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EXPERIMENTAL STUDY ON TORSIONAL BEHAVIOUR OF SINGLY TYPE OF REINFORCEMENT WITH FERROCEMENT “U” WRAPS

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Abstract

The behaviour of rectangular concrete beams with singly type of reinforcement under pure torsion is experimentally investigated with ferrocement “U” wraps. The presented experimental program comprises 6 beams. Test results of this study clearly indicated that the use of singly type of reinforcement could not provide enhanced torsional capacity, but it improved torsional stiffness by resisting more twist. Compared to beams with equal quantity of the commonly used “U” wraps, the increase of the torsional strength for the tested beams under imposed torsion increases twist of the members 74.31% , 74.31% and 81.64% respectively for three, four and five layers when reinforced with longitudinal direction and the same was found 15.60 %, 17.43% and 28.10 % respectively for transversely reinforced beams.
However, it is stressed that the increase in twist or ductility was not prominent with increase in ferrocement mesh layers. Torsion tests on reinforced wrapped members revealed that single type of reinforcement, either longitudinal or hoop reinforcement, cannot improve the torsional strength of the member beyond the torsional strength of the plain member. However, single type reinforcement improved the ductility of the member.

Keywords: *FRP; Ferrocement; Torsional capacity; Twist; wire mesh; Torsional rigidity.*

1. Introduction

The beneficial effect of provision of both longitudinal steel and transverse steel the torsional capacity and the ductility of Reinforced Concrete (RC) elements with rectangular cross-section has long been recognized by [1, 2, and 3]. The experimental results of these tests revealed that the application of RSR in many cases improved the overall seismic performance of the examined specimens in comparison with the conventionally reinforced beams [4, 5]. The recent technical expansion for massive use of continuous rectangular spiral reinforcement in rectangular reinforced concrete elements gives the opportunity for wide using of this kind of reinforcement in beams under torsion. Concerning the issue of torsion in concrete members, it is well-known that torsional cracks form a spiral pattern due to the principal tensile stresses developing in the diagonal concrete struts [6]. Thus, steel spirals that cross approximately 45^0 to the torsional cracks consist one of the most efficient transverse reinforcement against torsional action. The ratio of the steel longitudinal and transverse reinforcement along with the geometrical and mechanical properties of the RC members influences the angle of the diagonal cracking [7]. Therefore the optimum angle of the spiral links that should be provided has to be considered accordingly. The above discussion shows to resist torsion reinforcement is required in both directions. Again, torsion is one of the paramount factors to be considered along axial force, shear force and flexure. Generally torsion occurs as combined loading. The pure state of shearing stresses due to torsional load induces the principal diagonal tensile stress. The diagonal tensile stress thus developed is responsible for the failure of the plain concrete member. Strengthening or upgrading becomes necessary for these beams when these elements are unable to provide the resistance. Increased service loading, diminished capacity through aging and degradation, more stringent updates in code regulations have also necessitated for the retrofitting of the existing structures [3, 8]. FRP composites can be effectively used to upgrade such structural deficient reinforced concrete structures. Torsional retrofitting using FRP has received less attention [5, 9]. Strengthening structures with FRP increases ductility, strength in flexure, shear and torsion capacity as well as changes the failure mode and failure plane. Torsion, due to its circulatory nature, can be well resisted by closed form of reinforcement. But inaccessibility and extension of flanges over the web has necessitated strengthening the beams by “U” wrap rather than full wrap [10]. Few analytical and experimental studies were found to quantify the torsional strength of FRP bonded full wrap [11]. Very few attempts have been taken by [4] for quantification of torsional strength of "U" wrapped beams. Retrofitting by FRP is feasible to developed countries and urban areas of developing countries due to their high cost and skilled man power for its application [12]. From cost effective point of view and also from strength point of view ferrocement may be a substitute for FRP as it posses high tensile strength , water tightness and easy on application [13]. Torsional strength of a beam depends on longitudinal as well as transverse reinforcement. So, this research work forms a part of experimental investigation aimed at beneficial aspects of only one type of reinforcement either longitudinal or transverse reinforcement on existing concrete structures for enhancing torsional resistance when wrapped with ferrocement "U" wrap.

2. Experimental Program

Torsional strength of a beam is dependent upon its constituent materials and cross sectional area [2, 14]. Literature review reveals that the torsional response of a wrapped beam is dependent on aspect ratio, constituent materials of core and wrapping material [15]. The reinforcement provided in longitudinal and transverse direction controls the torque twist response in the post cracking stage [16, 17] . The torque-twist response of reinforced beams is characterized by different salient stages such as elastic, cracking and ultimate stages**.** Beams wrapped on three sides are of rehabilitation engineers' interest as the top side of a beam is not accessible due to the presence of slab. The beams wrapped on three sides only are referred as "U" wrapped beams. The "U" wrapped beams cannot perform in the same manner as that of full wrapped beams under torsional loading as it lacks one torsion resisting element.

Torque-twist response of a wrapped beam depends on the constituent material of wrap and the core along with cross sectional aspect ratio. A beam if wrapped with ferrocement "U" wrap, then its torque twist response is influenced by ferrocement wrap (ferrocement matrix strength and number of layers along with reinforcement in the core). Torque-twist response of a plain beam with "U" wrap differs than that of reinforced concrete beam with "U" wrap as the later posses the post cracking zone while the existence of post cracking zone for former depends on cracking of wrapped face.

The main influencing parameters in case of ferrocement "U" wrapped reinforced concrete beams are six states of torsion and number of mesh layers. The six possible reinforcements that can be arranged in a beam is as follows

- Beams with only longitudinal reinforcement
- Beams with only transverse reinforcement
- Under Reinforced Beams
- Longitudinally over reinforced and transversely under reinforced.
- Longitudinally under reinforced and transversely over reinforced
- Completely over reinforced.

Here an experimental program was taken up to investigate the torsional behaviour of beams with only longitudinal reinforcement and transverse reinforcement. The reinforced beams with normal strength core concrete 35 MPa was cast taking aspect ratio 2.0 with cross section (125 X 250) mm with ferrocement matrix of compressive strength 40 MPa. Reinforced concrete beams with only longitudinal reinforcement were designated as "L" beams and with only transverse reinforcement designated as "T" beams. The beam "L3N" refers a beam having only longitudinal reinforcement with three numbers of wire meshes in the ferrocement wrapping with mortar compressive strength of 40 MPa and core concrete strength 35 MPa.

The control beams without any reinforcement in core concrete were cast with three, four and five numbers of mesh layers in ferrocement "U" wrap taking same aspect ratio(B=2), the grade of ferrocement matrix constant(Q=40 MPa) and core concrete strength (N=35 MPa). BQ4N represents a beam with aspect ratio 2(B=2), ferrocement matrix strength 40 MPa (Q=40 MPa) and 4 layers of wire mesh with concrete compressive strength 35 MPa (N= 35 MPa).

The individual beams with "U" wrap details are presented in Table 1.

2.1 Material and Material Properties

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a) Cement

Ordinary Portland cement of 53 grade conforming to [18] was used throughout the experimental program. The standard consistency was 28%, whereas the initial and final setting time was 95 min. and 210 min. respectively. The specific gravity of cement was 3.14 and its compressive strength after 28 days was 57 MPa.

b) Coarse Aggregate

Crushed hard granite stone of maximum size 20 mm was used for concrete. The bulk density of aggregates was 16.95 kN/m^3 and specific gravity was found 2.65.

Table 1: Beams details with designations

Designation	Core Reinforced Concrete			
	Longitudinal Steel	**Transverse steel**		**Outer Wrap**
	Diameter, No. of bars	**Diameter, Spacing**	**Yield Strength (MPa)**	**No. of mesh layers (yield strength of wire mesh 250 MPa) Wire diameter=0.72 mm**
BQ3N				3
BQ4N				4
BQ5N				5
L3N	12 mm, 4 nos.		440	3
L4N	12 mm, 4 nos.		440	4
L5N	12 mm, 4 nos.		440	5
T3N		8mm @ 100 mm c/c	465	3
T4N		8mm @ 100 mm c/c	465	4
T5N		8mm @ 100 mm c/c	465	5

c) Fine Aggregate

IFIC (International Ferrocement Information Centre) ACI-1979 [13] suggests that the size of sand particle in ferrocement matrix should not be more than one half of the opening of mesh. The mesh opening was 6.35 mm. The river sand passing through the 1.18 mm sieve was used in the ferrocement matrix preparation. The specific gravity of sand was 2.65. The bulk density was found 16.05 kN/m^3.Fine aggregate used for this entire investigation for concrete was river sand conforming to zone-II of [19]. The fineness modulus was 2.81.

d) Water

Potable water was used for casting as well as curing as per IS-456 [20].

e) Super plasticizer

To achieve both strength and a workable mortar, a ferrocement matrix with flow value more than 80 cm and desired compressive strength, a regulated dosage of super plasticizer CONPLAST SP-337 was used.

f) Wire meshes

Galvanized steel square woven wire meshes were used for “U” wraps. The diameter of wire was 0.72 mm, yield strength 250 N/mm^2 and centre to centre spacing of wires is 6.35 mm. The yield strength of wire mesh was found be 250 MPa.

g) Reinforcement

6 mm, 8 mm, 10 mm and 12 mm diameter bars were used in the entire experimental study. The yield stresses of these bars were 350 N/mm^2, 465 N/mm^2 445 N/mm^2 and 440 N/mm^2 respectively.

h) Mix Proportion

The ferrocement matrix mix was prepared with trial basis to achieve the compressive strength 40 MPa with flow value more than 80. The concrete mix was prepared for a compressive strength of 35 MPa.

i) Moulds for Casting of Specimens

All the beams were prepared for a breadth of 125 mm and depth of 250 mm. Wooden moulds were prepared for the above mentioned size. Diagonal cracks are formed in the form of helix under torsional loads. To allow this pattern of cracking and to form two complete spirals in the central test region of the beam, a length 1500 mm is required. In order to hold the specimen and to apply the torque, the end zones are heavily reinforced for a length of 250 mm on either side of the beam. Thus the total length of the beam is fixed as 2000 mm.

Moulds are prepared for casting of specimens accordingly.

j) Vibrator

The table vibrator and needle vibrator were used for casting of specimen for compaction purpose.

2.2 Casting of Specimen

a) Mesh Layer Preparation

The required length of mesh layer is cut up to a length 1980 mm and bent to the desired shape. All the layers required for a beam are prepared in the same manner and arranged one above the other. The layers are separated by smaller diameter spacer bars.

b) Preparation of End Cage

To force the failure in the middle zone of beam, the ends were reinforced heavily. Care was taken to avoid congestion of reinforcement in the end region.

c) Casting

The mould (125 mm X 250 mm X 2000 mm) is assembled with nuts and bolts. Light plaster of Paris coating was applied at the joint to avoid the possibility of leakage of water. The wooden mould and companion specimen moulds were oiled for smooth removal of specimen. The companion specimens are cast along with specimens.Specimens are cast in two stages seamlessly. First ferrocement “U” wrap is cast and then central core concrete along with reinforcement is cast. Mesh layers are cut according to the required size and bent to the “U” shape. Temporary spacer bars are used to maintain spacing of mesh layers and are kept in the mould for casting of ferrocement “U” wrap. The cement mortar is placed in the bottom of the mould up to a depth of 25 mm. Wooden piece of concrete core size is put in the mould and mortar is poured from top to fill up the sides of wrap with continuous vibration. Then the wooden piece of concrete core size is carefully removed and the reinforcement is placed in the core portion. Core is filled with concrete and vibrated. After 24 hours of casting, the specimens are removed from the moulds and are kept in water tank for curing. The designations of beams were marked with permanent marker on beams before these were put in the tank. The total casting procedure is shown in the Figure 1 and Figure 2.

Fig. 1 Mould Ready for placing mortar

Fig. 2 Only transverse Reinforcement

2.3 Testing

a) Pre-testing Arrangements

The test specimen and companion specimens were removed from the water tank and allowed for surface dry and then whitewashed. The actual cross-sectional dimensions of the specimen were measured at different locations. A grid on the beam was marked with help of a pencil for measuring the crack inclination and for fixing the twist meters and supports.

b) Testing

Beams were tested on the torsion test rig available in the laboratory. The marked beams were mounted on the wing table of Tinius-Olsen testing machine in east west direction, width being kept parallel to north south direction. Rollers in the lateral direction at the reaction end were provided to allow the beam to slide freely along the longitudinal direction to avoid any axial restraint. The loading end was supported on a cylindrical roller placed in the longitudinal direction of the beams to allow twist under pure torsion. The set up was shown in Figure 3. Specially made steel trusses were used as lever arms and placed at either supports to apply transverse loads, which in turn produce torsion on the member. Twist was calculated from four dial gauge readings which were placed below the two twist meter frames. The two twist meter frames were placed 500 mm apart. The loading frame was kept perpendicular to longitudinal axis of beam to avoid bending. Neoprene pads were provided between beam sides and loading frame plates to avoid local crushing. The load was applied gradually through the load cell. The reaction end was provided with another load cell to verify reaction torque.

As shown in Figure 3, the load was applied through the load cell. The length of the lever arm and radius for single twist meters were recorded before starting the application of load. The initial readings of twist meters were adjusted to suitable values. The load was gradually applied through the mechanical jack. The dial gauge readings attached to the twist meters were recorded for each increment of load. The load at first crack was noted and then the cracks formed for increments of load were marked along with crack extension by the permanent marker. The peak load was recorded. A few possible load readings were taken in the post cracking stage of the beam also. Typical observation chart of a beam were presented in the Table 2. The experimental results of normal strength beams were presented in Table 3.

Table 2. Typical Observation Chart of L4N

Load cell reading	**Dial Gauge Reading**				**Torque (kNm)**	**Twist (rad/m) (10^{-3})**
	South		**North**			
	S1	**S2**	**N1**	**N2**		
0	700	100	3000	200	0	0
10	731	102	2974	197	0.40110	0.00025
20	769	106	2945	194	0.80221	0.0005
30	809	109	2918	192	1.20332	0.0009
40	856	114	2891	189	1.60442	0.00125
50	896	117	2869	187	2.00553	0.00155
60	938	120	2862	185	2.40663	0.00185
70	1059	128	2810	185	2.80774	0.0021
80	1135	135	2800	184	3.20885	0.00245
90	1187	139	2778	182	3.60995	0.00275
100	1221	142	2758	180	4.01106	0.0032
110	1274	147	2713	177	4.41217	0.0036
120	1311	150	2689	174	4.81327	0.00444
130	1371	155	2645	170	5.21438	0.005
140	1852	159	2620	164	5.61549	0.0055
143	1929	163	2540	158	5.73582	0.0095

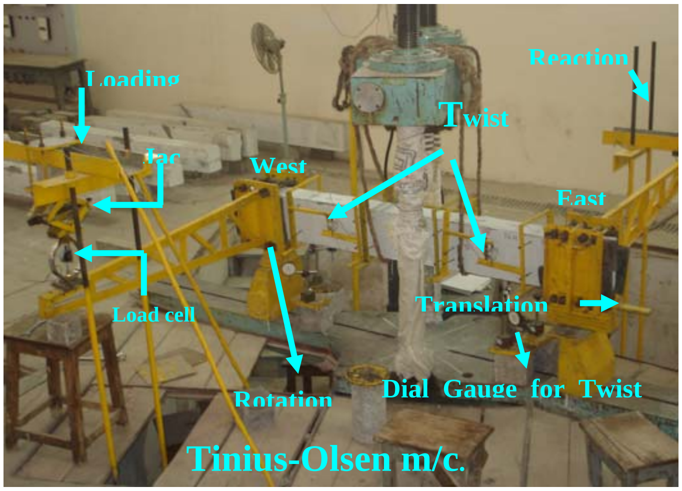

Fig. 3 Torsion Test rig

Table 3. Experimental Test Results

Beam designation	torsional stiffness (kN-m^2)			Torque (kN-m)		Toughness (kN-m/m)	Twist (rad/m)	
	Initial	Cracking	Ultimate	Cracking	Ultimate		Ultimate	Breaking
BQ 3N	1337	993		5.41		0.01731	0.00545	
BQ 4N	1458	1021		5.41		0.017	0.00545	
BQ 5N	1403	1027		5.49		0.01767	0.00523	
L3N	1448	1002	600	5.61	5.69	0.040	0.0056	0.0095
L4N	1457	1020	603	5.61	5.73	0.04051	0.0055	0.0095
L5N	1462	1045	603	5.69	5.73	0.0411	0.0054	0.0095
T3N	1434	1006	839	5.53	5.45	0.0228	0.0055	0.0063
T4N	1466	1044	852	5.53	5.45	0.02323	0.0053	0.0064
T5N	1484	1006	814	5.53	5.45	0.026	0.0055	0.0067

3. Test Results and Discussion

Analytical model was developed using Hsu's softened truss model to calculate post cracking torsional strength of ferrocement "U" wrapped beams cannot predict the strength as singly type reinforced beams lacks either longitudinal or transverse reinforcement. Experimental and analytical results were compared in this section and presented below.

3.1 Crack Pattern and Failure Characteristics of control specimens and Beams:

Plain "U" wrap beams (Control Specimens BQ3N, BQ4N and BQ5N) showed no cracking when tested under pure torsion at cracking torque of un-wrapped plain beams. All the beams failed with a single potential crack developed in the middle of the unwrapped concrete face i.e. top face. Similar behaviour of formation of single potential crack is observed while testing plain concrete beams and plain fibrous beams by earlier researchers [2, 17]. Due to non availability of reinforcement on un-wrapped face of concrete, the failure took place just at the formation of first visible crack. A single crack found on the un-wrapped face having inclination of approximately 45^0 with the longitudinal axis of the beam. The theoretical crack angle for concrete and ferrocement face should be 45^0 [2] due to same volume fraction of reinforcement in jacketed faces of plain beams as square mesh was provided. On further attempts of loading beyond the ultimate, de-bonding of ferrocement layer was noticed at the interface of concrete and ferrocement snapping of wires of ferrocement was also observed. The crack initiated on the unwrapped face may be due to the fact that induced shear stress by applied torsion was more than the shear strength of concrete provided on the un-wrapped face of the beam [10].

The torque-twist diagram of ferrocement "U" wrapped control beams are linear. This linearity ends once the torque reaches to elastic torque. Torque beyond this point of inflection is almost coincides with the onset of cracking on the specimen. The physical observation when correlated with the torque-twist behaviour gives an understanding that the stiffness has reduced after initiation of this micro-cracking. Visible crack is noticed beyond certain stage of the end of the linearity in the torque-twist diagram. That means, in between the stage from change of linearity to formation of visible crack, there could have been formation of few micro-cracks and stiffness might have been reduced. So, the micro-cracking stage is initiated from change of linearity and ends with formation of first macro crack. The macro crack is nothing but formation of a potential crack that could be visible to naked eye. The behaviour explained above can be noticed from the experimental torque-twist curve presented in Figure 4.

A reinforced concrete member when subjected to torsion, longitudinal reinforcement, transverse reinforcement and the concrete present in the diagonal strut resist the load. For a single type of reinforcement, as one of the load resisting elements is absent, the load carrying capacity is theoretically limited to plain beams only. Thus the beams with single type of reinforcement with ferrocement "U" wrap can be analyzed as plain ferrocement “U” wrapped beams. The beams L3N, L4N and L5N were similar to the beams BQ3N, BQ4N and BQ5N respectively if the later beams were provided with only longitudinal steel. The amount of longitudinal steel provided was torsionally over reinforced with respect to concrete strength in the core and presented in Table- 1. The beams T3N, T4N and T5N have only extra reinforcement in transverse zone in comparison to the beams BQ3N, BQ4N and BQ5N respectively. All these six normal strength beams have similar torque twist response as their control specimens. All the beams have crack angles 45^0 as explained earlier. Figure 5 shows the crack pattern of T4N.

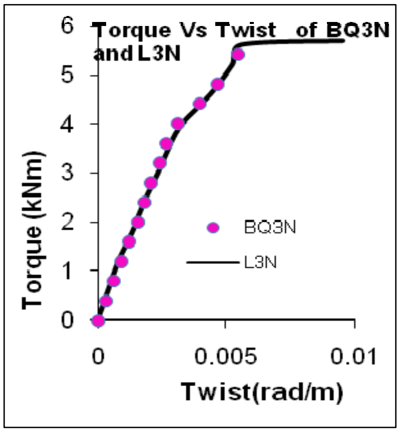

Fig. 4 Torque twist diagram of BQ3N and L3N

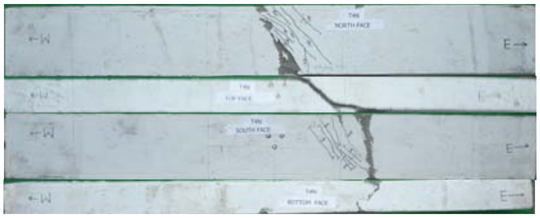

Fig. 5 Crack Pattern of T4N

3.2 Torsional Behaviour

The ultimate torque of control specimens BQ3N,BQ4N and BQ5N calculated by the Hsu’s skew bending theory was found to be 3.66 kNm for all three beams against their experimental values 5.415 KNm, 5.415 KNm and 5.415 KNm respectively. This proves that torsional strength of a beam depends upon constituent materials and area as already stated by [2].

The ultimate torque of these beams L3N, L4N and L5N were found 5.69 kNm, 5.73 kNm and 5.73 kNm respectively. Their control specimens have ultimate torque of 5.415 kNm. This indicates that there was 5.08 %, 5.81% and 5.81% over their control specimens BQ3N, BQ4N and BQ5N respectively. Improvement in ultimate torque carrying capacity of these beams beyond cracking torque is due to presence of longitudinal reinforcement [2]. The torque-twist response of these beams was reported in Figure 6.The cracking and ultimate torsional strength of all these beams T3N, T4N and T5N were found to be 5.53 kNm. The torque increased by 2.21%, 2.21% and 0.72% for beams T3N, T4N and T5N over their plain “U” wrapped beams BQ3N, BQ4N and BQ5N respectively. Figure 7 and Figure 8 shows torque twist response of transversely reinforced beams.

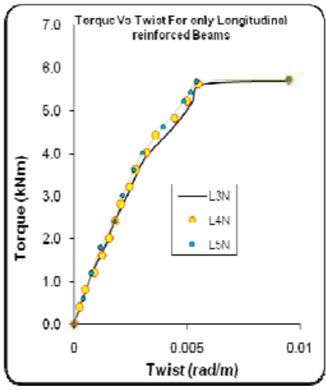

Fig. 6 Torque twist diagram of L3N, L4N and L5N

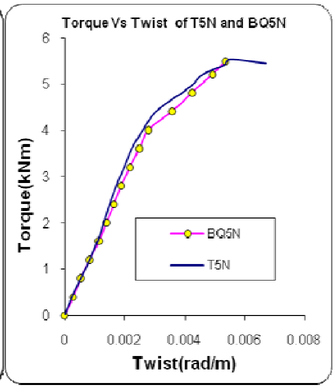

Fig. 7 Torque twist diagram BQ5N and T5N

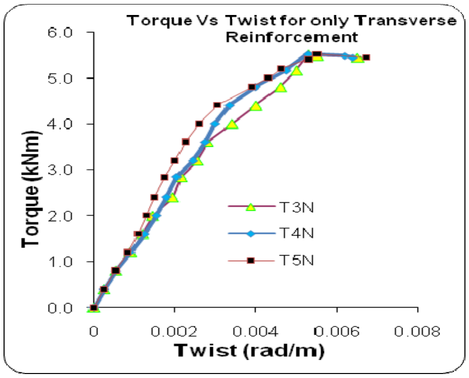

Fig. 8 Torque twist diagram of T3N, T4N and T5N

This shows that the improvement in torque of singly type reinforced beams over their control specimens is very marginal as they lack one of reinforcement system (either longitudinal or transverse reinforcement) in the core portion. The reinforcement provided in longitudinal and transverse direction controls the torque twist response in the post cracking stage [3, 16 and 17].This proves torsion can be well resisted by both longitudinal and transverse reinforcement.

3.3 Twist

The experimental ultimate twists of three plain ferrocement “U” wrapped beams BQ3N, BQ4N and

BQ5N as reported in Table- 3 were found to be 0.0054 rad/m, 0.0053 rad/m and 0.0052 rad/m. All three longitudinally reinforced beams L3N, L4N and L5N had ultimate twist more than 74.31% , 74.31% and 81.64% of their base beams BQ3N, BQ4N and BQ5N. L5N have 81.64% of increase in twist over its control specimen BQ5N. The increase in twist for these beams T3N, T4N and T5N were found to be 15.60 %, 17.43% and 28.10 % over their base beams. Increase in twist over their control specimens were reported in Figure 9.

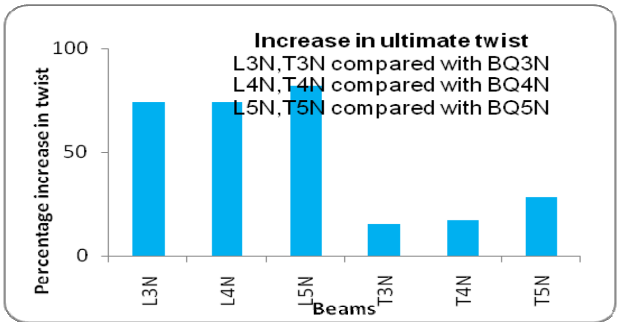

Fig. 9 Increase in ultimate twist over base beams

Provision of only longitudinal or transverse reinforcement in “U” wrapped beams cannot enhance the ultimate torque, but capable of providing better toughness due to increase in twist.

3.4 Stiffness

The initial stiffness of these beams L3N, L4N and L5N were found to be 1448 kNm^2, 1457 kNm2 and 1462 kNm^2, while their secant stiffness at ultimate torque were found to be 600 kNm^2, 603 kNm^2 and 600 kNm^2 respectively. The initial stiffness of the beams T3N, T4N and T5N were found to be 1434 kNm^2, 1466 kNm^2 and 1484 kNm^2 respectively against their predicted values 1458 kNm^2 which was equal for all beams. The secant stiffness at ultimate torques for the above beams was found to be 839 kNm^2, 852 kNm^2 and 814 kNm^2.Initial stiffness of a beam is independent of reinforcement. The secant stiffness at cracking was presented in Figure 10.

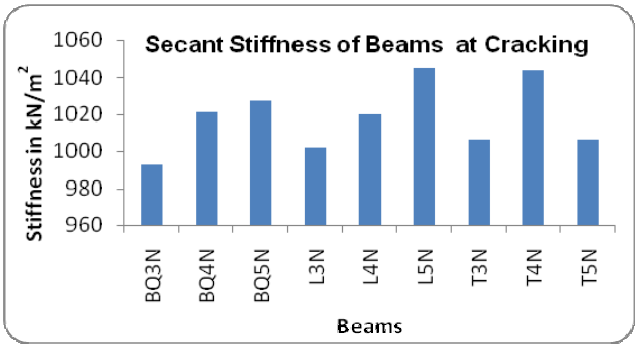

Fig. 10 Secant stiffness of beams at Cracking

3.5 Toughness

The toughness of a beam is calculated as the area under torque-twist diagram. The toughness of the control specimens BQ3N, BQ4N and BQ5N were found to be 0.017 kNm/m, 0.01731 kNm/m and 0.0176 kNm/m respectively. The wrapped beams have more twist than the control specimens. Beams L3N, L4N and L5N showed improvement in toughness over plain “U” wrapped beams due to increase in twist. The toughness of these L3N, L4N and L5N beams were found to be 0.04 kNm/m, 0.0451 kNm/m and 0.0411 kNm/m at ultimate. L3N, L4N and L5N have 131.08%, 138.29% and 132.60% increase in toughness over beams BQ3N, BQ4N and BQ5N respectively due to more twist. The toughness of T3N was increased by 1.34 times over BO3N, T4N increased by 1.36 times over BO4N and T5N was increased by 1.47 times over the beam BQ5N. The increase in toughness is presented in Figure 11.

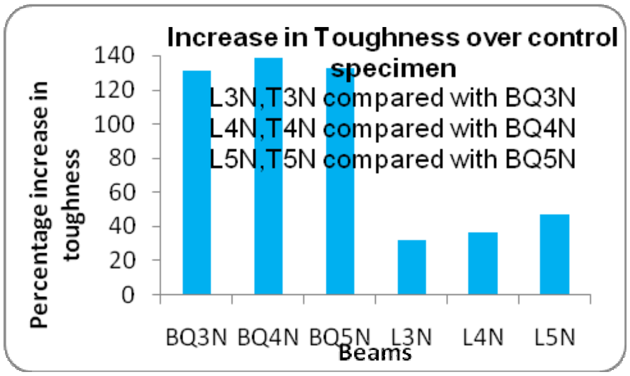

Fig. 11 Increase in toughness of beams over base beams

The increase in twist enhances the toughness of the beam over plain “U” wrapped beam. From the investigation of above two series of beams, it was clear that single type of reinforcement could not improve in torsional strength of ferrocement “U” wrapped beams, but was capable of increasing the toughness for normal strength and high strength beams. Toughness enhancement is marginal over number of mesh layers.

3.6 Comparison between only longitudinally and only transversely reinforced Beams with four mesh layers on outer wrap:

Torque twist response of BQ4N, L4N and T4N is plotted in Figure 12 and it is found that torque twist response is linear at the initial stage up to micro cracking stage. Then deviation starts due to participation of mesh layer in torque resisting mechanism. Cracking torque of all longitudinally reinforced and transversely reinforced beams could not increase sufficiently over their control specimens. Longitudinally reinforced beams have higher cracking torque than transversely reinforced beams as already stated by Hsu-1984. It is found that the failure plane is initiated on un-wrapped shorter face as the stress induced is more than the tensile strength of concrete and the stress induced in wrapped faces are below the tensile strength of ferrocement. As the twist is more for longitudinally reinforced beams, they have higher toughness over their control specimens & transversely reinforced beams of same section and same material.

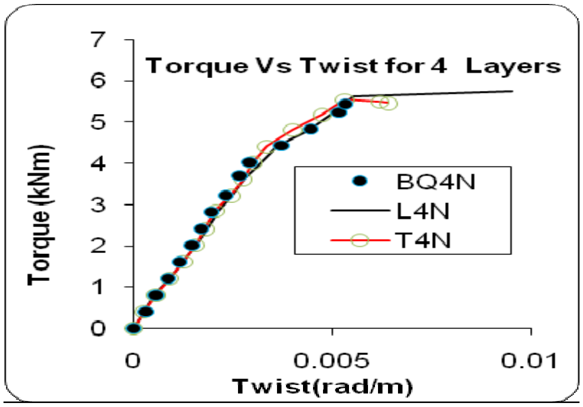

Fig. 12 A comparative study of Torque twist diagram of Four layers of mesh

4.0 Conclusion:

From experimental study for torsional behaviour of "U" wrapped plain and singly reinforced concrete beams, the following conclusions were drawn.

- Single type of reinforcement either longitudinal or transverse reinforcement with "U" wrap is effective in enhancing the torsional strength over un- wrapped plain beams.
- The number of mesh layers in Single type of reinforcement either longitudinal or transverse reinforcement with "U" wrap is ineffective in enhancing the torsional strength over un-wrapped plain beams.
- Single type of reinforcement either longitudinal or transverse reinforcement is ineffective in enhancing the torsional strength with respect plain "U" wrapped beams. Longitudinally reinforced beams have higher cracking torque than transversely reinforced beams.
- Single type of reinforcement with "U" wrap is capable resisting more twist than unwrapped plain beams and "U" wrapped plain beams. Particularly longitudinal reinforced beams resist more twist than transversely reinforced beams.
- Single type of reinforcement with "U" wrap has significant increase in torsional toughness than unwrapped plain beams and "U" wrapped plain beams. Particularly longitudinal reinforced beams resist more toughness than transversely reinforced beams.
- The number of mesh layers does not contribute significantly towards torsional strength or toughness.

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