# Numerical Investigation On Effect Of CFRP on Shear Strengthening Of RC Beams

[1]Kilaru Divya, [2]Velivela Ramesh

[1]Assistant Professor, Dept of Civil Engg, P V P Siddhartha Institute of Technology, Vijayawada, India.

[2]Associate Professor, Dept of Civil Engg, V R Siddhartha Engineering College, Vijayawada, India.

**Abstract: The objective of the study is to estimate the influence of parameters on externally bonded Carbon Fiber Reinforced Polymer on shear strengthening of RC beams which are deficient in shear by analytically and numerically using ABAQUS modeling. Shear span to effective depth ratio, effect of internal transverse reinforcement, amount, distribution and orientation of CFRP are the parameters which were studied. Overall 20 beams were modeled and analyzed under four point bending system. All beams are categorized into 2 groups based on shear span to effective depth ratio as 3 & 4. Each group divided into two sub groups, with and without internal transverse reinforcement. Each sub group having 5 beams, in which one was control beam and remaining 4 beams strengthened with CFRP under various conditions. Test results shows that U-wrap strips strengthening method was best choice. The contribution of CFRP to shear resistance was increased with increase in shear span to effective depth ratio. The full tensile strength of CFRP was utilized in the beams having without internal transverse reinforcement.**

***Key Words: Shear strength, Carbon fiber reinforced polymer, ABAQUS, internal transverse reinforcement, shear span to effective depth, reinforced concrete beams.***

## I. Introduction

Now-a-days retrofitting or strengthening of structures are frequent due to the increase of service loads, design or construction faults, old design codes and change in use of structure. There are many methods to strengthen the structures RC jacketing, steel jacketing, FRP jacketing etc. In earlier days concrete jacketing and steel jacketing are used to increase the capacity of existing structure, but the dead weight of structure also increases to bare the new additional dead weight foundation also must be strengthened. For the past 30 years Fiber reinforced polymers are becoming popular in strengthening of concrete structural components due to its corrosion resistance to environmental agents as well as the advantages of light weight, high tensile strength, high durability and ease of installation, high stiffness-to-weight and strength-to-weight ratios when compared to conventional construction materials. Faulty construction practices, insufficient design practice etc leads to structural failure without any hazards and natural calamities also leads structural failure. In a structure while designing in earthquake point of view beam is a weak member where it has to fail without disturbing the other structural components in which most of the beams were failed under shear before flexure. The need for shear strengthening is required when the RC beams found to be deficient in shear or shear capacity of beams falls below its flexural capacity. In 1989 using of CFRP in full-scale application to strengthen the reinforced concrete beams. Strengthening of shear deficient beams using CFRP laminate and strips under various strengthening methods depends on different parameters which affects the behavior of strengthening and mode of failure. In this study the behavior and failure of different strengthening methods with CFRP studied.

***Objectives of the study***

1. Developing a numerical model using ABAQUS for shear strengthening of RC beam with CFRP.
2. Evaluating the effect of different parameters which are influencing the behavior CFRP while strengthening.
3. Comparing the analytical and numerical simulation data for load carrying capacity and shear capacity of beams.

***Parameters selected in this study***

1. Effect of shear span to effective depth ratio
2. Effect of internal transverse reinforcement
3. Amount and distribution of CFRP
4. Orientation of CFRP with respect to longitudinal axis of beams

 

ISSN : 2454-9150

## II. METHODOLOGY

All 20 beams of 150×300×3000mm size are categorized into 2 groups based on shear span to effective depth ratio as 3 & 4. Each group divided into two sub groups, with and without internal transverse reinforcement. Each sub group having 5 beams, in which one was control beam and remaining 4 beams strengthened with CFRP under different cases as U wrap continuous, U wrap strips, side strips of $90^0$ orientation and side strips of $45^0$ orientation. All beams tested under four point bending system.

### *Materials Specifications*

**Properties of Concrete:** $M_{30}$ grade concrete was used to model the beam because it has better ductility properties when combine with FRP material which was indicated by literature Compressive strength of concrete = 30 MPa**,** Density of concrete = 25KN/m$^3$**,** Young's modulus = E = $5000\sqrt{f_{ck}}$ = $5000\sqrt{30}$ = 27386.127 N/mm$^2$. **Properties of Steel:** $Fe_{415}$ grade steel is used for longitudinal and transverse steel, 32 mm diameters bars are used as longitudinal reinforcement, 10mm diameter bars are used for stirrups. **Properties of CFRP:** Nitrowrap EP(CF) was used as CFRP material, Fibre orientation = Unidirectional, Weight of fiber = 200g/m$^2$, Density of fiber = 1.8 g/cc, Fiber thickness = 0.30 mm, Ultimate elongation (%) = 1.5, Tensile strength = 3500 nmm$^2$, Tensile Modulus = 285×10$^3$ N/mm$^2$

***Shear strength improved by CFRP as per ACI-440 2R08 :***

***FRP contribution to shear strength:***

U wrap or side strips :

Bond reduction coefficient $Kv = \frac{K1K2Le}{(11900\varepsilon_{fu})} \leq 0.75$

Where $Le = 23300/(n_f t_f E_f)^{0.58}$

$K_1 = (f_c/27)^{2/3}$

For U wrap $K_2 = (d_{fv} - L_e)/d_{fv}$

For side strips $K_2 = (d_{fv} - 2L_e)/d_{fv}$

Strain in FRP $\varepsilon_{fe} = Kv\ \varepsilon_{fu}$

Area of reinforcement $A_{fv} = 2nt_f w_f$

Tensile stress in FRP $f_{fe} = \varepsilon_{fe} E_f$

The shear contribution of FRP shear reinforcement

$$V_f = (A_{fv}\, f_{fe}\,(\sin\propto + \cos\propto)d_{fv}) / S_f$$

$$Vf \leq 0.66bd\sqrt{fc}$$

**Table-1: Summary of data Shear strengthening with CFRP**

| **Specification of method** | **Effective length Le(mm)** | **K1** | **K2** | **Kv** | **Afv (mm$^2$)** | **Sf (mm)** | **Vf (KN)** |
|---|---|---|---|---|---|---|---|
| U wrap continuous | 32.122 | 1.072 | 0.885 | 0.179 | 1500 | 1 | 306825.540 But 151.828 |
| U wrap strips | 32.122 | 1.072 | 0.885 | 0.179 | 60 | 220 | 55.786 |
| Side strips $90^0$ | 32.122 | 1.072 | 0.770 | 0.156 | 60 | 220 | 48.532 |
| Side strips $45^0$ | 32.122 | 1.072 | 0.770 | 0.156 | 60 | 220 | 68.635 |

## III. NUMERICAL ANALYSIS

### *Modeling of Beams using ABAQUS:*

A RC beam of 150×300mm cross-section and extrude it through solid extrusion to 3000mm length in ABAQUS - 6.10. Placing of longitudinal reinforcement both compression and tension side as 3.57% of gross-sectional area which 2no. of 32 mm dia bars using planar wire frame. All beams same flexural reinforcement. 2 legged stirrups 10mm dia of size 110×260mm placed as internal transverse reinforcement at specified distances. Taking $M_{30}$ grade concrete for design and modeling and concrete damage plasticity model was consider in ABAQUS and $Fe_{415}$ grade steel is used the true stress and yield strain values are given for steel under plasticity. All the models were tested under four point bending system under simply support condition.

### *Strengthening methods with CFRP:*

There are 4 methods of strengthening of RC beam in shear with CFRP. CFRP laminate is continuous wrap on three sides of beam of length 2500mm known as U wrap continuous (Fig-5.3a), only strips of 100mm width and 220mm center to center spacing were attached to three sides of beams known as U wrap strips (Fig-5.3b), strips of width 100mm and 220mm center to center spacing attached to only two opposite sides of beams in $90^0$ orientation (Fig-5.3c) and strips of same size and width as mentioned above were attached to sides of beams at $45^0$ orientation (Fig-5.3d) with respect to the longitudinal axis of beam.

Limitation: Assuming a perfect bond between CFRP and concrete surface, avoiding debonding failure which was generally occurs in field.


Fig - 5.3a Beam strengthened with CFRP U wrap continuous method

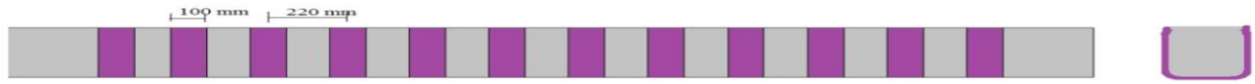


Fig - 5.3b Beam strengthened with CFRP - U wrap strips method


Fig - 5.3c Beam strengthened with CFRP - Side strips 90° orientation method


Fig - 5.3d Beam strengthened with CFRP - side strips 45° orientation method

**Modeling of beams having shear span to effective depth ratio 3 and 4, beams having with and without internal transverse reinforcement**: A total of 5 beams are grouped in each set in which one was control beam taken for reference 2 legged 10mm diameters having stirrups of 110×260mm size are spaced at 300mm center to center along the length of beam, similarly in beams having without stirrups110×260mm size are placed support and at load points but not in the shear span of interest. Two point loading applied at 840mm distance from nearest support for beams having a/d=3(Fig 5.4a& Fig 5.4b) and 1100mm distance from nearest support for beams having a/d=4(Fig-5.4c), a overhang of 250mm maintained at each support. Remaining 4 beams were modeled similarly but strengthened with CFRP as mentioned above.

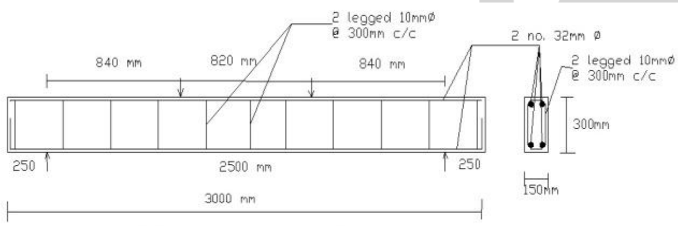


Fig 5.4 a Beam having a / d = 3 and with stirrups

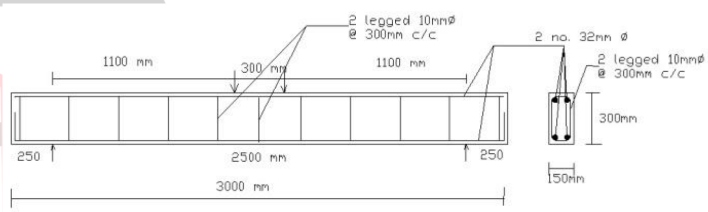


Fig 5.4 c Beam having a / d = 4 and with stirrups

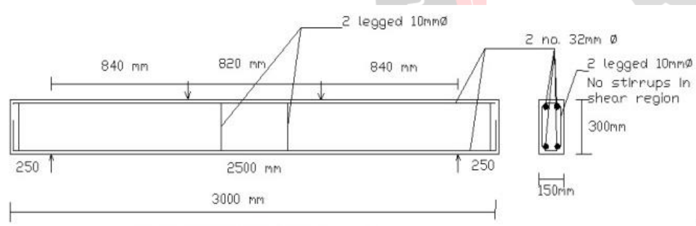


Fig 5.4 b Beam having a / d = 3 and without stirrups

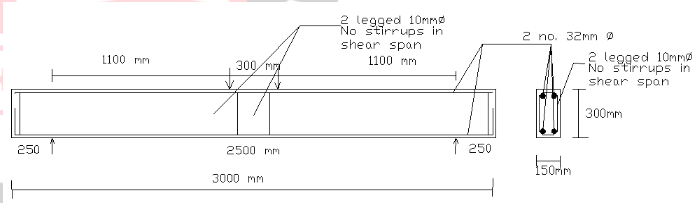


Fig 5.4 d Beam having a / d = 4 and without stirrups

## IV. Results and Discussions

1. **Beams with a/d = 3, and having internal transverse reinforcement:** Control beam has a crack pattern of predicted shape and diagonal shear crack produced and it was propagated from load point and support. The ultimate load carrying capacity of beam was 304.49 KN. Uwrap continuous beam fails by FRP rupture and concrete crushing occurs at load point and supports also. The ultimate load carrying capacity is 579.68KN.U wrap strips has ultimate capacity of 645.870 KN(fig-1) and third strip from nearest support has high stress concentration. In side strips 900 the strips at load and support has high stress concentration and ultimate load carrying capacity was 523.00 KN. In side strips 450 the strips at center of load and support has high stress concentration and ultimate load carrying capacity was 335.941 KN.

2. **Beams with a/d = 3, and without internal transverse reinforcement:**
   Control beam has more prominent shear stress concentration starts at middle of diagonal shear crack region and propagates and $P_u$= 124.7626 KN. In U wrap continuous the way as in beam having stirrups but $P_u$ = 419.070 KN. In U wrap strips the more stress concentration was located in between strips so the crack will develop there and $P_u$ = 399.845 KN. Side strips have similar pattern of stress concentration as beam having stirrups and $P_u$ = 299.729KN and 193.817 KN for $90^0$ and $45^0$ side strips.

ISSN : 2454-9150

3. **Beams with a/d = 4, and having internal transverse reinforcement:**

The stress contours was similar to beams having stirrups and a/d=3 for control and U wrap continuous but for U wrap strips beam the strips under load point was damaged in terms of stress and stresses started in between strips. The deflection of beams were more when compared a/d = 3 beams and load carrying capacity also less. Control $P_u$ = 225.2812KN, Uwrap continuous $P_u$ = 580.00KN, U wrap strips $P_u$ = 423.670KN, Side strips $90^0$ $P_u$ =402.00KN, for $45^0$ orientation $P_u$ = 315.746 KN

4. **Beams with a/d = 4, and without internal transverse reinforcement:**

All the stress contours similar to beams having stirrups but U wrap strips does not stress too much compare to previous cases and the load carrying capacities are control Pu = 110.939KN, U wrap continuous Pu = 395.070KN, U wrap strips Pu= 237.420, Side strips $90^0$ = 185.603KN, $45^0$ strips Pu= 209.698KN.

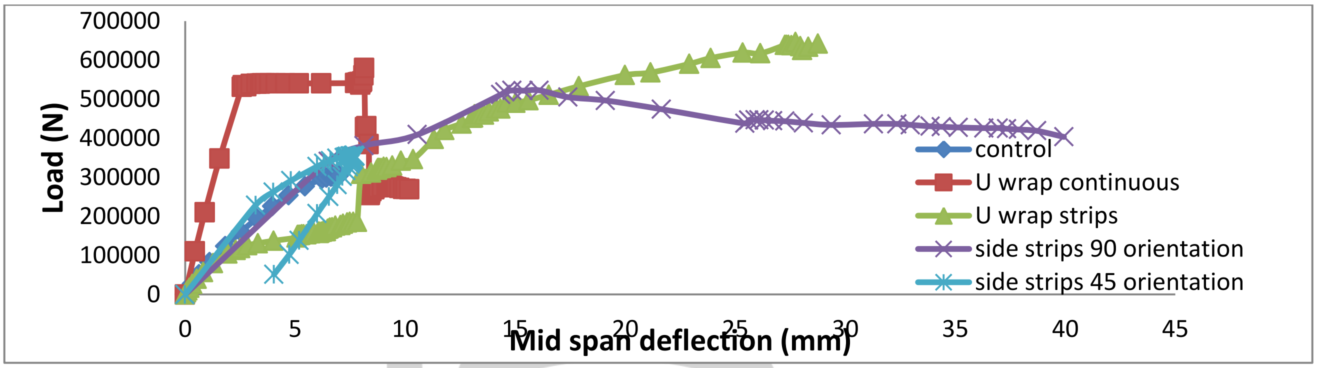


**Fig-1 Load vs mid span deflection for set a/d=3, having stirrups**

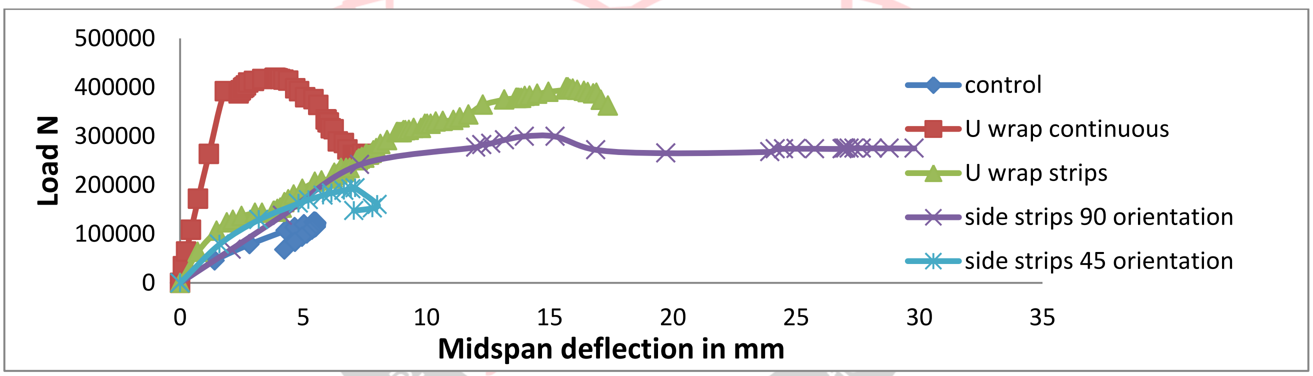


**Fig-2 Load vs mid span deflection for set a/d=3, without stirrups**

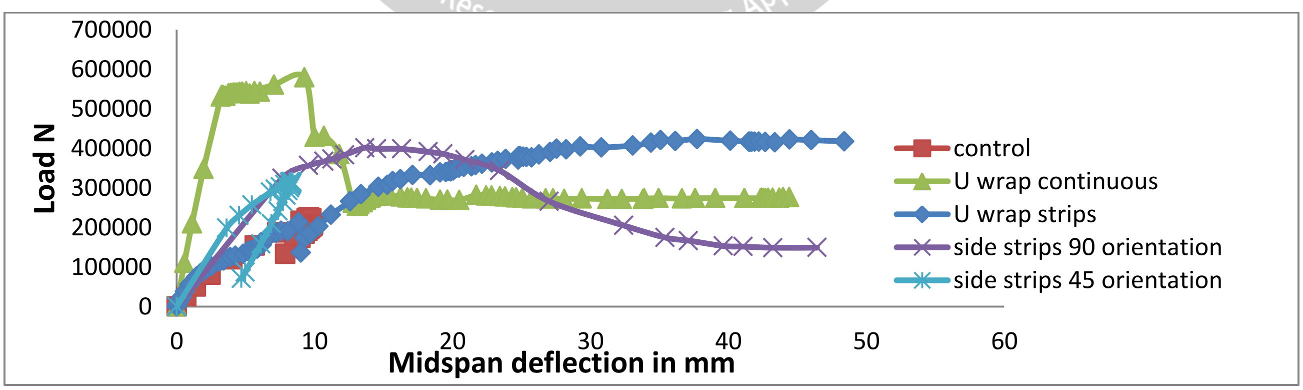


**Fig-3 Load vs mid span deflection for set a/d=4, having stirrups**

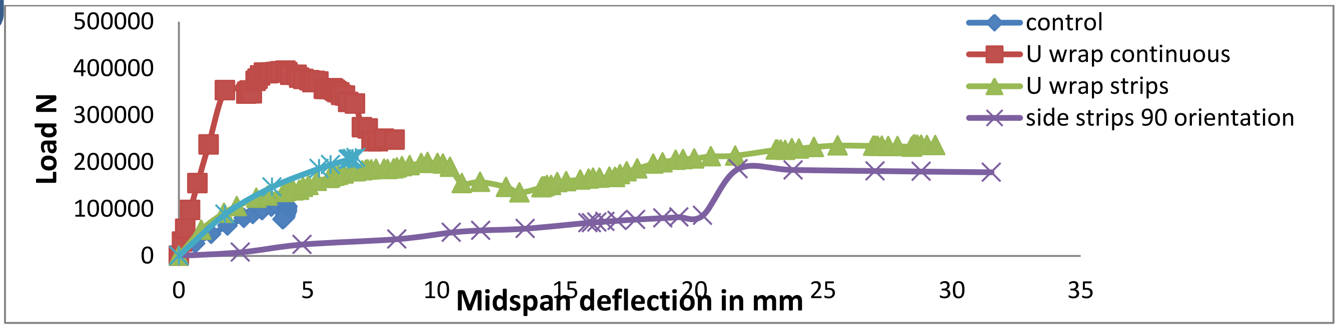


**Fig-4 Load vs mid span deflection for set a/d=4, without stirrups**

**Table-2: Test summary of test data.**

| Specimen | a/d | Steel stirrups | CFRP | Ultimate load P(KN) | Effectiveness of CFRP (%) |
|---|---|---|---|---|---|
| 3 C WO | 3 | - | - | 124.762 | - |
| 3 UC WO | 3 | - | U wrap continuous | 419.070 | 235.89 |
| 3 US WO | 3 | - | U wrap strips | 399.845 | 220.48 |
| 3 S90 WO | 3 | - | Side strips $90^0$ orientation | 299.729 | 140.239 |
| 3 S45 WO | 3 | - | Side strips $45^0$ orientation | 193.817 | 55.34 |
| 3 C W | 3 | 2 legged 10mm @ 300mm | - | 304.490 | - |
| 3 UC W | 3 | 2 legged 10mm @ 300mm | U wrap continuous | 579.680 | 90.37 |
| 3 US W | 3 | 2 legged 10mm @ 300mm | U wrap strips | 645.870 | 112.115 |
| 3 S90 W | 3 | 2 legged 10mm @ 300mm | Side strips $90^0$ orientation | 523.000 | 71.76 |
| 3 S45 W | 3 | 2 legged 10mm @ 300mm | Side strips $45^0$ orientation | 355.941 | 16.89 |
| 4 C WO | 4 | - | - | 110.939 | - |
| 4 UC WO | 4 | - | U wrap continuous | 395.070 | 256.113 |
| 4 US WO | 4 | - | U wrap strips | 237.420 | 114.009 |
| 4 S90 WO | 4 | - | Side strips $90^0$ orientation | 185.603 | 67.30 |
| 4 S45 WO | 4 | - | Side strips $45^0$ orientation | 209.698 | 89.02 |
| 4 C W | 4 | 2 legged 10mm @ 300mm | - | 225.281 | - |
| 4 UC W | 4 | 2 legged 10mm @ 300mm | U wrap continuous | 580.000 | 157.45 |
| 4 US W | 4 | 2 legged 10mm @ 300mm | U wrap strips | 423.670 | 88.06 |
| 4 S90 W | 4 | 2 legged 10mm @ 300mm | Side strips $90^0$ orientation | 402.000 | 78.44 |
| 4 S45 W | 4 | 2 legged 10mm @ 300mm | Side strips $45^0$ orientation | 315.746 | 40.156 |

**Table – 3 Comparison between numerical analysis data and calculated values:**

| Specimen | Numerical Results | | | Design Approach ( ACI 440- 2R08 Format) | | | |
|---|---|---|---|---|---|---|---|
| | Vn (KN) | Vc +Vs (KN) | $V_f$ (KN) | Vc+Vs *(KN)* | $V_f$ *(KN)* | Vn (KN) | $\phi V_n = 0.85(V_c + V_s)+0.7V_f$ |
| 3 C WO | 62.381 | 62.381 | - | 40.320 | - | 40.32 | 34.272 |
| 3 UC WO | 209.535 | 62.381 | 147.154 | 40.320 | 151.828 | 192.148 | 140.551 |
| 3 US WO | 199.922 | 62.381 | 137.541 | 40.320 | 72.194 | 112.514 | 84.807 |
| 3 S90 WO | 149.864 | 62.381 | 87.483 | 40.320 | 48.532 | 88.852 | 68.244 |
| 3 S45 WO | 96.908 | 62.381 | 34.527 | 40.320 | 68.635 | 108.955 | 82.316 |
| 3 C W | 152.245 | 152.245 | - | 93.252 | - | 93.252 | 79.2642 |
| 3 UC W | 289.84 | 152.245 | 137.595 | 93.252 | 151.828 | 245.08 | 185.543 |
| 3 US W | 322.935 | 152.245 | 170.69 | 93.252 | 72.194 | 165.446 | 129.799 |
| 3 S90 W | 261.5 | 152.245 | 109.255 | 93.252 | 48.532 | 141.784 | 113.236 |

 

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 3 S45 W | 177.970 | 152.245 | 25.725 | 93.252 | 68.635 | 161.887 | 127.308 |
| 4 C WO | 55.469 | 55.469 | - | 40.320 | - | 40.32 | 34.272 |
| 4 UC WO | 197.535 | 55.469 | 142.066 | 40.320 | 151.828 | 192.148 | 140.551 |
| 4 US WO | 118.71 | 55.469 | 63.241 | 40.320 | 72.194 | 112.514 | 84.807 |
| 4 S90 WO | 92.801 | 55.469 | 37.332 | 40.320 | 48.532 | 88.852 | 68.244 |
| 4 S45 WO | 104.849 | 55.469 | 49.38 | 40.320 | 68.635 | 108.955 | 82.316 |
| 4 C W | 112.640 | 112.640 | - | 93.252 | - | 93.252 | 79.2642 |
| 4 UC W | 290.0 | 112.640 | 177.36 | 93.252 | 151.828 | 245.08 | 185.543 |
| 4 US W | 211.835 | 112.640 | 99.195 | 93.252 | 72.194 | 165.446 | 129.799 |
| 4 S90 W | 201.0 | 112.640 | 88.36 | 93.252 | 48.532 | 141.784 | 113.236 |
| 4 S45 W | 157.873 | 112.640 | 45.233 | 93.252 | 68.635 | 161.887 | 127.308 |

## V. CONCLUSIONS

1. The U wrap strip strengthening method is concluded as best technique out of all strengthening techniques.
2. The amount of CFRP used in specimen U wrap continuous is 208% of that used in specimen U wrap strips but increase in load carrying capacity was minimal i.e., -11.4%, 4.8% in beams having a/d = 3 comparing with and without internal transverse reinforcement respectively.
3. The increase in shear resistance owing to CFRP was greater in beams having a/d = 4 in case of U wrap continuous strengthening method.
4. In view of fiber orientation of side strips, $45^0$ orientation shows a lesser increase in load carrying capacity compared to $90^0$ orientation strips.
5. Beams having side strips of $90^0$orientation shows more ductility than the U wrap continuous beam.
6. The increase in shear resistance of beams owing to CFRP was marginal while comparing the beams having with and without stirrups, which refers that CFRP strength utilizes fully in beams having without stirrups.

## REFERENCES

[1] Ahmed Khalifa, Antonio Nanni. Improving shear capacity of existing RC T-section beams using CFRP composites. Cement and concrete composites Elsevier science 2000

[2] Bjorn Taljsten .STRENGTHENING CONCRETE BEAMS FOR SHEAR WITH CFRP SHEETS. Construction and building materials Elsevier science 2003

[3] J.F. Chena, J.G. Tengb. SHEAR CAPACITY OF FRP-STRENGTHENED RC BEAMS: FRP DEBONDING. Construction and building materials Elsevier science 2003

[4] Ghani Razaqpur, Marwan Shedid and Burkan Isgor SHEAR STRENGTH OF FIBER-REINFORCED POLYMER REINFORCED CONCRETE BEAMS SUBJECT TO UNSYMMETRIC LOADING, Journal of composites for construction ASCE / october 2011

[5] Amir Mofidi and Omar Chaallal, M.ASCE Shear Strengthening of RC Beams with Externally Bonded FRP Composites: Effect of Strip-Width- to-Strip-Spacing Ratio Journal of composites for construction ASCE / october 2011

[6] Ahmed Godat, Zhe Qu, Xinzheng Lu SIZE EFFECTS FOR RC BEAMS STRENGTHENED IN SHEAR WITH CFRP Strips Journal of composites for construction ASCE 2010.

[7] O.Chaallal, M.J.Nollet D. Perraton., "Shear strengthening of RC beams by externally bonded side CFRP strips" Journal of composites for construction 1998.

[8] Ahmed Khalifa, Abdeldjelil Belarbi and Antonio Nanni "Shear performance of RC members strengthened with externally bonded FRP wraps" 12WCEE 2000.

[9] Amir Mofidi, Omar Challal "Tests and design provisions for reinforced concrete beams strengthened in shear using FRP sheets and strips".International Journal of Concrete Structures and Materials.

[10] Ancy Joseph, Dr. P. Siva kumar, Jayasree Ramanujan "Linear behavior of Carbon fiber reinforced polymer plate bonded beam" International Conference on Emerging Technology Trends 2011

 