especially under shear and flexure. Very few works are published to study the effect of beams with opening in torsion.

The aim of the present work is to experimentally investigate the behaviour of rectangular RCC beams with rectangular small and large openings. The beams are retrofitted with GFRP fabrics of different orientations and width. GFRP strips of widths 10cm and 20cm fiber orientations (90/90/90/90/90) and (45/90/45/90/45) are used for retrofitting. The behaviour of beams were studied in terms of collapse load, torsional moment vs angle of twist, failure patterns.

ACKNOWLEDGEMENT

The satisfaction on successful completion of any task would be incomplete without the mention of the people who made it possible whose constant guidance and encouragement crowned out effort with success. I would like to express my heartfelt gratitude to my esteemed supervisor, **Prof Asha Patel** for her technical guidance, valuable suggestions, and encouragement throughout the experimental and theoretical study and in preparing this thesis. It has been an honour to work under **Prof. Asha Patel**, whose expertise and discernment were key in the completion of this project. I am grateful to the **Dept. of Civil Engineering, NIT ROURKELA,** for giving me the opportunity to execute this project, which is an integral part of the curriculum in M.Tech (Dual degree) programme at the National Institute of Technology, Rourkela.

Many thanks to my friends who are directly or indirectly helped me in my project work for their generous contribution towards enriching the quality of the work. I would also express my obligations to Mr.R.Lugun and Mr.Sushil, Laboratory team members of Department of Civil Engineering, NIT, Rourkela and academic staffs of this department for their extended cooperation.

This acknowledgement would not be complete without expressing my sincere gratitude to my parents for their love, patience, encouragement, and understanding which are the source of my motivation and inspiration throughout my work. Finally I would like to dedicate my work and this thesis to my project guide Prof. Asha Patel

SAI RAM REDDY SARIPALLI

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ACRONYMS AND ABBREVATIONS

IS Codes	Indian Standard Codes
FRP	Fiber Reinforced Polymer
GFRP	Glass Fiber Reinforced Polymer
HYSD	High-Yield Strength Deformed
CB	Control beam
BRO	Beam with rectangular opening
BSRO	Beam with small rectangular opening
BRO1	Beam with rectangular opening with 10cm GFRP[90/90/90/90/90]
BRO2	Beam with rectangular opening with 10cm GFRP[45/90/45/90/45]
BRO3	Beam with rectangular opening with 20cm GFRP[90/90/90/90/90]
BRO4	Beam with rectangular opening with 20cm GFRP[45/90/45/90/45]
BSRO1	Beam with small rectangular opening with 10cm GFRP[90/90/90/90/90]
BSRO2	Beam with small rectangular opening with 10cm GFRP[45/90/45/90/45]
BSRO3	Beam with small rectangular opening with 20cm GFRP[90/90/90/90/90]
BSRO4	Beam with small rectangular opening with 20cm GFRP[45/90/45/90/45]

CHAPTER 1

Introduction:

1.1 OVER VIEW

These days openings in floor beams and columns get to be important to give service lines like water supply lines, electric power lines, network lines, aerating and cooling pipes to pass through to save the story height especially in multi-story structures. Openings also reduce dead weight of structures causing cost savings and systematically placed utility duct improve aesthetic appearance.

The transverse openings through beams are a source of potential weakness. When the service systems are pre-planned, and necessary layout of pipes and ducts are decided well in advance then elements carrying them should be designed to ensure adequate strength and serviceability by following the method described in the different codes.

Fig 1.1 Water diversion pipe lines passing through the beams

In any case, this may not generally be the situation. While laying the ducts in a recently built building, the mechanical and electrician builder often comes up with an situation to make drill on beams for the sole purpose of simple arrangement the of pipes and wirings. At the time when such situation comes, the structural designer finds it hard to give a decision in matter of the fact that he needs to take the risk and responsibility for the strength and serviceability of the structure.

In recent years, a lot of research work had been done to study the behaviour of reinforced concrete beams with transverse openings. These research works mainly focused on the reinforced concrete beams with transverse opening under different combinations of flexure, shear and torsion loading.

Two sorts of transverse openings had been explored, the small and large opening and they are classified on the basis of profile of opening. For rectangular Opening if opening depth is less than or equal to 0.25 times the overall depth then it is called as Small opening and if opening depth is more than 0.25 times the overall depth then it is called as Large Opening.

An opening makes discontinuity in the normal flow of stresses, in this manner causing stress concentration at edges of the opening and cause early cracks in concrete. In order to avoid this, external reinforcement should be provided. In our case GFRP is used as external reinforcement.

Fibre reinforced polymer (FRP) is a composite material made of a polymer matrix strengthened with fibres. The fibres are typically glass or carbon fibre, while the polymer is generally an epoxy. Glass fibre fabrics are mainly used for strengthening of RC beams on account of its flexible nature easy handling and application, combined with high tensile strength weight ratio and stiffness.

FRP sheets are at present being studied and used far and wide for the repair and strengthening of concrete structures. FRP composite materials are of good interest in view of their prevalent properties, for example: high specific stiffness and specific strength and additionally simplicity of application when compared with other repairing materials. Likewise, the non-corrosive and nonmagnetic nature of the materials alongside its resistance to chemicals makes FRP a good choice for external reinforcement.

Research work on FRP has revealed that reinforcing using FRP gives a considerable increment in post-cracking stiffness and ultimate load carrying capacity of the concrete members subjected to flexure, shear and torsion.

Lot of research has been done to focus impact of openings on shear and flexural behaviour of RCC beams like rectangular, T beam, deep beam. Not much works have been done to study the impact of openings on torsional behaviour of RCC beam. Numerous research works are done on behaviour of beams with opening retrofitted with different types and configurations of FRP under shear and flexure.

1.2 OBJECTIVE:

Thus the aim of the present work is to study the effect of rectangular web openings on torsional behaviour of rectangular RCC beam. The work is further extended by retrofitting the beams with GFRP fibre. The variables considered are size of openings, width and orientation of GFRP fabrics.

1.3 METHODOLOGY:

Total eleven beams of same dimensions were cast. First one is control beam without opening. Remaining ten beams are divided in two sets. First set had five beams, cast with central small opening of size 90mm x 120mm. Second set had five beams with central large opening of 180mm x 120mm. In each set first beam was treated as control beam with opening and remaining four beams were retrofitted with five layers of GFRP fabrics following different orientations and sizes of GFRP strips.

One of both sized web opening beams are retrofitted with 10cm width, 5 layers and (90/90/90/90/90) orientation of GFRP. Similarly with 20cm width, 5 layers and (90/90/90/90/90) orientation of GFRP, 10cms width, 5 layers and (45/90/45/90/45) orientation of GFRP, 20cm width, 5 layers and (45/90/45/90/45) orientation of GFRP.

All the beams were tested after 28 days under loads acting on both projected parts simultaneously causing beam to torsion at centre of beam and tested till the torsional failure occurs. While testing deflections at three different cross sections were taken by using measuring gauges to evaluate the twisting angle at respective cross sections.

During the test crack formations on beams are observed. Difference in crack patterns for non-retrofitted and retrofitted beams are also observed.

CHAPTER 2

LITERATURE REVIEW:

Somes and Corley (1974) defined small and large opening on the basis of experimental and analytical study. The study was confined to circular opening. A circular opening was considered as large opening when its diameter exceeds 0.25 times the depth of the web.

Mansur, M.A. and Paramasivam, P (1984), Studied the effect of small opening in Reinforced Concrete Beams under bending and torsion in terms of torsional moment capacity by varying the opening size.

Akhtaruzzaman (1990) developed a sets of generalized strength equations based on the skew bending model to predict the torsional strength and failure mode of reinforced concrete beams with or without a small transverse opening. They developed Interaction curves for rectangular beams with opening under combined actions of torsion, shear and flexure.

Hasnat et al, (1993) had tested seventeen pre-stressed concrete beams without stirrups containing transverse circular opening. In this research investigations were carried out on beams having two openings of different diameters and subjected to various combinations of torsion and bending.

M.A. Mansur (2006), gives a comprehensive treatment of the analysis and design of reinforced concrete beams that contain transverse openings through the web and are subjected to combined bending and shear. Recognizing the differences in beam behaviour, circular and large rectangular openings are treated separately. Practical situations of drilling an opening in existing beams and special design considerations for beams with multiple openings are also briefly discussed.

Amiri (2007) experimentally investigated together with a numerical study on reinforced concrete beams subjected to torsion that are strengthened with FRP wraps in a variety of configurations. Experimental results show that FRP wraps can increase the ultimate torque of fully wrapped beams considerably in addition to enhancing the ductility.

Soroush Amiri et al (2011) carried out study on behaviour of reinforced concrete beams with rectangular and circular openings. Then effects of the size and location of the openings on the behaviour of such beams are examined and the strengths of these openings are explored as well.

CHAPTER 3

EXPERIMENTAL PROGRAM

3.1 MATERIAL PROPERTIES

3.1.1. Concrete

A concrete mix design of M20 was done by using Portland slag cement, sand of Zone III and mix of 10cm and 20cm aggregate by following IS 10262:2009 code.

The proportion of design mix adopted for the experiment is 1:1.6:3.2 by weight and water cement ratio is taken as 0.6.

Concrete properties after 28 days are measured as shown in table 3.1

Table 3.1 Properties of Concrete after 28 days

Beams	Compressive Strength N/mm^2		Tensile Strength N/mm^2	
	Cube *Fck*	**Cylinder *Fc***	**Split Tensile Strength**	**Flexural Strength Of Concrete *fr***
CB	22.51	18.32	2.67	2.85
BRO	22.97	18.92	2.73	3.10
BSRO	21.82	18.60	2.62	3.20
BRO1	23.42	19.84	2.84	3.25
BRO2	22.51	19.72	2.71	3.15
BRO3	24.78	21.48	2.91	3.05
BRO4	25.15	22.12	2.96	3.25
BSRO1	22.32	20.03	2.63	3.10
BSRO2	22.58	19.71	2.73	3.15
BSRO3	24.47	21.27	2.85	3.20
BSRO4	24.71	21.44	2.98	3.30

3.1.2 Reinforcing Steel

For reinforcement HYSD Steel bars of Fe415 grade of 8mm, 10mm, 12mm and 16mm diameter are used. All bars are tested for Tensile strength and they comply with the code IS 1786-.1985.

Table 3.2 Tensile Properties of Reinforcing steel bars

Diameter of Bar Mm	0.2% Proof Stress N/mm^2	Ultimate Tensile Strength N/mm^2	% Elongation	Remark
8	531	673.04	22.50	All bars are complied with IS 1786-1985
	527	663.28	22.50	
	549	656.24	22.50	
10	528	680.47	20.00	
	521	664.86	20.00	
	526	659.82	20.00	
12	528	702.30	23.33	
	572	680.63	20.00	
	536	706.60	23.33	
16	496	665.72	22.50	
	490	701.23	22.50	
	478	633.43	22.50	

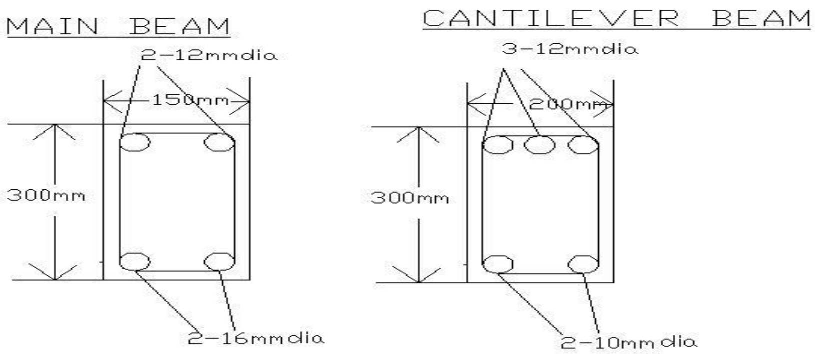


Fig 3.1 Reinforcement Detailing of Beam

3.1.3 Fiber Reinforced Polymer (FRP)

Fiber reinforced materials with polymeric matrix (FRP) are considered as composite materials, they are anisotropic and heterogeneous materials with a prevalent linear elastic behaviour up to failure. Mostly, Glass and Carbon fibres are used as reinforcing material for FRP. For present work bi directional woven GFRP fabric was used.

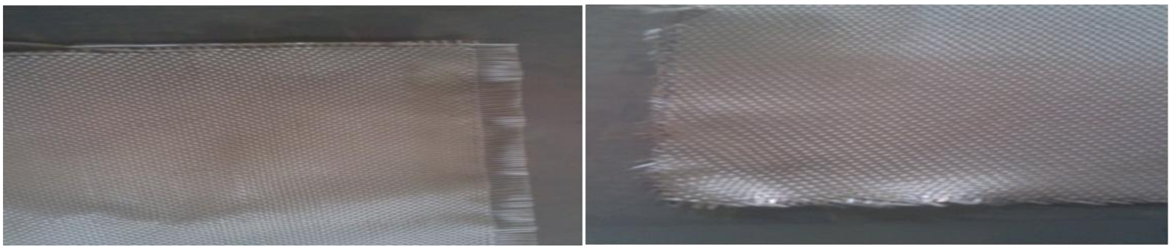


FIG 3.2 a) GFRP fabrics in [90^0] **b) GFRP fabrics in [45^0]**

Fig 3.3 Roller Used To Remove Air Bubbles

3.1.4 Epoxy resin

The epoxy resins are used as glue to stick the layers of GFRP and to stick GFRP to concrete structures. This plays key role in strength of retrofitting because of bond between concrete-GFRP and each layer of GFRP.
Hardener is used to make epoxy resin hard and strong. The epoxy and hardener are mixed in proportion of 0.9:0.1.
In the present work 5layers of GFRP is used under two different orientations for which tensile properties are studied by making standard coupons of 25cm long x 2.5cm wide and tested in INSTRON UTM machine.

TABLE 3.3 TENSILE PROPERTY OF GFRP FABRIC

GFRP Coupon (5 layers)	Thickness of coupon (mm)	Ultimate stress N/mm^2	Ultimate load in kN	Young's modulus N/mm^2
90/90/90/90/90	2.15	295	16.735	9973
45/90/45/90/45	2.32	297	17.105	10132

3.2 Casting of Specimens:-

All beams are of same size and shape with same steel reinforcements and are designed to fail in torsion so no stirrups are provided except at the ends in order to keep longitudinal reinforcements fixed and be in positions. The figure below shows the dimensions of the beam

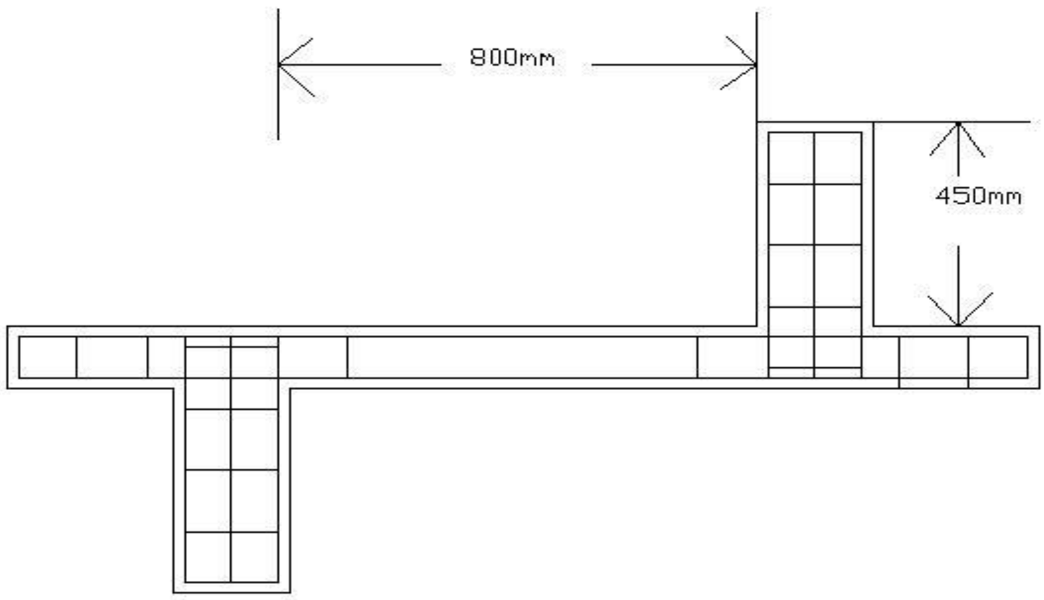


Fig 3.4 Detailing of the Beam

3.3 STRENGTHENING OF BEAMS

First the concrete surface on beams are made rough and cleaned so that GFRP sticks well. A plastic mug is used to mix epoxy resin and hardener. As per the required size and orientation GFRP is cut and then stick these GFRP sheets to beams across the web opening on both sides by using GFRP as glue one layer after the other and roller is used to remove air bubbles that are entrapped in between the layers of GFRP. For epoxy and GFRP to set it takes 7days after that the retrofitted beam gets strength and is ready to be tested.

3.4 Form Work

FIG 3.5 Form Work of Beam

3.5. EXPERIMENTAL SETUP

Beams are tested under monotonically incremented static loads on both arms of projected parts at a time, this cause's torsional load on centre of beam. Beams are tested till torsional failure occurs. When testing loads are increased and similarly to that deflections that are observed using dial gauges also increases. The crack patterns are to be observed.

Fig 3.6 Experimental Set-up for Testing

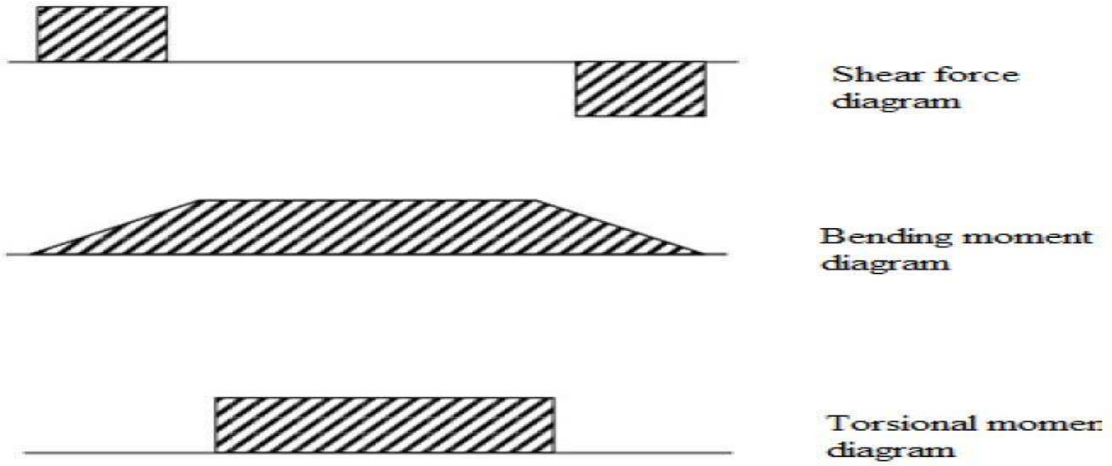


FIG 3.7Shear Force, Bending Moment and Torsional Moment Diagrams

CHAPTER 4

RESULTS AND DISCUSSIONS:

4.1 Testing Of Beams:-

All the eleven beams were tested till complete failure occurs. Two dial gauges were placed across the width at three sections (below centre of opening, middle sections between opening and projected arms) ,to measure deflections in order to calculate angle of twisting moments Demac gauges were fixed on vertical face of the beam to measure strains with a mechanical strain gauge. Loads were applied in increments and dial gauges and strain gauge readings were observed. During the testing cracks formations and propagation were critically observed. After testing GFRP jacketing was removed and inclination of major crack formed was measured.

Table 4.1 Description of Beams

CB	Control beam
BRO	Beam with rectangular opening
BSRO	Beam with small rectangular opening
BRO1	Beam with rectangular opening with 10cms GFRP[90/90/90/90/90]
BRO2	Beam with rectangular opening with 10cms GFRP[45/90/45/90/45]
BRO3	Beam with rectangular opening with 20cms GFRP[90/90/90/90/90]
BRO4	Beam with rectangular opening with 20cms GFRP[45/90/45/90/45]
BSRO1	Beam with small rectangular opening with 10cms GFRP[90/90/90/90/90]
BSRO2	Beam with small rectangular opening with 10cms GFRP[45/90/45/90/45]
BSRO3	Beam with small rectangular opening with 20cms GFRP[90/90/90/90/90]
BSRO4	Beam with small rectangular opening with 20cms GFRP[45/90/45/90/45]

4.1.1 CONTROL BEAM (CB):-

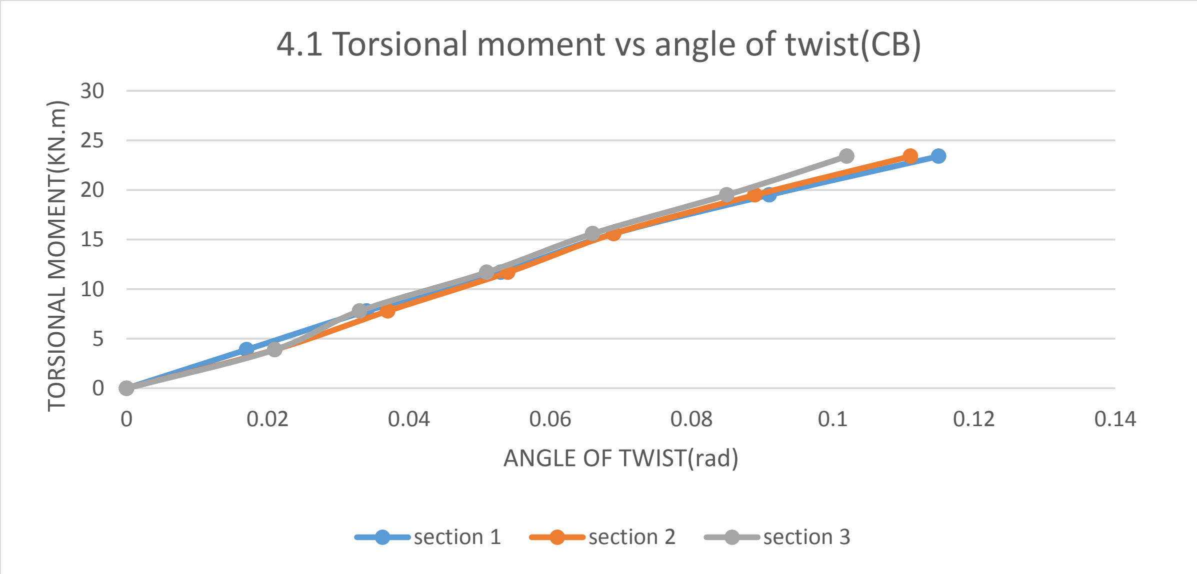
Control beam CB had no opening. The beam was tested under monotonically applied increasing loads applied on the two projected moment arm of the beams which generated torsion in middle 0.8 m long span of the beam. Deflections and strains were observed at each increment of the load through dial gauges and strain gauge. The load at which the first visible crack is appeared was recorded as initial cracking load and the load at which complete failure occurred was recorded as collapse load. The data obtained from dial gauges were used to calculate twisting angles. The values of torsional moments and angle of twist observed at three sections were given in table 4.1 and the graphs torsional moments Vs angle of twist at the three sections were given in Graph 4.1. The photo of CB at failure is shown in Fig 4.1. The crack pattern was inclined at 45 degrees and found to be pure torsion failure.

Fig 4.1 Crack pattern in CB

The initial crack was observed at 52KN and ultimate failure load was 68KN.

TABLE 4.2 Torsional Moment Vs Angle of Twist for CB

Load kN	Torsional Moment kN-m	Section 1	Section 2	Section 3	Remarks
		Angle of twist(radians)			
0	0	0	0	0	
10	3.9	0.017	0.021	0.021	
20	7.8	0.034	0.037	0.033	
30	11.7	0.053	0.054	0.051	
40	15.6	0.069	0.069	0.066	
50	19.5	0.091	0.089	0.085	Initial crack 52KN
60	23.4	0.115	0.111	0.102	
68	26.52				Ultimate load 68KN



4.1.2 BRO - Beam with rectangular opening.

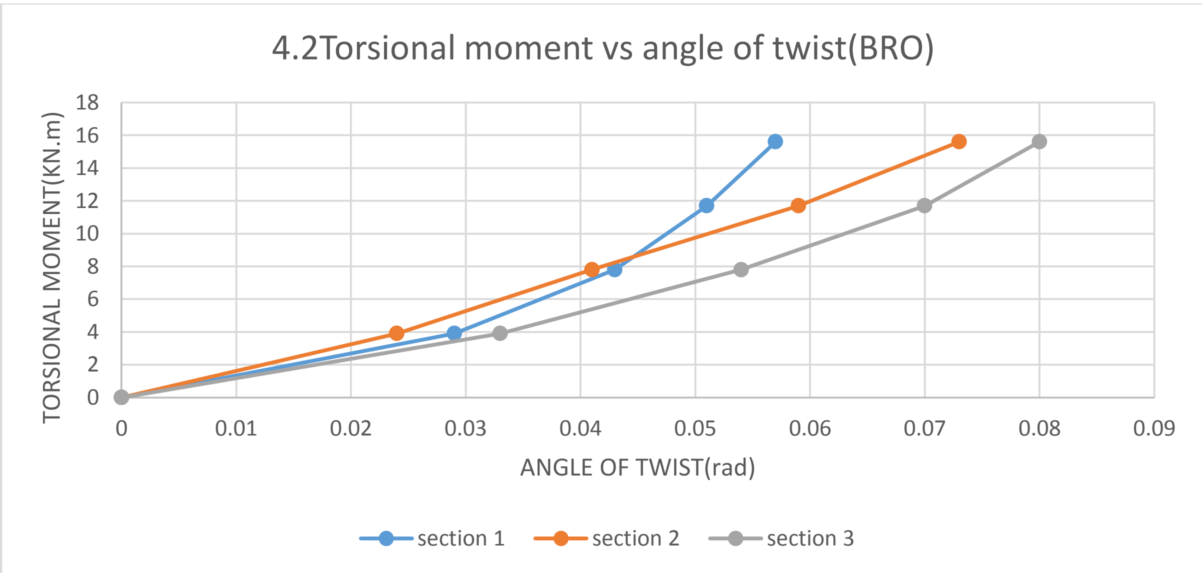
BRO-Beam with same dimensions as control beam (CB) with a web opening at the middle span of beam with dimensions (l x h) – 120mm x 180mm without GFRP jacketing. By using dial gauges the angle of twist were noted at the same three sections as like in control beam (CB) at each increment of load applied. The load was applied till failure. The initial crack was observed at 35KN and ultimate failure load was 42KN. Cracks initiated from the corners of the opening as shown in fig 4.2. The load applied, angle of twist calculated were shown in table 4.2

Fig 4.2(a) Setup of the BRO

Fig 4.2(b) Crack pattern in BRO

TABLE 4.3 Torsional Moment Vs Angle of Twist for BRO

Load Kn	Torsional Moment kN-m	Section 1	Section 2	Section 3	Remarks
		Angle of twist(radians)			
0	0	0	0	0	
10	3.9	0.029	0.024	0.033	
20	7.8	0.043	0.041	0.054	
30	11.7	0.051	0.059	0.07	
40	15.6	0.057	0.073	0.08	INITIAL CRACK 35KN
42	16.4				ULTIMATE LOAD 42KN



4.1.3 BSRO - Beam with small rectangular opening.

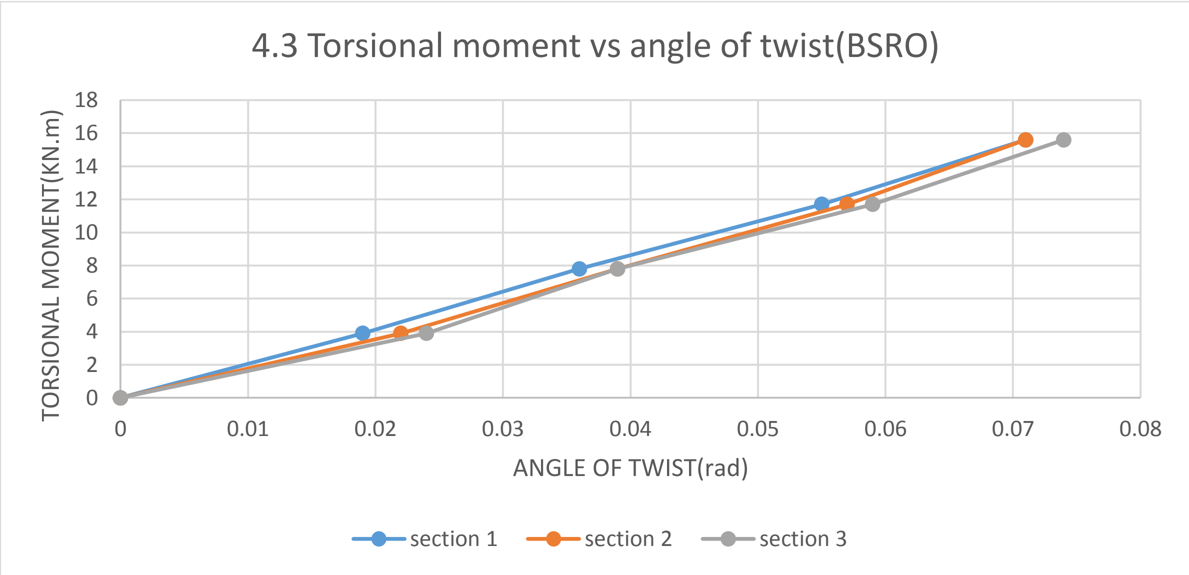
BSRO-Beam with same dimensions as control beam (CB) and with a web opening at the middle span of beam with dimensions (l x h) – 120mm x 90mm and no external reinforcement is provided. By using dial gauges the angle of twist is noted corresponding to the increment of load. The load was applied till failure. The initial crack was observed at 39KN and ultimate failure load was 49KN. Cracks initiated from the corners as shown in fig 4.3 and table 4.3 shows the load applied and angle of twist at three sections.

Fig 4.3(a) Setup of the BSRO

Fig 4.3(b) Crack pattern in BSRO

TABLE 4.4 Torsional Moment Vs Angle of Twist for BSRO

Load Kn	Torsional Moment kN-m	Section 1	Section 2	Section 3	Remarks
		Angle of twist(radians)			
0	0	0	0	0	
10	3.9	0.019	0.022	0.024	
20	7.8	0.036	0.039	0.039	
30	11.7	0.055	0.057	0.059	
40	15.6	0.071	0.071	0.074	INITIAL CRACK 39KN
49	16.4				ULTIMATE LOAD 49KN



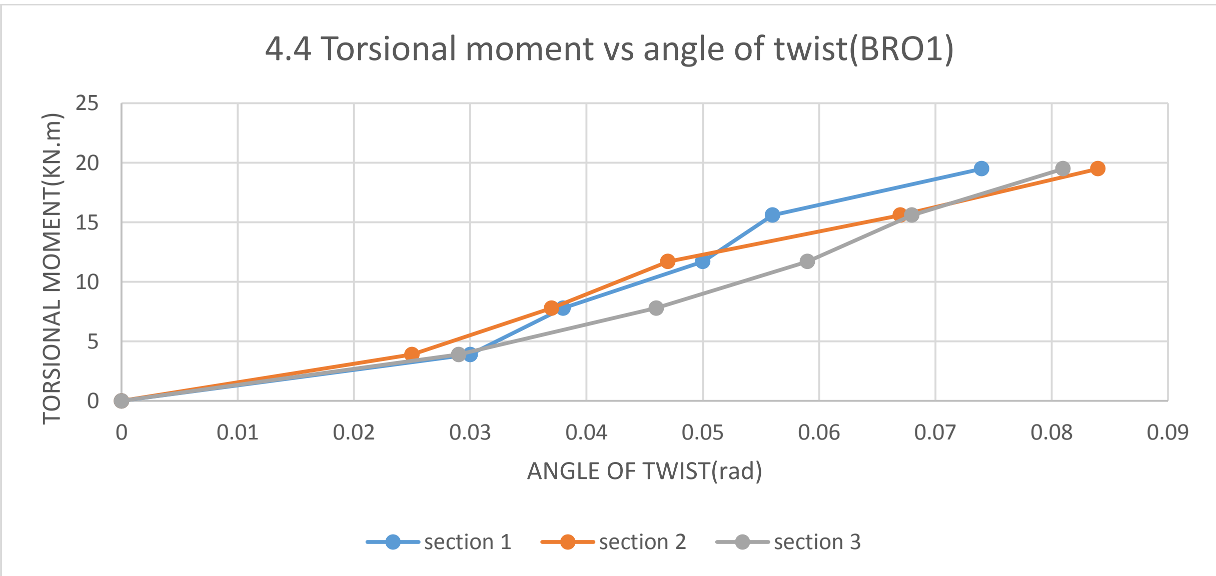
4.1.4 BRO1 - Beam with rectangular opening with 10cms GFRP [90/90/90/90/90]

BRO1- Beam with same dimensions as control beam (CB) and with a web opening at the middle span of beam with dimensions (l x h) – 120mm x 180mm and external reinforcement of GFRP in 5layers is provided across the both sides of web opening with 10cms width and 90/90/90/90/90 orientation. By using dial gauges the angle of twist was noted corresponding to the load increment. The load was applied till failure. The initial crack was observed at 44KN and ultimate failure load was 53KN. Cracks have formed along the diagonal line of web opening and passed through GFRP sheets as shown in fig 4.4. The table 4.4 shows the load applied and angle of twist at three sections.

Fig 4.4 Crack pattern in BRO1

TABLE 4.5 Torsional Moment Vs Angle of Twist for BRO1

Load kN	Torsional Moment kN-m	Section 1	Section 2	Section 3	Remarks
		Angle of twist(radians)			
0	0	0	0	0	
10	3.9	0.03	0.025	0.029	
20	7.8	0.038	0.037	0.046	
30	11.7	0.050	0.047	0.059	
40	15.6	0.056	0.067	0.068	INTITIAL CRACK 44KN
50	19.5	0.074	0.084	0.081	
53	20.67				ULTIMATE LOAD 53KN



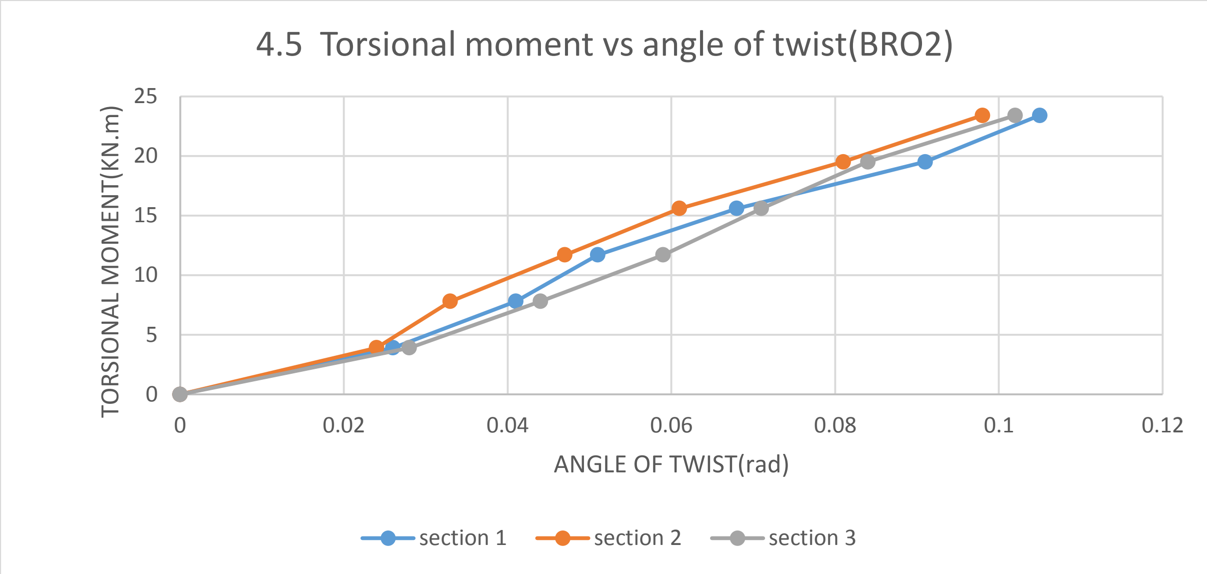
4.1.5 BRO2 - Beam with small rectangular opening with 10cms GFRP [45/90/45/90/45]

BRO2- Beam with same dimensions as control beam (CB) and with a web opening at the middle span of beam with dimensions (l x h) – 120mm x 180mm and external reinforcement of GFRP in 5layers is provided across the both sides of web opening with 10cms width and 45/90/45/90/45 orientation. By using dial gauges the angle of twist is noted corresponding to the load increment. The load was applied till failure. The initial crack was observed at 49KN and ultimate failure load was 65KN. The crack has formed on one edge of web opening and passed through GFRP sheets as shown in fig 4.5. The table 4.5 shows the load applied and angle of twist at three sections.

Fig 4.5 Crack pattern of BRO2

TABLE 4.6 Torsional Moment Vs Angle of Twist for BRO2

Load kN	Torsional Moment kN-m	Section 1	Section 2	Section 3	Remarks
		Angle of twist(radians)			
0	0	0	0	0	
10	3.9	0.026	0.024	0.028	
20	7.8	0.041	0.033	0.044	
30	11.7	0.051	0.047	0.059	
40	15.6	0.068	0.061	0.071	INTITIAL CRACK 49KN
50	19.5	0.091	0.081	0.084	
60	23.4	0.105	0.098	0.102	
65	25.35				ULTIMATE LOAD 65KN



4.1.6 BRO3 - Beam with rectangular opening with 20cms GFRP [90/90/90/90/90]

BRO3- Beam with same dimensions as control beam (CB) and with a web opening at the middle span of beam with dimensions (l x h) – 120mm x 180mm and external reinforcement of GFRP in 5layers is provided across the both sides of web opening with 20cms width and 90/90/90/90/90 orientation. By using dial gauges the angle of twist is noted corresponding to the load increment. The load was applied till failure. The initial crack was observed at 61KN and ultimate failure load was 73KN. The cracks initiated across on top portion above the web opening and passed through GFRP layers as shown in fig 4.6. The table 4.6 shows the load applied and angle of twist at three sections.

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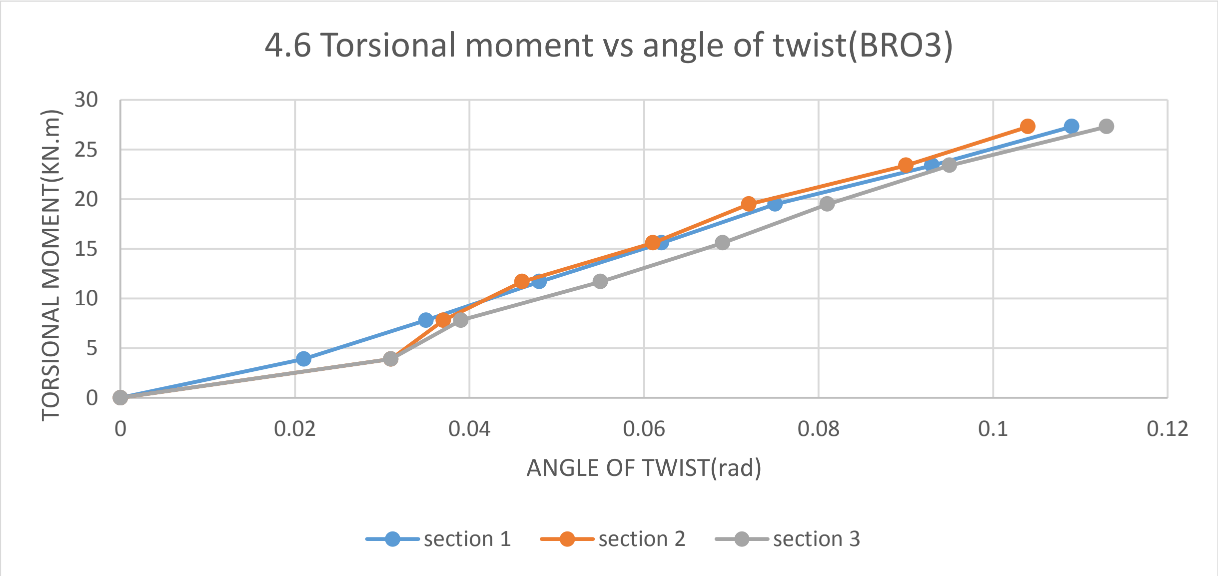
Fig 4.6 Crack pattern in BRO3

TABLE 4.7 Torsional Moment Vs Angle of Twist for BRO3

Load Kn	Torsional Moment kN-m	Section 1	Section 2	Section 3	Remarks
		Angle of twist(radians)			
0	0	0	0	0	
10	3.9	0.021	0.031	0.031	
20	7.8	0.035	0.037	0.039	
30	11.7	0.048	0.046	0.055	
40	15.6	0.062	0.061	0.069	
50	19.5	0.075	0.072	0.081	
60	23.4	0.093	0.09	0.095	INITIAL CRACK 61KN
70	27.3	0.109	0.104	0.113	
73	28.47				ULTIMATE LOAD 73KN



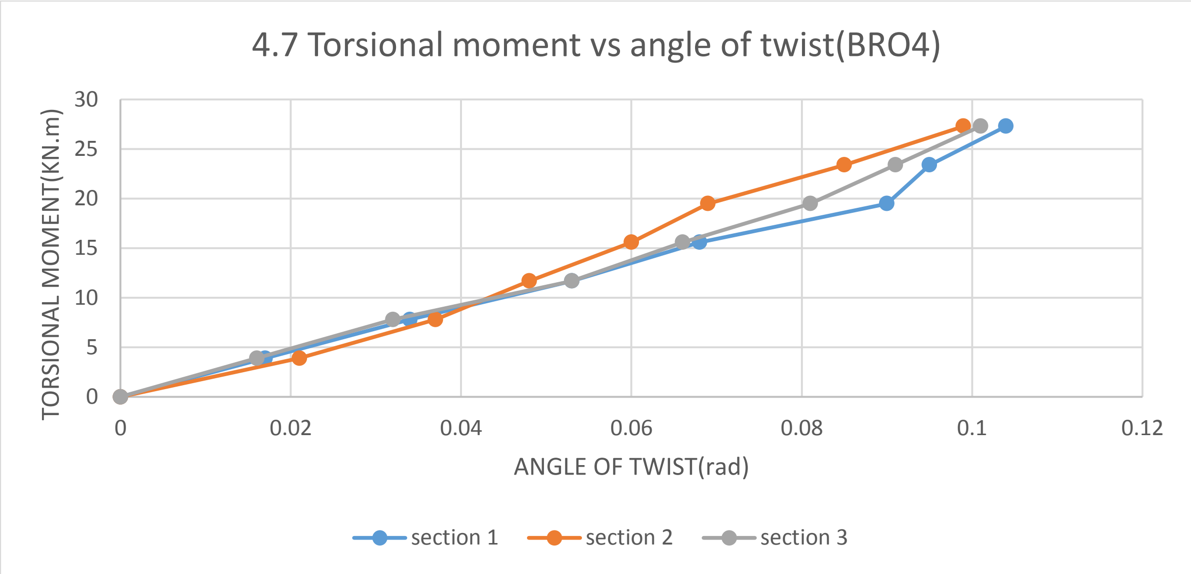
4.1.7 BRO4 - Beam with rectangular opening with 20cms GFRP [45/90/45/90/45]

BRO4- Beam with same dimensions as control beam (CB) and with a web opening at the middle span of beam with dimensions (l x h) – 12mm x 18mm and external reinforcement of GFRP in 5layers is provided across the both sides of web opening with 20cms width and 45/90/45/90/45 orientation. By using dial gauges the angle of twist is noted corresponding to the load increment. The load was applied till failure. The initial crack was observed at 63KN and ultimate failure load was 78KN. The crack was initiated on the lower portion below web opening. The inclined crack was initiated from lower portion below web opening and passing through GFRP layers as shown in fig 4.7. The table 4.7 shows the load applied and angle of twist at three sections.

Fig 4.7 Crack pattern in BRO4

TABLE 4.8 Torsional Moment Vs Angle of Twist for BRO4

Load Kn	Torsional Moment kN-m	Section 1	Section 2	Section 3	Remarks
		Angle of twist(radians)			
0	0	0	0	0	
10	3.9	0.017	0.021	0.016	
20	7.8	0.034	0.037	0.032	
30	11.7	0.053	0.048	0.053	
40	15.6	0.068	0.06	0.066	
50	19.5	0.09	0.069	0.081	
60	23.4	0.095	0.085	0.091	Initial crack 63KN
70	27.3	0.104	0.099	0.101	
78	30.42				Ultimate load 78KN



4.1.8 BSRO1 - Beam with small rectangular opening with 10cms GFRP [90/90/90/90/90]

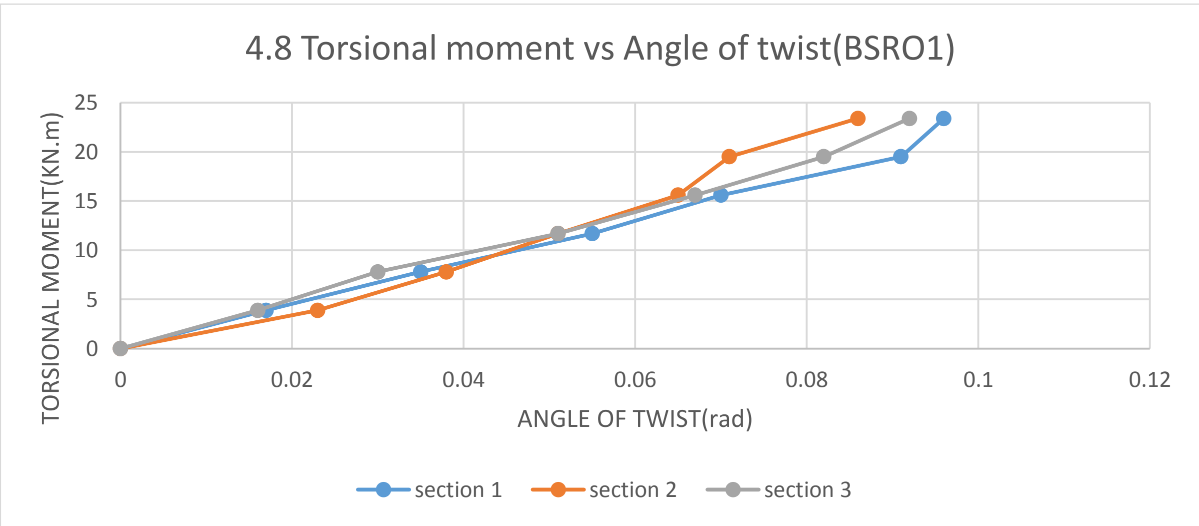
BSRO1- Beam with same dimensions as control beam (CB) and with a small web opening at the middle span of beam with dimensions (l x h) – 120mm x 90mm and external reinforcement of GFRP in 5layers is provided across the both sides of web opening with 10cms width and 90/90/90/90/90 orientation. By using dial gauges the angle of twist is noted corresponding to the load increment. The load was applied till failure. The initial crack was observed at 55KN and ultimate failure load was 65KN. Set up and crack pattern are shown in fig 4.8(a) and fig 4.8(b). The table 4.8 shows the load applied and angle of twist at three sections.

Fig 4.8(a) Setup of BSRO1

Fig 4.8(b) Crack pattern in BSRO1

TABLE 4.9 Torsional Moment Vs Angle of Twist for BSRO1

Load Kn	Torsional Moment kN-m	Section 1	Section 2	Section 3	Remarks
		Angle of twist(radians)			
0	0	0	0	0	
10	3.9	0.017	0.023	0.016	
20	7.8	0.035	0.038	0.03	
30	11.7	0.055	0.051	0.051	
40	15.6	0.07	0.065	0.067	
50	19.5	0.091	0.071	0.082	Initial crack 55KN
60	23.4	0.096	0.086	0.092	
65	25.35				Ultimate load 65KN



4.1.9 BSRO2 - Beam with small rectangular opening with 10cms GFRP [45/90/45/90/45]

BSRO2- Beam with same dimensions as control beam (CB) and with a small web opening at the middle span of beam with dimensions (l x h) – 120mm x 90mm and external reinforcement of GFRP in 5layers is provided across the both sides of web opening with 10cms width and 45/90/45/90/45 orientation. By using dial gauges the angle of twist is noted corresponding to the load increment. The load was applied till failure. The initial crack was observed at 55KN and ultimate failure load was 70KN. Cracks formed mainly on one side. Set up and crack pattern are shown in fig 4.9(a) and fig 4.9(b). The table 4.9 shows the load applied and angle of twist at three sections.

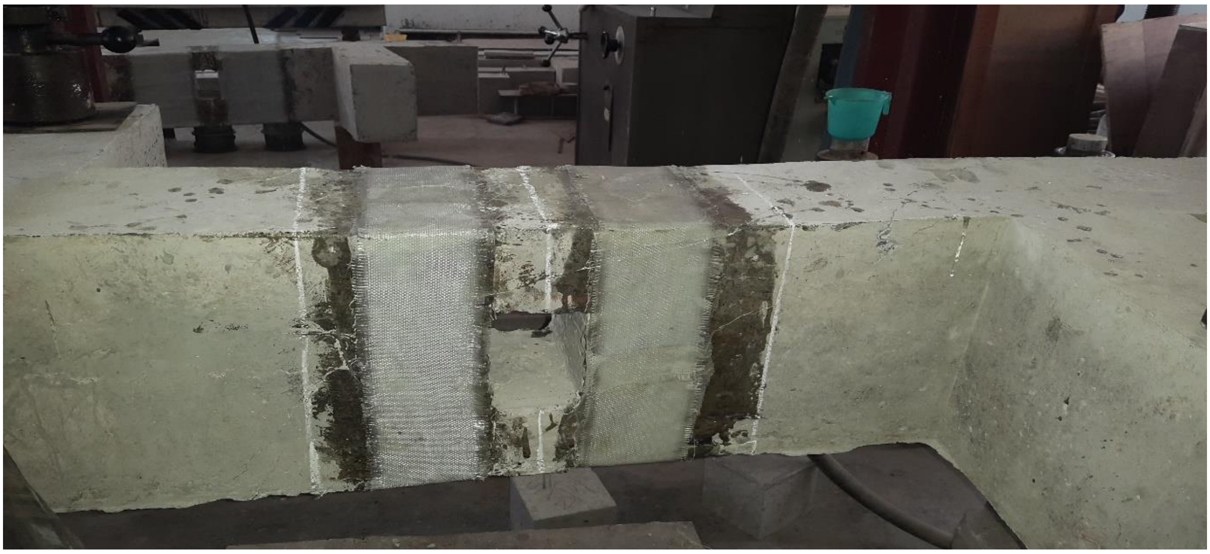
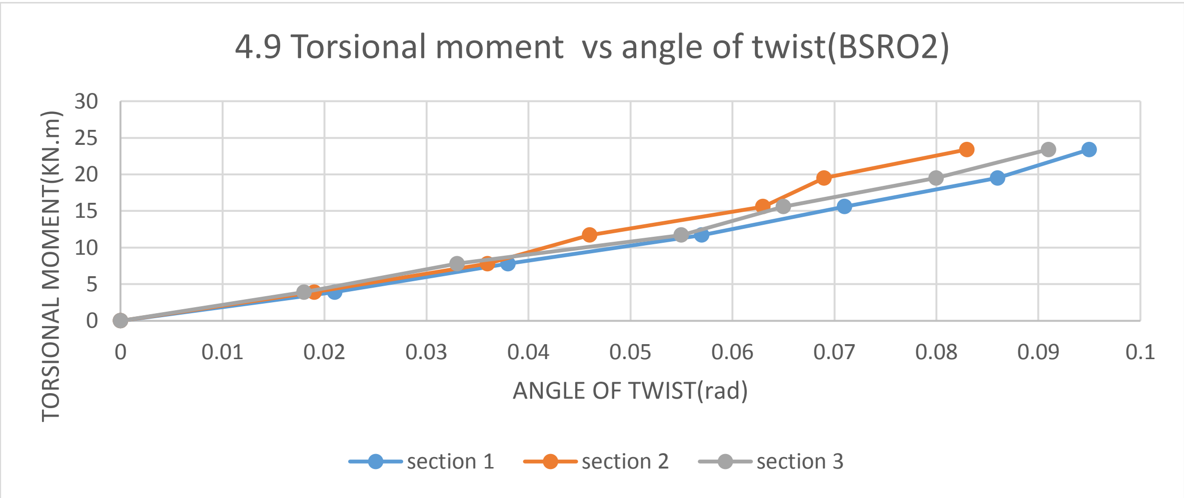


Fig 4.9(a) Setup of BSRO2

Fig 4.9(b) Crack pattern in BSRO2

TABLE 4.10 Torsional Moment Vs Angle of Twist for BSRO2

Load Kn	Torsional Moment kN-m	Section 1	Section 2	Section 3	Remarks
		Angle of twist(radians)			
0	0	0	0	0	
10	3.9	0.021	0.019	0.018	
20	7.8	0.038	0.036	0.033	
30	11.7	0.057	0.046	0.055	
40	15.6	0.071	0.063	0.065	
50	19.5	0.086	0.069	0.08	Initial crack 55KN
60	23.4	0.095	0.083	0.091	
70	27.3				Ultimate load 70KN



4.1.10 BSRO3 - Beam with small rectangular opening with 20cms GFRP [90/90/90/90/90]

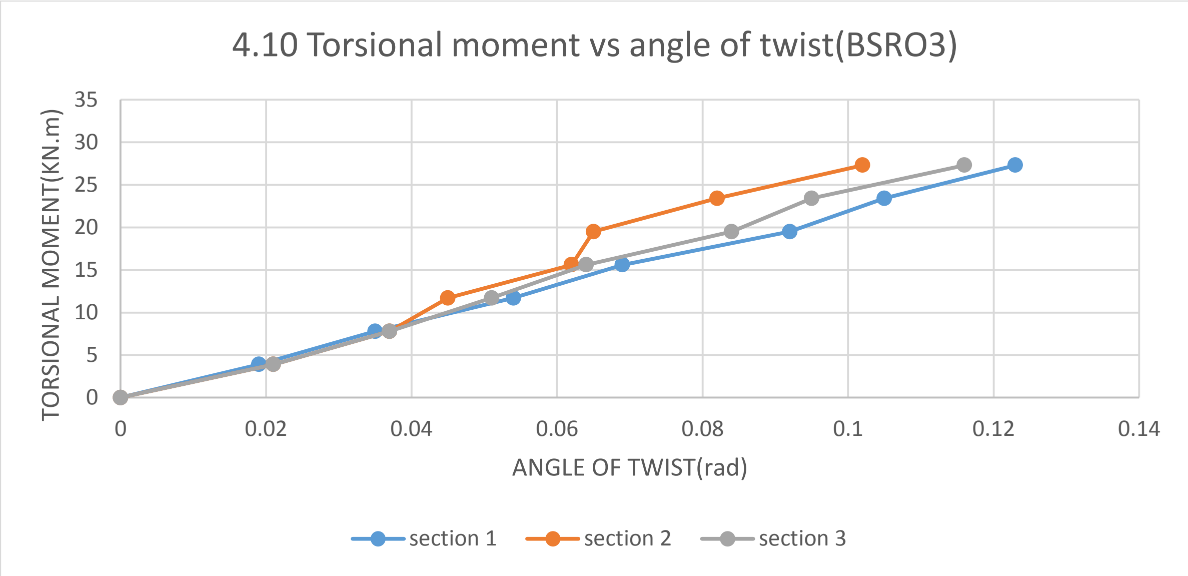
BSRO3- Beam with same dimensions as control beam (CB) and with a small web opening at the middle span of beam with dimensions (l x h) – 120mm x 90mm and external reinforcement of GFRP in 5layers is provided across the both sides of web opening with 20cms width and 90/90/90/90/90 orientation. By using dial gauges the angle of twist is noted corresponding to the load increment. The load was applied till failure. The initial crack was observed at 65KN and ultimate failure load was 80KN. cracks are initiated across the web opening but due to GFRP retrofitting the failure has occurred on un-strengthened sections of beam. Set up and crack pattern are shown in fig 4.10(a) and fig 4.10(b). The table 4.10 shows the load applied and angle of twist at three sections.

Fig 4.10(a) Setup of BSRO3

Fig 4.10(b) Crack pattern of BSRO3

TABLE 4.11 Torsional Moment Vs Angle of Twist for BSRO3

Load Kn	Torsional Moment kN-m	Section 1	Section 2	Section 3	Remarks
		Angle of twist(radians)			
0	0	0	0	0	
10	3.9	0.019	0.021	0.021	
20	7.8	0.035	0.037	0.037	
30	11.7	0.054	0.045	0.051	
40	15.6	0.069	0.062	0.064	
50	19.5	0.092	0.065	0.084	
60	23.4	0.105	0.082	0.095	Initial crack 65KN
70	27.3	0.123	0.102	0.116	
80	31.2				Ultimate failure load 80KN



4.1.11 BSRO4 - Beam with small rectangular opening with 20cms GFRP [45/90/45/90/45]

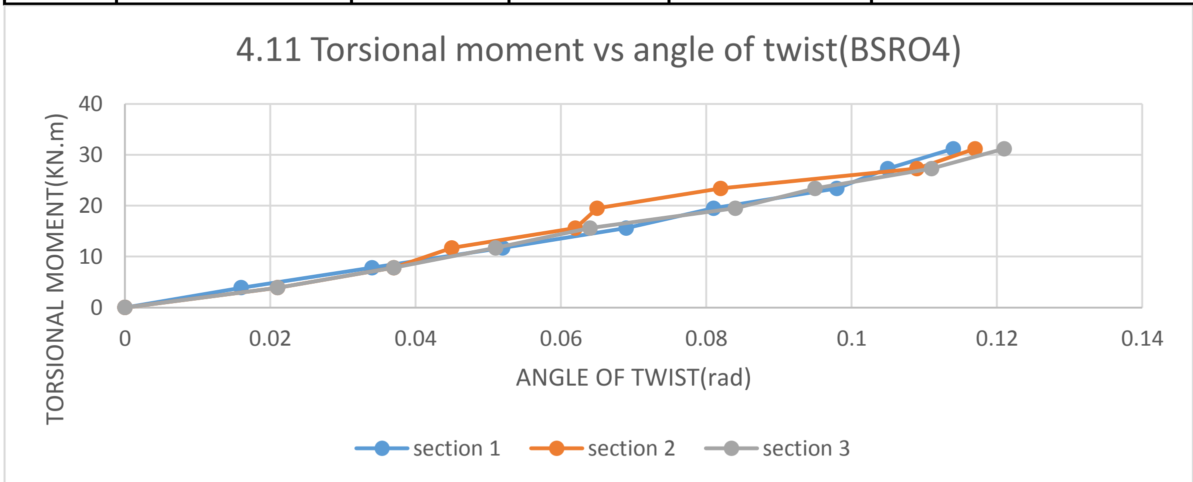
BSRO4- Beam with same dimensions as control beam (CB) and with a small web opening at the middle span of beam with dimensions (l x h) – 120mm x 90mm and external reinforcement of GFRP in 5layers is provided across the both sides of web opening with 20cms width and 45/90/45/90/45 orientation. By using dial gauges the angle of twist is noted corresponding to the load increment. The load was applied till failure. The initial crack was observed at 68KN and ultimate failure load was 88KN. The cracks are formed across the web opening and failure has occurred. Set up and crack pattern are shown in fig 4.11(a) and fig 4.11(b). The table 4.11 shows the load applied and angle of twist at three sections.

Fig 4.11(a) Setup of BSRO4

Fig 4.11(b) Crack pattern in BSRO4

TABLE 4.12 Torsional Moment Vs Angle of Twist for BSRO4

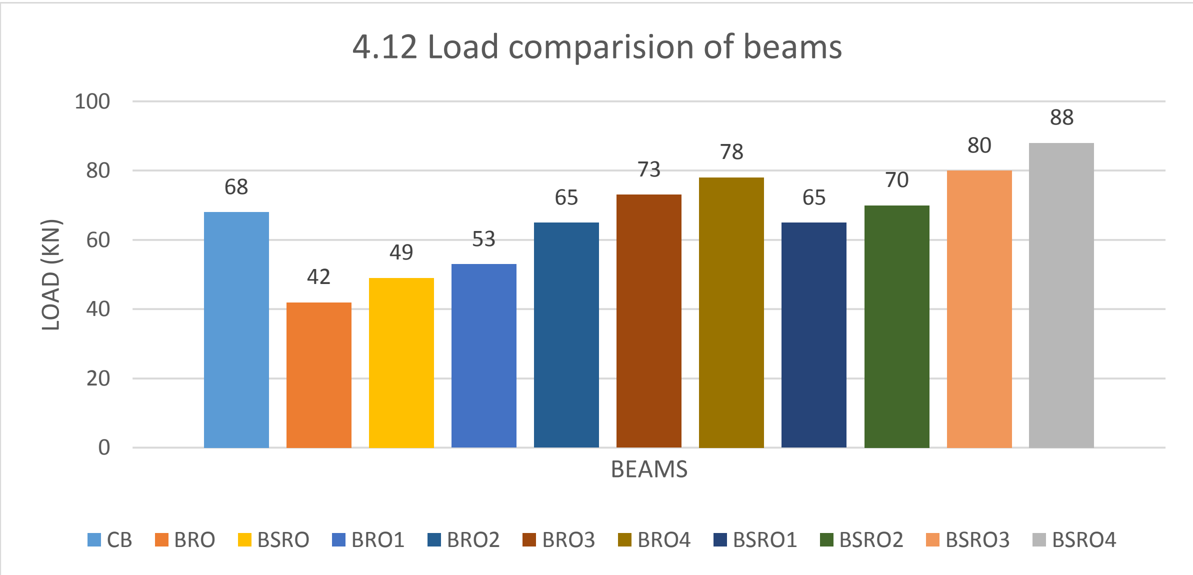
Load kN	Torsional Moment kN-m	Section 1	Section 2	Section 3	Remarks
		Angle of twist(radians)			
0	0	0	0	0	
10	3.9	0.016	0.021	0.021	
20	7.8	0.034	0.037	0.037	
30	11.7	0.052	0.045	0.051	
40	15.6	0.069	0.062	0.064	
50	19.5	0.081	0.065	0.084	
60	23.4	0.098	0.082	0.095	Initial crack 68KN
70	27.3	0.113	0.098	0.111	
80	31.2	0.119	0.107	0.121	
88					Ultimate failure load 88KN



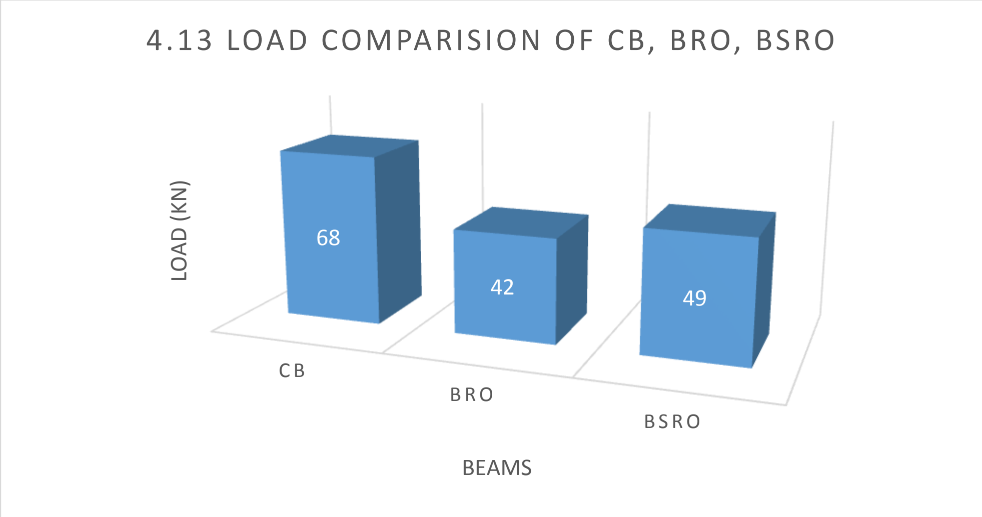
4.2 COMPARISIONS:

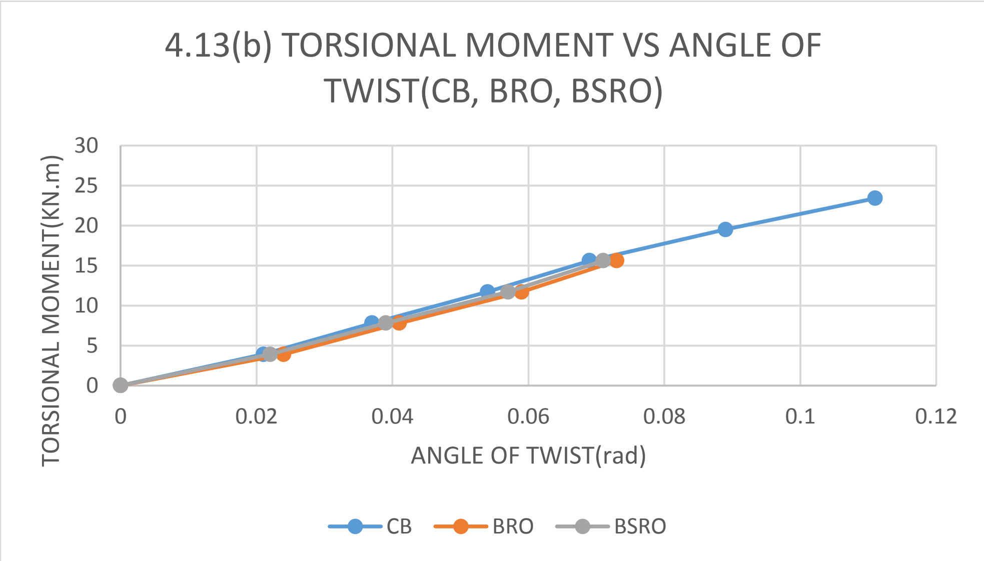
4.13 Torsion capacity of beams

	Beam	Load (kN)	Torsional moment (kN.m)	Percentage increase or decrease wrt CB	Percentage increase wrt unretrofitted beams
Control beam without opening	CB	68	26.52		
Beams with small opening	BSRO	49	19.11	-27.94	
	BSRO1	65	25.35	-4.41	32.65
	BSRO2	70	27.3	+5.88	42.85
	BSRO3	80	31.2	+17.64	63.26
	BSRO4	88	34.32	+29.41	79.59
Beams with large opening	BRO	42	16.38	-38.23	
	BRO1	53	20.67	-22.05	26.19
	BRO2	65	25.35	-4.41	54.76
	BRO3	73	28.47	+7.35	73.81
	BRO4	78	30.42	+14.70	85.71

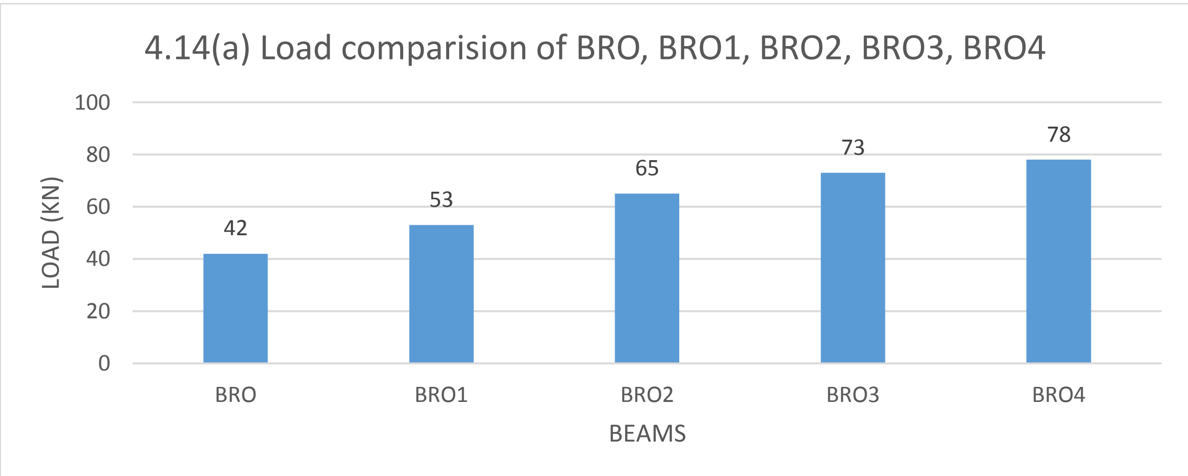


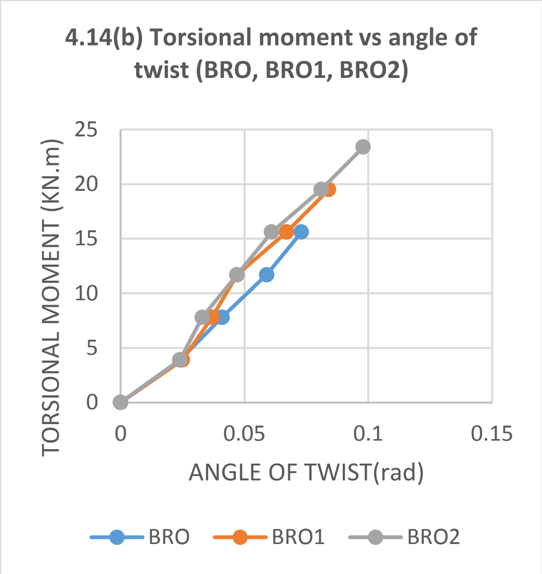
4.2.1 COMPARISION OF UNSTRENGTHENED BEAMS CB, BRO, BSRO

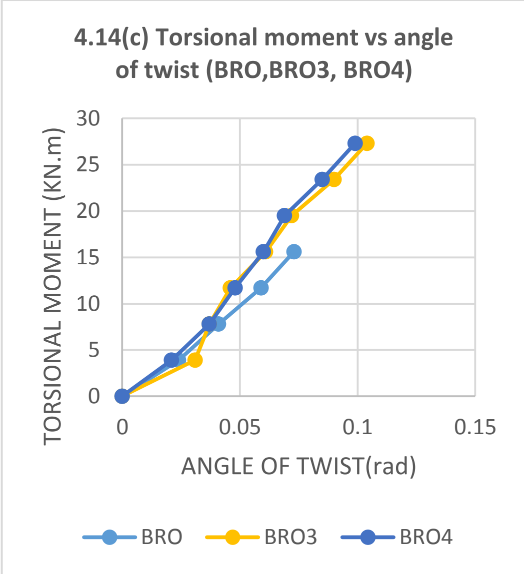




4.2.2 COMPARISION OF BRO, BRO1, BRO2, BRO3, BRO

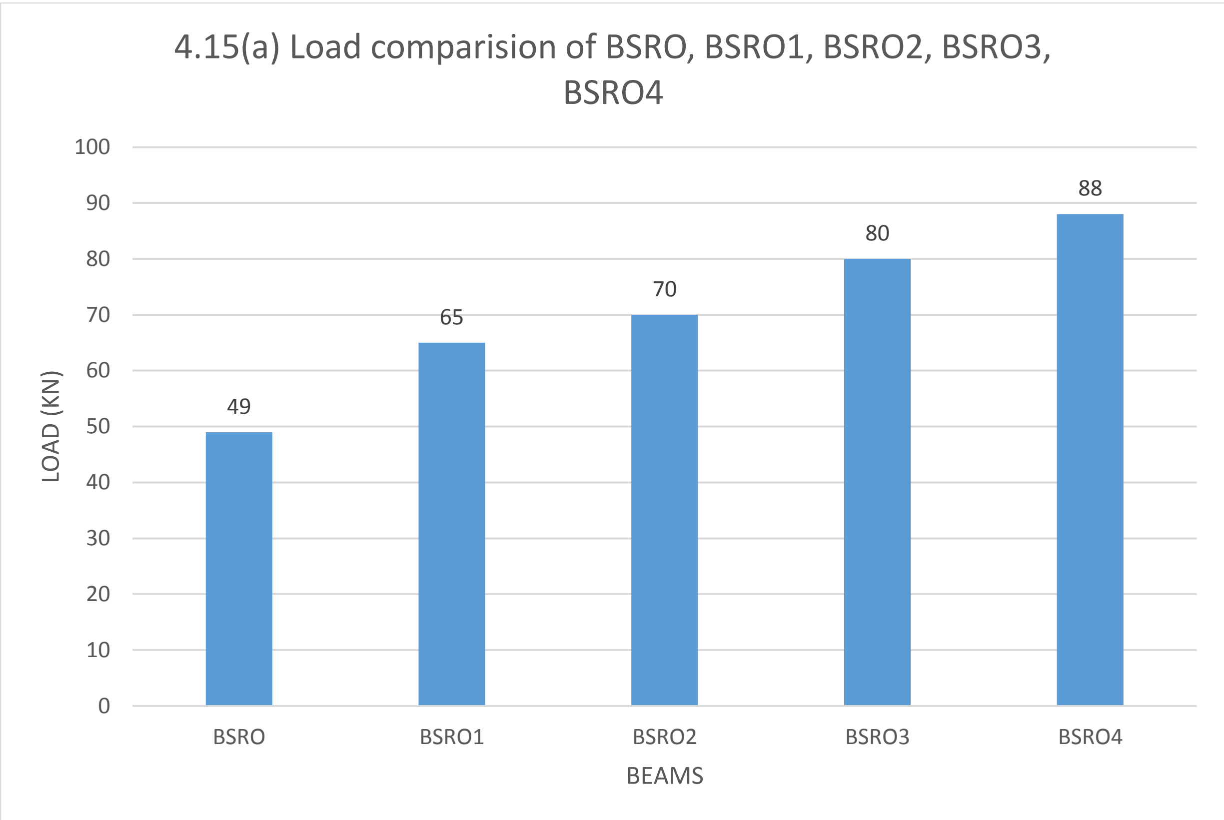


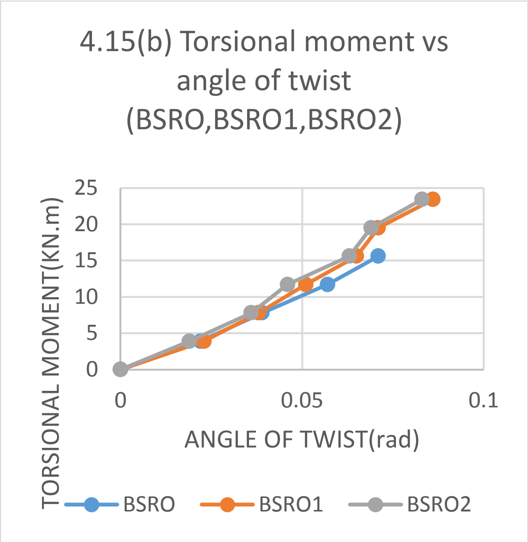


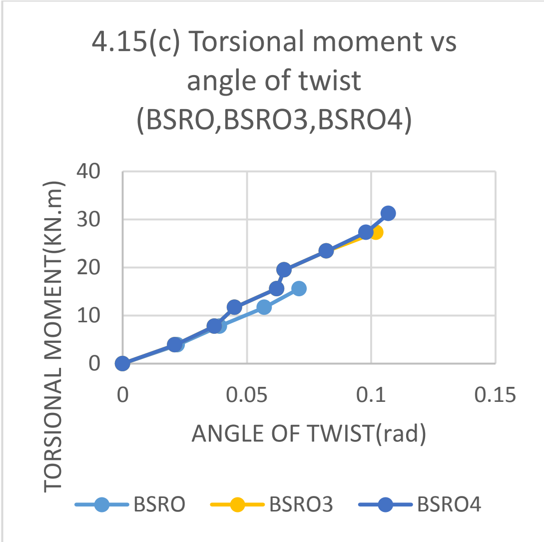


The figures 4.14(b) & 4.14(c) indicate slight improvement in ductility for [45/90/45/90/45] scheme of orientation. Both the schemes of retrofitting have exhibited more ductility when compared with un retrofitted beam.

4.2.3 COMPARISION OF BSRO, BSRO1, BSRO2, BSRO3, BSRO4

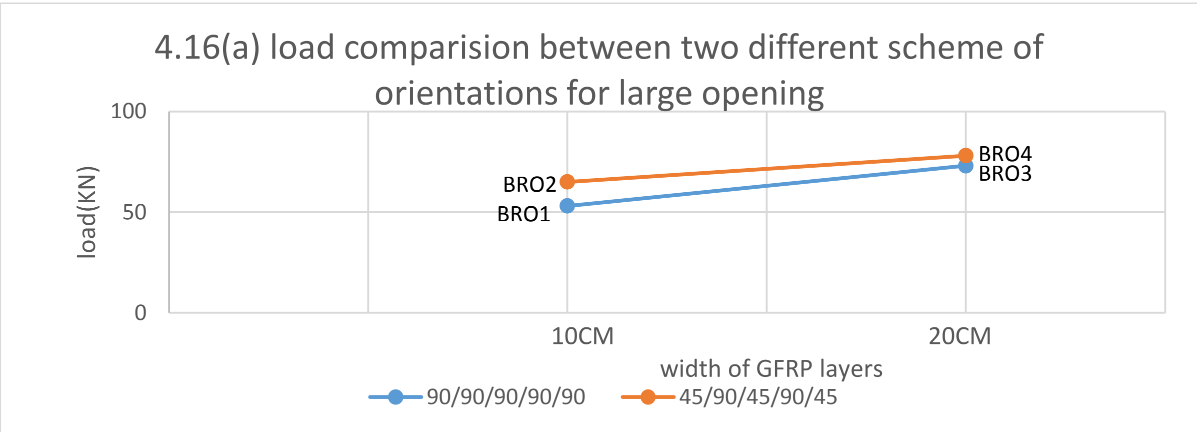


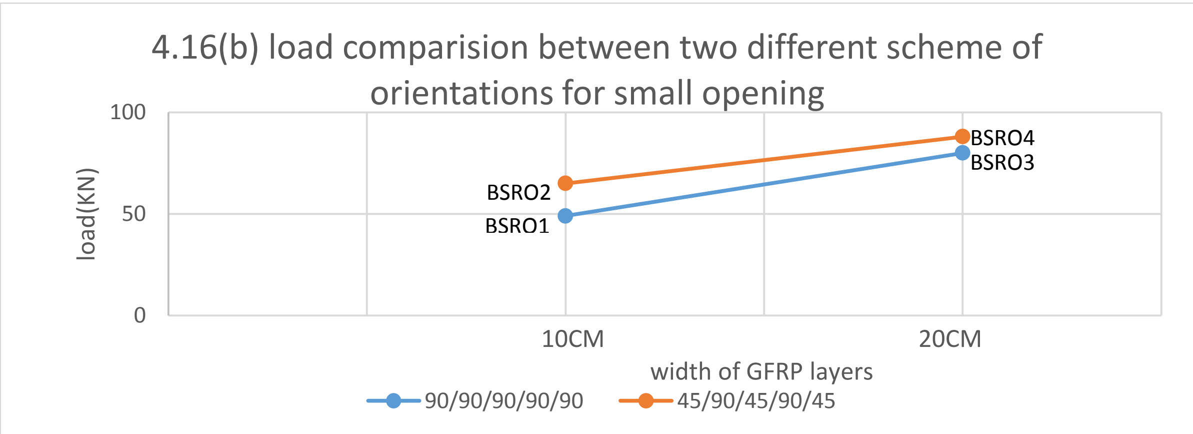




The figures 4.15(b) & 4.15(c) indicate slight improvement in ductility for [45/90/45/90/45] scheme of orientation. Both the schemes of retrofitting have exhibited more ductility when compared with un retrofitted beam.

4.2.4 COMPARISION OF SCHEME OF ORIENTATION OF GFRP IN BEAMS





From the fig 4.16(a) and 4.16(b) it clearly shows that the [45/90/45/90/45] scheme of orientation have restored more torsional capacity than the [90/90/90/90/90] scheme adopted.

CHAPTER 5

CONCLUSIONS

Following conclusions are drawn from the present study

1. Web openings in beams cause reduction in torsion moment capacity and increase in deflections because of reduction in stiffness. Reduction was found to be more for beams with large opening.

2. The un retrofitted beams with opening have shown Beam type of failure.

3. All schemes of retrofitting exhibited increase in torsion capacity of beams with openings.

4. The beams with small openings, retrofitted with 10mm wide GFRP stripes restored strength by 32.65% following first scheme (90/90/90/90/90) and 42.85% following second scheme (45/90/45/90/45).

5. The beams with large openings, retrofitted with 10mm wide GFRP stripes restored strength by 26.19% following first scheme (90/90/90/90/90) and 54.76% following second scheme (45/90/45/90/45).

6. The beams with small openings, retrofitted with 20mm wide GFRP stripes restored strength by 63.26% following first scheme (90/90/90/90/90) and 79.59% following second scheme (45/90/45/90/45).

7. The beams with large openings, retrofitted with 20mm wide GFRP stripes restored strength by 73.81% following first scheme (90/90/90/90/90) and 85.71% following second scheme (45/90/45/90/45).

8. Beams that are retrofitted with 10cms wide GFRP for both schemes of orientation has shown delaminated GFRP failure, while beams with 20cms wide GFRP has shown fracture type of failure and failure occurred due to the cracks that are propagated beyond GFRP layers.

9. The 20cms wide strips retrofitting of GFRP has shown better results in restoring the torsional capacity than 10cms wide strips. And the 45/90/45/90/45 has resulted better restoring torsional capacity when compared to other scheme.

10. Beams retrofitted with [90/90/90/90/90] scheme of orientation have exhibited more stiffness.

11. The Beams that are retrofitted with [45/90/45/90/45] scheme of orientation have shown better ductility and restored more torsional capacity of the beams.

12. The best option of retrofitting was found to be 5 layers of 20cm wide GFRP with [45/90/45/90/45] scheme of orientation.

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