Use Of Kevlar Fabric To Enhance Flexural Strength Of RC Beams

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Abstract

Improving properties of reinforced concrete beams involves strengthening of existing members to carry higher ultimate loads or to satisfy certain serviceability requirements. In structural engineering the introduction of advanced composite materials, particularly adhesive bonded Kevlar fabric as externally bonded retrofit materials, has offered many benefits (i.e. corrosion free, excellent strength to weight ratio, ease for site handling, flexibility to conform to any shape). The use of Kevlar fabric will enhance the flexural behavior of concrete beams. Two point loading test has to be conducted on controlled and strengthened beams by varying the wrapping system. The experimental results are compared with the analytical. The merits and demerits of application of adhesive bonded Kevlar fabric are also discussed.

Keywords- Kevlar, adhesive bonded fabric, flexure

Abbreviations used:
RC =Reinforced concrete
c/s =cross sectional

"1.Introduction"

The maintenance, rehabilitation and upgrading of structural members, is perhaps one of the most crucial problems in civil engineering applications. Moreover, a large number of structures constructed in the past using the older design codes in different parts of the world are structurally unsafe according to the new design codes. Since replacement of such deficient elements of structures incurs a huge amount of public money and time, strengthening has become the acceptable way of improving their load carrying capacity and extending their service lives.

Infrastructure decay caused by premature deterioration of buildings and structures has lead to the investigation of several processes for repairing or strengthening purposes. One of the challenges in strengthening of concrete structures is selection of a strengthening method that will enhance the strength and serviceability of the structure while addressing limitations such as constructability, building operations and budget. One of the techniques used to strengthen existing reinforced concrete members involves external bonding of steel plates by means of epoxy adhesives. By this way, it is possible to improve the mechanical performance of a member. The wide use of this method for various structures, including buildings and bridges has demonstrated its efficiency and convenience.

In spite of this fact, the plate bonding technique presents some disadvantages due to the use of steel as strengthening material. The drawback of steel is its high weight which causes difficulties in handling the plates on site and its vulnerability against corrosive environments. Moreover, steel plates have limited delivery lengths and non-flexibility to conform to any shape. This has led to the idea of using Kevlar fabric as external bonding material along with adhesives.

"A. Strengthening using adhesive bonded fabric"

Strengthening with adhesive bonded fabric has been established as an effective method applicable to many types of concrete structures such as columns, beams, slabs and walls. The fabric materials are non-corrosive, non-magnetic and resistant to various types of chemicals therefore they are increasingly being used for external reinforcement of existing concrete structures [1]. It generally consists of high strength carbon, aramid, or glass fibers in a polymeric matrix i.e. thermosetting resin. Adhesive bonded fabric sheets may be adhered to the tension side of slabs or beams to provide additional flexural strength.

"B. Merits"

- Fiber composite strengthening materials have higher ultimate strength and lower density as compared to steel.
- The lower weight makes handling and installation significantly easier than steel.
- No bolts or rivets are required.
- These are available in very long lengths and are flexible enough which simplify the installation. The material can take irregularities in the shape of the concrete surface.
- These materials can follow a curved profile; while steel plates require bending operations.
- The material can be readily installed behind existing services.
- Fibers and resins are durable if correctly specified and require little maintenance.
- If they are damaged in service, it is relatively simple to repair them by adding an additional layer.
- The use of textile reinforcement does not significantly increase the weight of the structure or the dimensions of the member.

"C. Demerits"

- Fiber material has the risk of fire, vandalism or accidental damage, unless the structure is protected.
- In case of bridges over roads has the risk of soffit reinforcement being hit by over height vehicles.
- Textile reinforcement has relatively high cost of the materials, steam sensitivity, low ductility, sensitivity against radiations as well as cross pressure and soaking.

"2. Experimental Investigation"

The purpose of this study is to investigate the effect of adhesive bonded fabric layer on the strength and ductility of RC beams.

"A. Materials"

"a. Kevlar fibers"

Kevlar (poly-paraphenylene terephthalamide) is the brand name for a synthetic material constructed of para-aramid fibers by its manufacturer Du Pont. The company claims that it is five times stronger than the same weight of steel, while being lightweight, flexible [5]. It is also very heat resistant and decomposes above 400°C without melting. It was invented by Stephanie Kwolek of Du Pont from research into high performance polymers and patented by her in 1966 and first marketed in 1971.Originally intended to replace the steel belts in tires, it is probably the most well known name in soft armor (bulletproof vests). It is also used in extreme sports equipment, high-tension drumhead applications, animal handling protection, composite aircraft construction, fire suits, yacht sails and as an asbestos replacement. When this polymer is spun in the same way that a spider spins a web, the resulting commercial para-aramid fiber has tremendous strength, and is heat and cut resistant. Para-aramid fibers do not rust or corrode and their strength is unaffected by immersion in water. When woven together, they form a good material for mooring lines and other underwater objects. However, unless specially waterproofed, para-aramid fiber's ability to stop bullets and other projectiles is degraded when wet.

Kevlar is a type of aramid that consists of long polymeric chains with a parallel orientation. Kevlar derives its strength from inter-molecular hydrogen bonds and aromatic stacking interactions between aromatic groups in neighboring strands. These interactions are much stronger than the Van der Waals interaction found in other synthetic polymers and fibers like Dyneema. The presence of salts and certain other impurities, especially calcium, would interfere with the strand interactions and has to be avoided in the production process. Kevlar consists of relatively rigid molecules, which form a planar sheet-like structure similar to silk protein. These properties result in its high mechanical strength and its remarkable heat resistance. Because it is highly unsaturated, i.e. the ratio of carbon to hydrogen atoms is quite high, it has a low flammability. Kevlar molecules have polar groups accessible for hydrogen bonding. Water that enters the interior of the fiber can take the place of bonding between molecules and reduce the material's strength, while the available groups at the surface lead to good wetting properties. This is important for bonding the fibers to other types of polymer, forming a fiber reinforced plastic. This same property also makes the fibers feel more natural and sticky compared to non-polar polymers like polyethylene. In structural applications, Kevlar fibers can be bonded to one another or to other materials to form a composite. It can have a great tensile strength; sometimes in excess of 350 MPa.The properties of Kevlar fabric are given in table 1.

Table1. Properties of fabric

Property(unit)	Type
Material	Kevlar fabric
Structure of fabric	Biaxial 0 ° /90 °
Weight (g/m^2)	105
Nominal thickness per layer (mm)	0.6
Maximum tensile stress (N/mm^2) (experimental)	1812.53

"b. Matrix Materials"

Commonly used matrix materials are epoxy resin and hardener, properties of which are (supplied by the manufacturer) tabulated below in table2.

ISSN: 2278-0181
Vol. 2 Issue 6, June - 2013

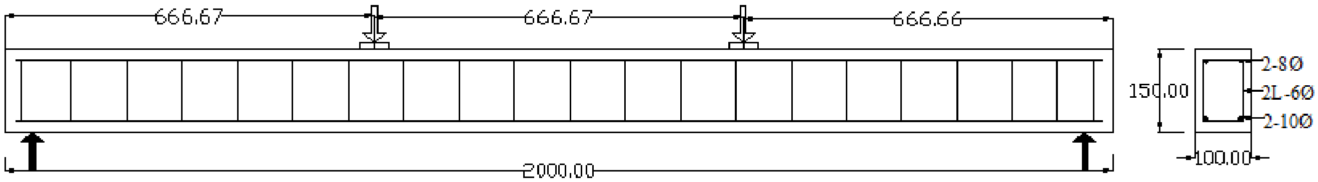

Figure.1 Reinforcement details of beams

“c. Concrete”

In the present work, the materials conforming to Indian standard were used for concrete mix design. Indian Standard method (IS: 10262 - 1982) has been used for mix design of concrete of grade M30.

“B. Casting of Beams”

As per concrete mix design, beams of size 150mm x 230mm x 2000mm; with 2-12 mm φ bars on tension side, 2-8mm φ bars on compression side and 6 mm φ bars as stirrups at a spacing of 125 mm center to center were prepared .The reinforcement details are as shown in fig.1.Summary of beam specimen prepared is given in table 3.

Table 2. Properties of epoxy resin and hardener

Property(unit)	Resin	Hardener
Type	Bondit BR-101	Bondit BH-209
Quantity,(pbw)	100	50
Color	Clear	Colorless
Odor	Slight	Ammonia
Physical State	Liquid	Liquid
Solubility in water	Insoluble	Miscible
Vapor Pressure	< 0.01 Pa at 20^0C	<0.01 mm Hg at 20^0C
Density at 25° C (gm/cm^3)	1.15 – 1.2 at 25^0C	1 at 20^0C
Boiling Point	>200^0C	>200^0C
Decomposition Temperature	>200^0C	>200^0C
Specific gravity	1.80	2.00

Table3. Summary of Beam Specimen

S.N.	Beam ID	Number of specimen	Type of specimen	Strengthening pattern
1	CB	03	Reference beam	-
2	K-B1	03	Single layer Kevlar fabric	U-wrapped
3	K-B2	03		Bottom wrapped

“C. Bonding Procedure of Fabric to Beam”

The concrete surface is made rough by wire brush and it is thoroughly cleaned to remove all dirt and debris. The epoxy resin and hardener are weighed in the ratio of 1:1 and mixed thoroughly and applied over the concrete surface. The fabric is then placed on the top of epoxy resin coating such that the warp direction of the fabric is kept along the longitudinal reinforcement of the beam as shown in fig.2.During hardening of the epoxy, a constant uniform pressure is applied to ensure good contact between the epoxy, the concrete and the fabric. Concrete beams with fabric are cured for 7 days at room temperature before testing.

Figure.2 Application of epoxy - hardener and fixing of Kevlar fabric on the beam

“D. Testing of Beams”

The testing procedure for the entire specimen was same. After the curing period of 28 days, the beam surface was cleaned and white washed for clear visibility of cracks. Before testing, the member was checked for dimensions and a detailed visual inspection was made with all information carefully recorded.

After setting and reading all gauges, the load was increased incrementally up to the calculated working load, with loads and deflections recorded at each stage. Loads will then normally be increased again in similar increments up to failure, with deflection gauges replaced by a suitably mounted scale as failure approaches. This is necessary to avoid damage to gauges and although accuracy is reduced, the deflections at this stage will usually be large and easily measured from a distance.

Similarly, cracking and manual strain observations must be suspended as failure approaches. Special safety precautions shall be taken; if it is essential to take precise deflection readings up to collapse. Cracking and failure mode was checked visually, and a load-deflection plot was prepared. The most commonly used load arrangement for testing of beams will consist of two-point loading as shown in fig.1.

"3. Analytical study"

In this chapter flexural strength of reference RC beams and reinforced concrete beams strengthened by means of externally bonded Kevlar fabric is calculated.

"A. Assumptions"

Following assumptions are made in calculating the flexural resistance of a section strengthened with an externally applied Kevlar fabric:

1) Design calculations are based on the actual dimensions, internal reinforcing steel arrangement and material properties of the member being strengthened.

2) The strains in the reinforcement and concrete are directly proportional to the distance from the neutral axis, that is, a plane section before bending remains plane after bending.

3) There is no relative slip between external adhesive bonded fabric and the concrete.

4) The shear deformation within the adhesive layer is neglected since the adhesive layer is very thin with slight variations in its thickness.

5) The maximum usable compressive strain in the concrete is 0.0035.

6) The tensile strength of concrete is neglected.

7) The maximum usable tensile strain in the Kevlar fabric is 0.06.

8) In case of U-wrapped RC Beam, fabric area below the neutral axis is effective in resisting the tensile stresses.

"B. Common Notations used"

f_{ck} =characteristic compressive strength (N/mm^2)

f_y = yield strength of steel (N/mm^2)

f_{sc} = stress in steel at the level of compression reinforcement (N/mm^2)

f_c = stress in concrete at the level of compression reinforcement (N/mm^2)

f_f = stress in fabric (N/mm^2)

ε_{sc} = strain in steel at the level of compression reinforcement

b = width of beam (mm)

d = effective depth of beam (mm)

d' = effective cover to the compression reinforcement (mm)

A_{sc}= c/s area of compression reinforcement (mm^2)

A_{st}= c/s area of tension reinforcement (mm^2)

A_f = c/s area of Kevlar fabric (mm^2)

$X_{u,cr}$ = critical depth of neutral axis (mm)

T_f = tensile force carried by fabric (N)

Ts= tensile force carried by steel (N)

Cc= total compression (N)

M_u= moment of resistance (kNm)

"C. Calculation of Flexural Strength of the Beams"

The moment of resistance of the beams are obtained from the following calculations (As per IS 456: 2000, Clause 38.1 and Annex G).

b = 150 mm

d = 230-25-12/2 = 199 mm

d'=25+8/2=29 mm

f_y= 500 N/mm^2

f_{ck}= 30 N/mm^2

A_{sc} = 2-8mmΦ = 100.53 mm^2

A_{st}= 2-12mmΦ = 226.2 mm^2

$X_{u,cr}$= 0.46 x d = 89.24 mm

ε_{sc}=0.0035[1-(d'/$X_{u,cr}$)]=0.002362

f_{sc} =397.77 MPa

f_{cc} = 0.446 f_{ck} = 13.38 MPa

"a. Flexural strength of reference beam"

To find out actual depth of neutral axis-

Total force due to compression = total force due to tension (Refer to figure 3).

$0.36\ fck\ .\ b.Xu + Asc\ .(fsc - fcc\ ) = 0.87fy.Ast$

$Xu = 36.88\ mm < X_{u\ max}\ (89.24\ mm)$

Therefore, the beam section is under reinforced section

$$Mu = 0.36\ fck\ .\ b\ .\ Xu\ (d - 0.42\ Xu) + Asc\ .(fsc - fcc\ )(d - d')$$

$Mu = 17.53\ kNm$

"b. Flexural strength of bottom wrapped beam"

Now considering the effect of strengthening of beam using layer of Kevlar fabric at bottom side, so an additional tensile force T_f will be acting. $T_f = f_f \times A_f$

The value f_f is obtained from manufacturer of Kevlar fabric. Assume, partial safety factor for tensile strength of Kevlar fabric= 2.

Therefore, f_f =1812.53/2= 906.265 N/mm^2

A_f = 150 x 0.6=90 mm^2

To find out actual depth of neutral axis-

Total force due to compression = total force due to tension (Refer to figure 4)

Cc= Ts +T_f

$$0.36fck\ .\ b.Xu + Asc(fsc - fcc\ ) = 0.87fy.Ast + ff.Af$$

X_u = 87.23mm

$X_{u\ ,actual}$ (87.23 mm) < $X_{u\ max}$ (89.24 mm)

Therefore, the beam section is a under reinforced section.

Point of application of total compression from top

$$y = \frac{0.36\ fck.b.Xu \times 0.42\ Xu\ + Asc(fsc - fcc)d'}{0.36\ \ fck.b.Xu\ + Asc\ (fsc - fcc)}$$

$y = 35\ mm$

Point of application of total tension from bottom

$$z = \frac{(0.87fy.Ast \times eff.cover)\ +\ (\ ff\ .Af \times 0.3)}{(0.87fy.Ast)\ +\ (\ ff.Af)}$$

$z = 17.09\ mm$

Therefore lever arm can be calculated as follows (refer to fig.4)

Lever arm=230-35-17.09=177.91 mm

$Mu = Total\ Tension\ x\ Lever\ Arm =$

$(0.87fy.Ast + ff.Af)\ L.A. = 32\ kNm$

Due to application of layer of Kevlar fabric at the bottom of the beam, the moment of resistance of the beam is =32 kNm.

"c. Flexural strength of u-wrapped beam"

Now considering the effect of strengthening of beam using U-wrapped Kevlar fabric.

The value of additional tensile force in this case is

$$Tf = ff\ .Af1\ + (\frac{ff}{2})Af\ 2$$

Area of fabric at bottom, A_{f1} = 150 x 0.6=90 mm^2

Area of fabric on sides of beam (considering area of fabric below neutral axis only, effective in resisting tension)

A_{f2} = 2 x (230-Xu) x 0.6=1.2(230-Xu) mm^2

To find out actual depth of neutral axis-

Cc= Ts +T_f (Refer to figure 5)

$0.36\ fck\ .\ b\ .\ Xu\ + Asc\ (fsc - fcc\ ) =$

$0.87\ .\ fy\ .\ Ast\ + ff\ 1\ x\ Af\ 1 + ff\ /2\ .\ Af\ 2$

X_u = 123.11 mm

$X_{u\ ,actual}$ (123.11 mm > $X_{u\ ,\ cr}$ (89.24 mm)

Therefore, the beam section is over reinforced.

Point of application of total compression from top

$$y = \frac{0.36\ fck.Xu.b \times 0.42\ Xu\ + Asc(fsc - fcc)d'}{0.36\ fck.b.Xu\ + Asc(fsc - fcc)}$$

$y = 48.02\ mm$

Point of application of total tension from bottom, z

$$= \frac{(0.87fy.Ast.Eff.cover) + (\ ff.Af1 \times 0.3) + \left(\frac{ff}{2}\right) Af2 \left(\frac{h}{3}\right)]}{(0.87fy.Ast)\ +\ (\ ff.Af1) + \left(\frac{ff}{2}\right) Af2}$$

$z = 21.612\ mm$

Therefore lever arm can be calculated as follows (refer to fig.5).

Lever arm=230 – 48.02 – 21.612=160.37 mm

M_u=Total compression x Lever Arm

$[0.36\ fck.b.Xu\ + Asc\ (fsc - fcc\ )]L.A$

M_u = 38.18 kNm

Due to application of U-layer of Kevlar fabric at the bottom of the beam, the moment of resistance of the beam is =38.18 kNm.

"4. Results and Discussions"

"A. Flexural Strength of Beams and the Nature of Failure"

The flexural and shear strength of a section depends on the controlling failure mode. The following flexural and shear failure modes were investigated for the reference beams and beams strengthened with Kevlar fabric (Refer table 4):

- Yielding of the steel in tension in controlled (CB) beams;
- Crushing of the concrete in compression before yielding of the reinforcing steel and Kevlar fabric; in U-wrapped (KB-1) beams.
- Yielding of the steel in tension followed by rupture of the Kevlar fabric in bottom wrapped (KB-2) beams;
- Failure modes include flexure failure; shear failure, flexural failure due to Kevlar fabric rupture and crushing of concrete at the top. Concrete crushing is assumed to occur if the compressive strain in the concrete reaches its maximum usable strain. Rupture of the Kevlar fabric is assumed to occur if the strain in it reaches its design rupture strain before the concrete reaches its maximum usable strain.

"B. Load - Deflection History"

The Mid-span deflections were much lower when bonded externally with Kevlar fabric. The graphs comparing the mid-span deflection of strengthened beams and their corresponding control beams are shown in Fig 6. The use of Kevlar fabric had effect in delaying the growth of crack formation. When KB-1 and KB-2 beams were loaded it was observed that, initially they behaved in a similar manner to that of controlled beams; but in later stage, the fabric resisted the load and the deflection reduced considerably as shown in fig.6.

It was observed that control beams had less load carrying capacity; when compared to that of the externally strengthened beams using Kevlar fabrics, as summerised in Table 5.

"5. Conclusions"

In this experimental investigation the flexural behavior of reinforced concrete beams strengthened by Kevlar fabric was studied. From the test results and calculated strength values, the following conclusions are drawn:

[1] Initial flexural cracks appear at higher load by strengthening the beam at soffit. The ultimate load carrying capacity of the strengthened beams KB-1 and KB-2 is noticeably more than that of controlled beams CB.

[2] Analytical analysis is also carried out to find the ultimate moment carrying capacity and compared with the experimental results. It was found that analytical analysis predicts higher values than the experimental findings.

[3] Flexural strengthening of the beam increases the ultimate load carrying capacity, but the cracks developed were not visible. Due to invisibility of the initial racks, it removes the fear from the minds of occupants regarding the collapse. Even though after the failure of steel and excessive deflection beam do not fail suddenly due to use of U-wrapping of Kevlar fabric.

[4] By strengthening the beam, performance of a weak structure can be improved and it will protect many lives from sudden failure.

[5] Additionally no minimum concrete cover is needed to prevent corrosion of the reinforcement.

[6] In the range of service loads, the Kevlar fabric reinforcement yields lower crack widths and crack intervals. In addition the deflections of the strengthened concrete elements were clearly lowered than that of non strengthened reference elements.

Finally we can conclude that, this method of strengthening the beams/structural members in existing old buildings is an effective solution.

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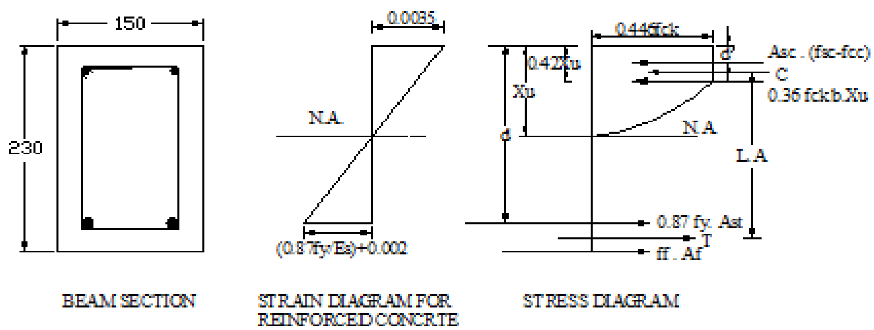

Fig.3 Stress-strain diagram for doubly reinforced reference beam

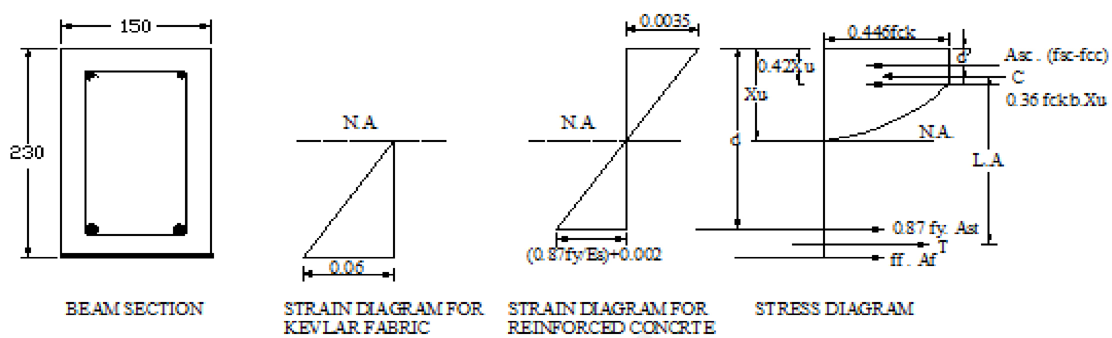

Fig.4 Stress diagram for doubly reinforced beam strengthened with bottom wrapped Kevlar fabric

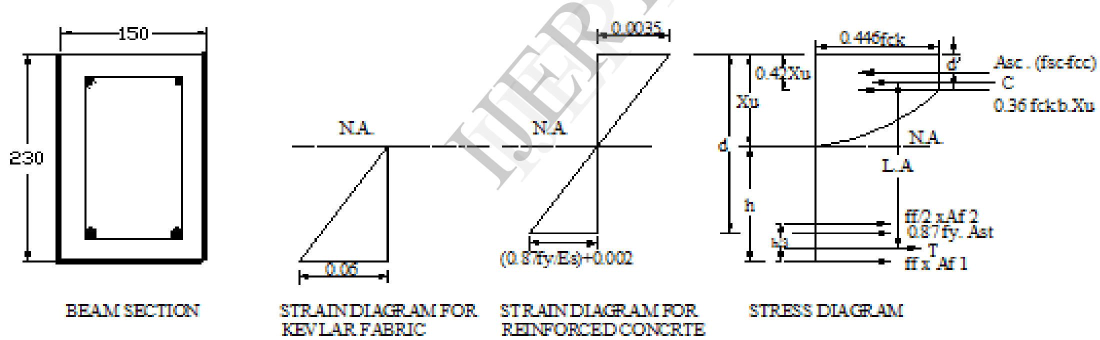

Fig.5 Stress diagram for doubly reinforced beam strengthened with U wrapped Kevlar fabric.

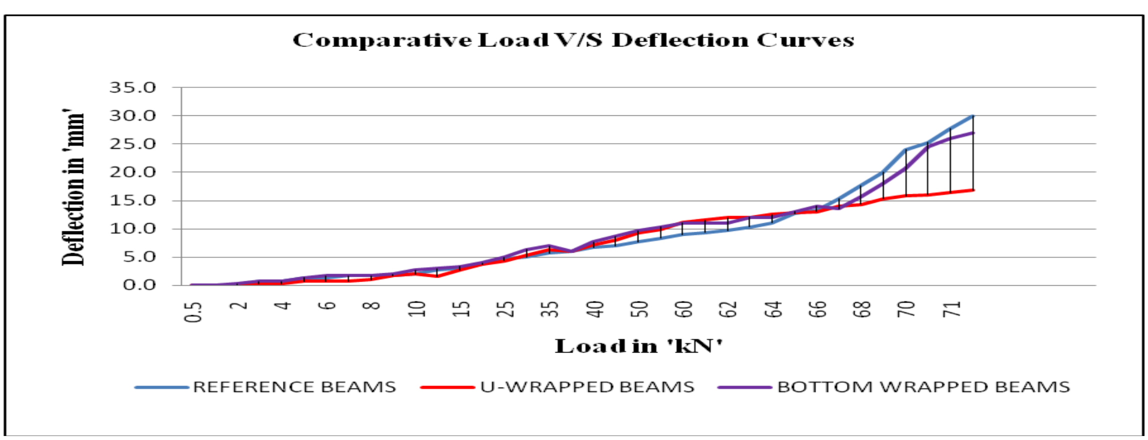

Figure.6 Comparative load v/s deflection curves crack patterns

Table 4. Comparison of flexural strength of beams and the nature of failure.

Beam	Analytical results			Experimental results			Nature of failure
	Depth of N.A. (mm)	Mu (kNm)	% increase in Mu	Load at failure (kN)	Mu (kNm)	% increase in Mu	
Reference	36.88	17.53	-	71.5	24.26	-	Yielding of the steel in tension
Bottom wrapped	87.23	32	82.54%	84	28.431	17.19%	Yielding of the steel in tension
U-Wrapped	123.11	38.18	117.8%	96	32.431	33.68%	Crushing of the concrete in compression

Table 5 Observation table for tested beam specimen

Sr. No.	Beam notation	Type of beam	Ultimate load (kN)	Maximum deflection (mm)	Nature of failure
1	B_1	Reference	71	31	Yielding of tensile reinforcement
2	B_2		71.5	29	
3	B_3		72	30	
4	B_4	U-Wrapped	96	34	Crushing of concrete
5	B_5		95	30	
6	B_6		97	37	
7	B_7	Bottom wrapped	80	32	Yielding of tensile reinforcement
8	B_8		85	33	
9	B_9		87	39	