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A Study on Torsional Behaviour of RCC beams Wrapped with Fibre Reinforced Polymer (FRP)

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ABSTRACT
Many beams located at the perimeter of buildings carry loads from slabs, joists and beams from one side of the member only. This loading mechanism generates torsional forces that are transferred from the beams to the columns. Such beams are deficient in torsional shear capacity and are in need of strengthening.. Fibre Reinforced Polymer (FRP) as an external reinforcement is used extensively to address the strength requirements related to flexure and shear in structural systems, but the strengthening of beams subjected to torsion is yet to be explored. In this project, the behaviour and performance of reinforced concrete beams strengthened with externally bonded Glass FRP (GFRP) sheets subjected to pure torsion has been studied. Experimental result reveal that externally bonded GFRP sheets can significantly increase both the cracking and the ultimate torsion capacity. Concrete with mix proportion 1:1.8:3.6 was used during the casting of the specimens. Glass fibre sheets used was bi-directional woven roving mat. Polymer matrix Epoxy resin with 10 % hardener was used as the binder of GFRP sheets with the concrete surface. The obtained result shows that the load carrying capacity of the retrofitted beam is far more than the control beam. FRP based strengthening has better aesthetic appearance compared to other methods and is easier to implement and is light in weight.

I. INTRODUCTION

A structure is designed for a specific period and depending on the nature of the structure, its design life varies. For a domestic building, this design life could be as low as twenty-five years, whereas for a public building, it could be fifty years. Deterioration in concrete structures is a major challenge faced by the infrastructure and bridge industries worldwide. The deterioration can be 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. As complete replacement or reconstruction of the structure will be cost effective, strengthening or retrofitting is an effective way to strengthen the same.

The most popular techniques for strengthening of reinforced concrete beams have involved the use of external epoxy-bonded steel plates. It has been found experimentally that flexural strength of a structural member can be increased by using this technique. Although steel bonding technique is simple, cost-effective and efficient, it suffers from a serious problem of deterioration of bond at the steel and concrete interphase due to corrosion of steel. Other common strengthening technique involves construction of steel jackets which is quite effective from strength, stiffness and ductility considerations. However, it increases overall cross-sectional dimensions, leading to increase in self-weight ofstructures and is labour intensive. To eliminate these problems, steel plate was replaced by corrosion resistant and light-weight Fibre Reinforced Polymer (FRP) Composite plates. FRPCs help to increase strength and ductility without excessive increase in stiffness. Further, such material could be designed to meet specific requirements by adjusting placement of fibres. So concrete members can now be easily and effectively strengthened using externally bonded FRP composites.

By wrapping FRP sheets, retrofitting of concrete structures 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. FRP systems can also be used in areas with limited access where traditional techniques would be impractical. However, due to lack of the proper knowledge on structural behavior of concrete structures, the use of these materials for retrofitting the existing concrete structures cannot reach up to the expectation. 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.

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 concretebeams and columns retrofitted with carbon fibre reinforced polymer (CFRP)/ glass fibre 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.

II. LITERATURE REVIEW

2.1 GENERAL

Studies have specifically focused on structural strengthening of RCC beam using GFRP. This includes the work of

Nikita Jain et al (2015)studied experimental works of glass fiber reinforced polymer (GFRP) retrofitted RC beams under symmetrical four-point static loading system. GFRP can increase the shear capacity of beams.The use of GFRP sheets as an external reinforcement is recommended to enhance the shear capacity of RC Beams with anchorage system.

D.N. Shinde et al (2014)investigates the Flexural behavior of R.C.C. beam wrapped with GFRP (Glass Fiber Reinforced Polymer) sheet.Experimental results shows thatEffective procedure of wrapping enhances the strength considerably and flexural retrofitting also increases the shear strength of concrete.

Rameshkumar U More et al (2014) studied experimentally the flexural behaviour of the beam externally bonded aramid fiber reinforced polymer specimens subjected to two point loading mechanism only..Ultimate load carrying capacity in beams is found to be increasing with increase in layer of AFRP strip.With increase in degree of damage, deflection at ultimate load is found to be decreasing by applying AFRP strip.

Sandeep G. Sawant et al (2013) investigates the effect of number of GFRP layers and its orientation on ultimate load carrying capacity and failure mode of the beams.Results shows that

U-Shape wrap and bottom wrap was good for improving shear strength as well as for reducing deflection of RC member as compare to both side wrap.

Patel Mitali R et al (2012)carried out experimental work on shear strengthening of different beams using FRP and the effect of different parameters on the strength of beams strengthened externally with FRP sheets or strips. Results show that for strengthening of beam in shear, use of strips of CFRP was best mechanism. This mechanism has largest residual strength and less brittle failure.51% increase in shear capacity was achieved with addition of CFRP reinforcement externally.

Yousef A. Al-Salloum et al (2012) carried out an experimental work of Shear Strengthening of Reinforced Concrete Beams Using Textile-Reinforced Mortar (TRM) which shows thatthe basalt textile-reinforced mortar layers provided substantial gain in the shear capacity of reinforced concrete beams ranging from 36–88%. As anticipated, the shear resistance increased as the number of TRM layers increased from two to four per side.

S. Roohollah Mousavi1 et al (2012) concluded that the reinforcement ratio and elastic modulus of FRP bars are the most significant variables for calculating the deflection.The deflections estimated using their model are more accurate than those predicted using the ACI 440.1R-03 (2003) and ACI 440.1R-06 (2006) provisions.

Amir Mofidiat al(2011) concluded the influence of conventional transverse-steel reinforcement on the contribution of FRP to shear resistance has been proved to be significant.A new FRP effective width, w_{fe}, were defined to transform a bonding area of a beam with multiline cracking pattern to an equivalent bonding area of a beam with a single-line cracking pattern. To address the effect of transverse steel on V_f, a coeffcient were been introduced. The sum of transverse-steel rigidity and FRP rigidity shows a good correlation.

Indrajit Ray et al (2011) observed that the Polymer-Modified Concrete (PMC) repaired beams failed crack-induced debonding and FRP rupture, whereas the CFO-repaired beams showed debonding of the concrete cover and subsequent FRP rupture. The FRP ruptures on the CFO-repaired beams were likely caused by localized direct tension in areas of high-stress concentration attributable to the substrate failure. In this case, no significant debonding occurred between the concrete and FRP strips.

Khaled Galal et al (2009) concluded that an externally bonded CFRP strengthening system without end anchorage increased the yield and the ultimate loads by about 16 and 5%, respectively, relative to those of the control beam. The T-beam failed prematurely due to peeling off of the CFRP sheet. The midspan deflections of the strengthened T-beam at ultimate load were54% less than that of the control beam.

M. Di Ludovico et al 2008)observed that the deformation capacity of the structure were likely been increased since the damage of the retrofit structure was significantly less than the damage of the "as-built" structure under the same seismic input. Moreover, FRP retrofit allowed the structure to withstand a level of excitation, in the two directions, 1.5 times larger than that applied to the "as built" structure.

Sing-Ping Chiew et al (2007) observed that by bonding GFRP laminates to the tension face of flexural RC beams, both strength and stiffness of the beams can be increased. The strengthening ratio increases linearly with the increase of the axial rigidity of the external GFRP laminates. In contrast, the variation of bond length in the shear span has little effect as long as the l_3 / l_2 ratio is larger than 0.56. The interfacial debonding is progressively activated with the increase of the external load from below the loading point toward the end of the laminate. The interfacial shear stress concentration due to the cutoff effect is less significant than that caused by flexural cracking Debonding failure occurs when the interfacial bond in the shear span is fully utilized.

Guido Camata et al (2005) observed that the governing failure mode of beams during their test was the delamination of the upper face from the core. The beams tests failed in a very brittle manner and in a ductile-like manner. The ductile-like behavior was due to premature progressive delamination caused by the poor bonding between the upper face and the core. Results indicated that increasing the face thickness increases the flexural stiffness of a beam.

Anthony J. Lamanna et al (2004)observed that beams strengthened with mechanically fastened FRP strips showed increases in yield moment over the control beams of up to 21.6% and showed increases in the ultimate moment of up to 20.1%. FRP strengthening strips attached to reinforced concrete beams with powder-actuated fasteners were as effective as the traditional method of bonding the strips to beams.

Sherrill Ross et al (2004) studied that that the use of GFRP as an external reinforcement for channel beam bridge girders increased ultimate flexural strength, increased elastic flexural stiffness, and reduced beam curvature at a given load level compared to non-retrofit beams. Experimental results were inconclusive regarding the effect of GFRP retrofitting on ultimate vertical deflection capacity. Design calculations predicted a decrease in the ultimate vertical deflection capacity of channel beams retrofit with GFRP.

enrik Thomsen et al (2004) ivestigates that FRP-strengthened RC beams tend to perform better under distributed loads than under four-point bending loading conditions. The distributed load does not cause a discontinuity in the plate force along the span. In the four-point bending case, the discontinuity caused by the concentrated load tended to cause mid-span debonding. Shorter plates in the distributed load case exhibit a similar failure mode to that of four-point bending, with plate-end peeling due to the geometric discontinuity in the section. RC beams with longer plates eventually fail due to plate failure, as the plate can develop its full strength before bond failure. While concentrated loads may simulate bridge girders, distributed loads better simulate beams in RC buildings.

Gregor Fischer et al (2003) studied that increasing flexural strength of FRP-reinforced ECC compared to reinforced concrete was mainly attributed to the compressive strength of ECC, the deflection capacity was fundamentally affected by improved composite interaction. The load-deformation response of FRP-reinforced ECC was dominated by flexural deformation up to relatively large drift levels and crack formation is found effectively independent of interfacial bond properties. Inelastic deformation of ECC in compression leads to flexural stiffness reduction and ultimately gradual mode of failure; however, it also induces compressive strain and tensile strength reduction in the FRP reinforcement.

J. F. Bonacci et al (2001) investigates that with proper design, externally strengthened beams can develop considerable deformation before failure. Proper design should involve limiting the relative axial stiffness of the FRP with respect to that of the internal steel reinforcement as well as using special anchorage details to delay brittle debonding types of failures. Further, it must be realized from the outset that significant strength gains using EB-FRP are easiest to achieve for lightly to moderately reinforced RC beams.

Abhijit Mukherjee et al (2001)carried out an investigation that when the RC beam was deficient in shear, or when its shear capacity was less than the flexural capacity after flexural strengthening, shear strengthening must be considered. It is critically important to examine the shear capacity of RC beams which are intended to be strengthened in flexure. Glass Fiber Reinforced Polymer (GFRP) composite material, as an external reinforcement is a viable technology recently found to be worth for improving the structural performance of reinforced concrete structures.

Aiello et al (2000) studied that the shear retrofit of the exterior joints and wall-type column prevented brittle mechanisms and thus allowed to fully exploit the improved energy dissipating capacity of the structure.

Oral Buyukozturk et al (1998) studied the experimental effect of GFRP material compatibilities and their resistances to degradation through both environmental and load cycles, and the assessment of retrofitted system integrity through the use of nondestructive evaluation. The potential to provide quantitative verification of elements essential to effective rehabilitation such as adherent thicknesses, crack and delamination identification, and void detection.

Ahmed Khalifa et al (1998)studied that based on the effective FRP stress, a function of its stiffness and ultimate strain. This design approach is valid for CFRP continuous sheets or strips and for any fiber orientation angle. It is only suitable if the failure is controlled by FRP sheet rupture.

Joseph M. Bracci et al (1997) develop an evaluation process which was successfully used to evaluate the experimental seismic response of a non-ductile low-rise model building and the subsequent response of the same building after retrofit by comparing the relative improvements in strength and deformation demand and capacities of original and modified structural systems.

Tom Norris et al (1997) studied that when the CFRP fibers were placed perpendicular to cracks in the beam, a large increase in stiffness and strength was observed and a brittle failure occurred due to concrete rupture as a result of stress concentration near the ends of the CFRP where flexural or shear cracks in the beam were repaired.

Hamid Saadatmanesh et al (1991)studied that significant increase in the flexural strength can be achieved by bonding GFRP plates to the tension face of reinforced concrete beams. The gain in the ultimate flexural strength was more significant in beams with lower steel reinforcement ratios.

III. RESULTS AND DISCUSSION

Both the beams were tested under pure torsion. The torsion was applied through the projected cantilever on both sides of the beam as shown in figure 1.
The following data were obtained for Beam 1 (CONTROL BEAM).

Table 1. Relation between angle of twist and torsional moment (Beam1)

TORSIONAL MOMENT (KNm)	ANGLE OF TWIST (rad/m)
2	0.3
4	0.7
6	1.5

8	2
10	2.9
12	3.7
14	4.65
16	5.6
18.4 *	6.4
20	7.4
22	8.3
24	9.4
26	10.4
28	11.7
29.5 **	12.9

*** Torsional Moment when the 1st crack appeared is 18.4 KN-m.**
**** Torsional moment at complete failure is 29.5 KN-m**

Figure 9. Graph between angle of twist and torsional moment.

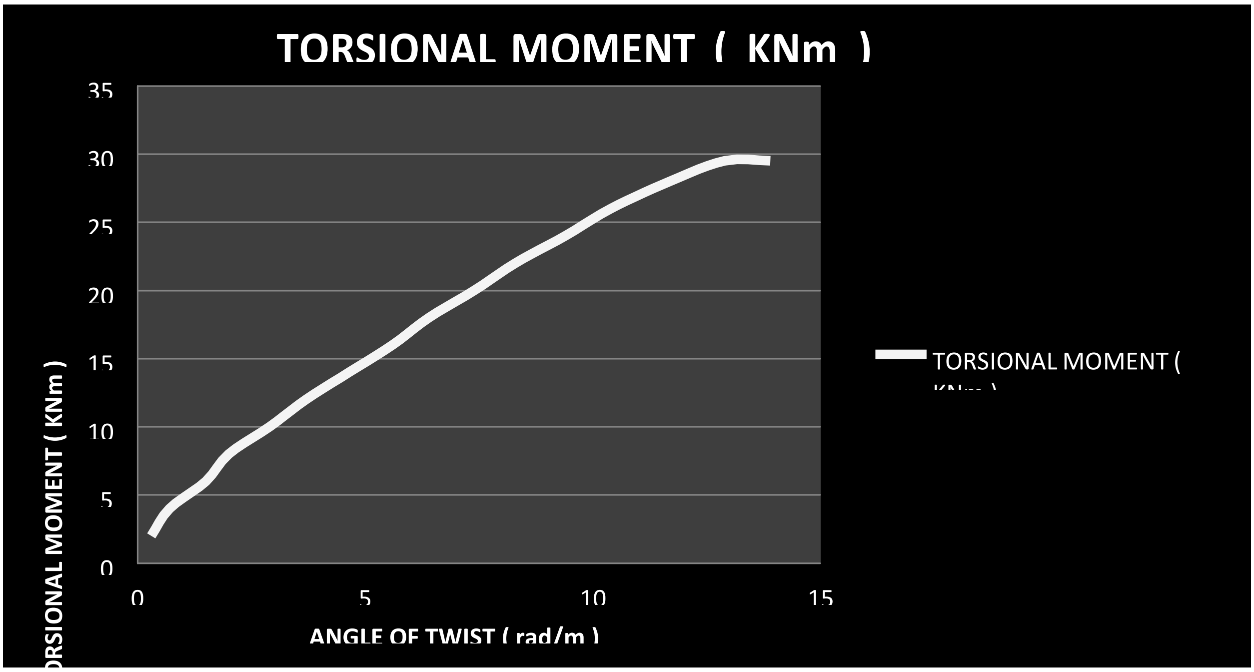

Figure 10 shows the failure of the control beam in torsion.

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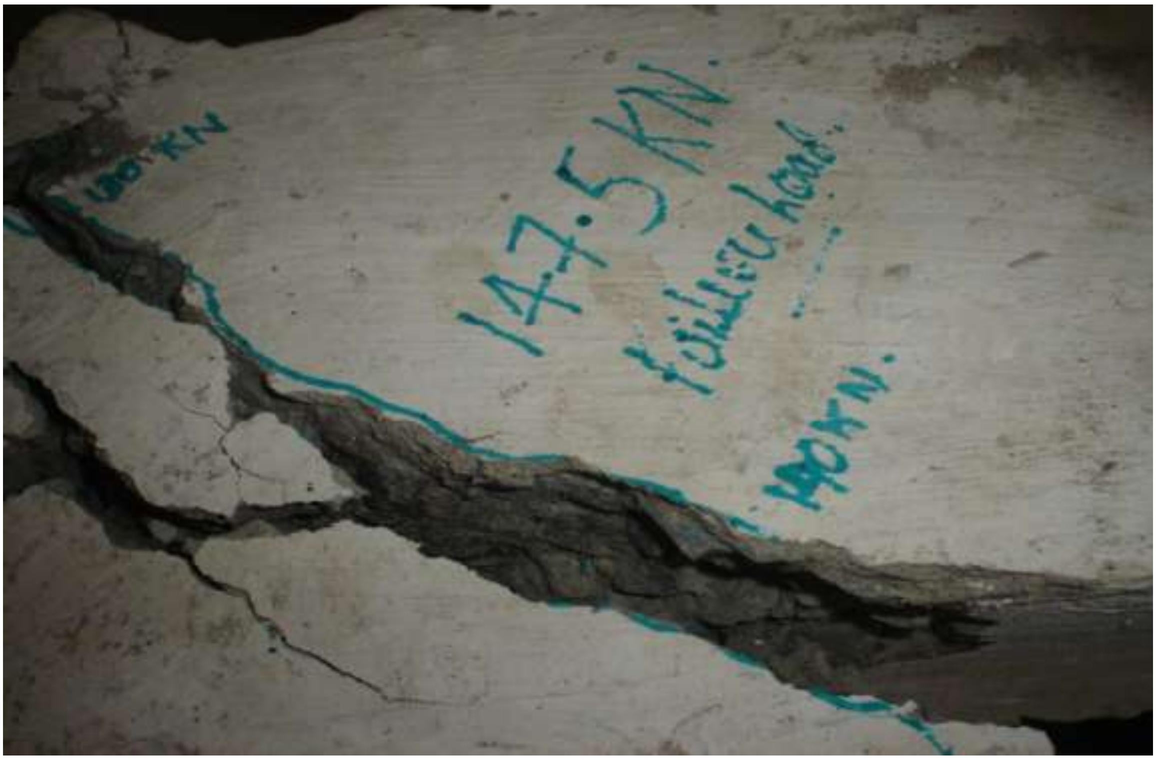

Fig. 11 Close view of the crack in Beam 1 after failure

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The following data were obtained for Beam 2 (RETROFITED BEAM) :

Table 2. Relation between angle of twist and torsional moment (Beam 2)

TORSIONAL MOMENT (KNm)	ANGLE OF TWIST (rad/m)
2	0.1
4	0.7
6	1.3
8	1.7
10	2.3
12	2.9
14	3.4
16	3.9
18	4.5
20	5.1
22	5.7
24	6.4
26	7
28*	7.5
30	7.9
32	8.4
34	8.867
36	9.3
38	9.8
40	10.4
41.6**	11.1

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*** Torsional Moment when 1st crack appeared is 28 KN-m.**

****Torsional Moment at complete failure is 41.6 KN-m.**

In **Figure 12** the curve represents, the angle of twist corresponding to torsional moment for beam 2 (Wrapped with FRP or RETROFITED BEAM)

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Figure 13 shows the failure of the retrofitted beam, when the GFRP sheet was still intact.

Figure 14 shows the failure pattern of the retrofitted beam, when the GFRP sheet was removed.

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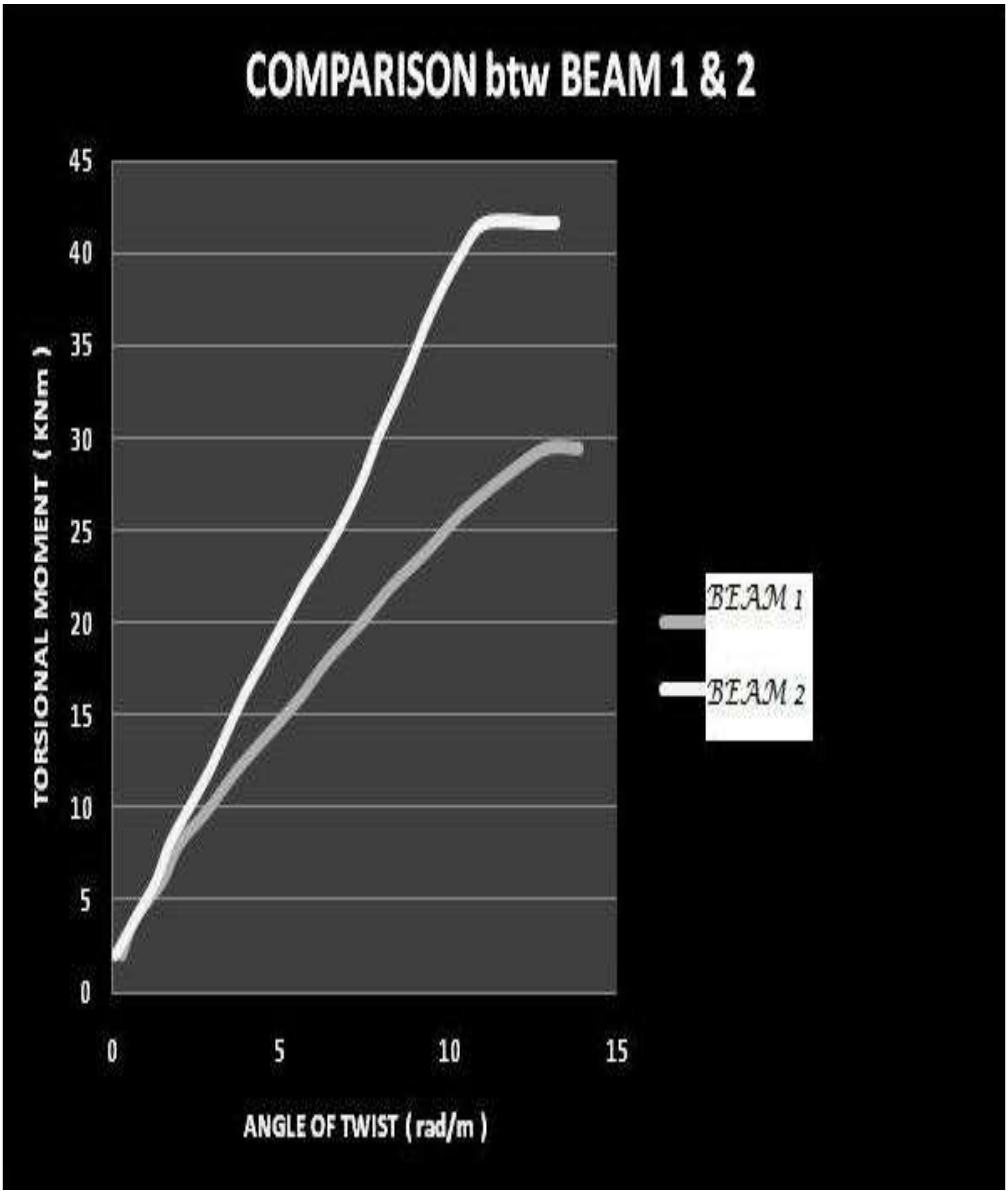
Figure 15 shows a graphical comparison between Beam 1 & 2.



IV. CONCLUSION

The following conclusions are drawn from the experimental work:-

- The beam wrapped with GFRP sheets exhibited significant increase in the cracking strength.
- When the test results were compared, it was found that the cracking strength of the retrofitted beam (Beam 2) is **53%** more than that of the control beam (Beam 1).
- There was a significant increase in the Ultimate load carrying capacity of the retrofitted beam.
- The ultimate load carrying capacity of the retrofitted beam increased by **42 %**.
- The increase in strength was mainly due to confinement offered by the FRP sheets, which acts like closely looped shear reinforcement.
- It was observed that the retrofitted FRP sheet starts working only after sufficient cracking occurs in the concrete.
- FRP based strengthening has better aesthetic appearance compared to other methods, and is easier to implement and is light in weight.

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