Shear Behaviour of Reinforced Concrete Beams without and with CFRP wrapping

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Abstract--**The present paper reports shear behaviour of reinforced concrete beams without and with CFRP wrapping. The experimental studies are conducted on six reinforced concrete beams under two-point loading with varying shear span to depth ratio and without and with CFRP wraps. The experimental results show the enhancement in first crack strength in the range of 20 to 60% while that of ultimate strength between 5 to 18% depending on the failure mode of the control beam. In addition the CFRP wrapping and the concrete is intact up to the failure of the beam which clearly indicates the composite action due to CFRP sheet.**

Key words: CFRP, Control beam, Wrapped beam, Load-deflection.

I. I. INTRODUCTION

Fiber reinforced polymer (FRP) composite systems, composed of fibers embedded in a polymeric matrix, can be used for shear strengthening of reinforced concrete (RC) members. Shear failure is catastrophic and occurs with no advance warning of distress. Many of the existing RC beams have been found to be deficient in shear strength and in need of strengthening. It is found that the CFRP is a very versatile material for strengthening of reinforced concrete beams. It is also found that CFRP wraps increase the shear strength of concrete beams. Reference [1], reports the shear performance and modes of failure of rectangular simply supported reinforced concrete (RC) beams. For the beams tested in the experimental program, increase in shear strength of 35 to 145% was achieved. Reference [2], investigated the shear performance of reinforced concrete (RC) beams with T-section. Different configurations such as continuous sheets versus series of strips, two sides versus U-wrapping, $90^0/0^0$ ply combination, and U wrap without end anchor versus with end anchor were tried. The experimental results show that externally bonded CFRP can increase the shear capacity of the beam significantly. In addition, the results indicated that the most effective configuration was the U-wrap with end anchorage. Reference [4], investigated different applications of fiber reinforced polymer composites (FRPCs) for external strengthening in civil construction. The experimental results of Reference [3], are useful for the development of a rational shear crack displacement prediction. Reference [5], reports externally bonded FRPC reinforcement is a viable solution towards enhancing strength, stiffness and energy dissipation characteristics of reinforced concrete beam-column joints subjected to regular as well as seismic loads.

In the present paper, the experimental results of cracking and deformation behaviour of reinforced concrete control- and CFRP wrapped- beams and the strengthening (shear) efficiency and ductility improvement of CFRP wrapping for the three different shear span-to-depth ratios, (a/d), are reported.

II. II EXPERIMENTAL PROGRAM

In the experimental program simply supported, singly reinforced concrete beams of rectangular cross-section (100 x 200 mm) with overall and effective spans of 1400 and 1500 mm respectively are considered. The beams are reinforced with two bars of 12 mm nominal diameter with two legged stirrups of 6mm diameter as shear reinforcement. Three sets of beams, with two beams in each set were cast. Each set contained one control beam and one beam with CFRP wrapping. To examine the efficiency of wrapping, the testing programme consisted of testing the first set of beams in flexure and the other two sets in shear. Keeping this in view, the shear span to depth (a/d) ratios have been chosen. For the first set of beams the (a/d) ratio was 2.57 while those of the other two sets are 1.85 and 1.71, respectively. For the last two sets, purposefully the beams are made shear deficient by considering the spacing of stirrups to be approximately equal or slightly more than the required design spacing. This has been done with a view to trigger shear failure in the control beams and to study the efficacy of the wrapping in controlling the shear failure in the wrapped beams.

The main focus of this investigation is to examine the efficiency of CFRP discrete wraps in improving the flexural/shear strength of simply supported singly reinforced concrete beams. From the review of literature, it is found that the presence of shear reinforcement, shear span to depth ratio are, amongst others, two important parameters to be considered in studying the efficiency of CFRP wraps. Keeping these in view, a comprehensive experimental program, involving testing of six beams (three wrapped- and three control- beams) in two-point bending, was carried out. For each casting three companion cubes were cast to determine the compressive strength of concrete. The steel bars used as stirrups and as main reinforcement were tested for their tensile strength. For each type, three nominally similar bars were tested. Details of Beam designation and the type of the beam are as shown in table 1.

In the present study, a total of 16 strain gauges were installed, six strain gauges of 2mm gauge were embedded to stirrup reinforcement bar, five strain gauges of 30 mm gauge were glued to CFRP laminates and concrete surface. And 30 mm gauge strain gauges were pasted on the strengthened beam on the surface of one on the CFRP strip and one on the concrete surface pasted in the direction of fiber in shear span (in each shear span four strain gauges were pasted). And in flexural region the two strain gauges were pasted perpendicular to the fiber. Strain gauge location, test setup and strengthening scheme (CFRP strips in the form of U-WRAP) is as shown in Fig. 1.

For Control beam, measurements of strains were made using the electrical resistance gauges pasted on the shear reinforcements as shown in Fig. 2. A total of six gauges were pasted on stirrups before casting of concrete. The deflections under the load points and at the centre of the beam were measured using automatic deflection dial gauges. The concrete surface strains were measured using Pfender gauges; Strains were measured on both the faces but only in the shear zones. The demec points were pasted on the surface of the beam few hours before testing was started and are as shown in Fig. 2.

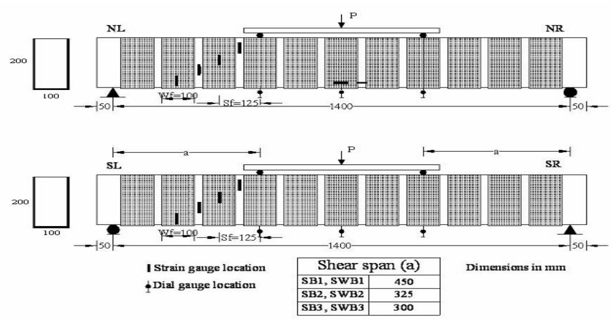


Fig.1. Test setup and strengthening scheme (CFRP strips in the form of U-WRAP)

Fig. 2 Two points loading experimental arrangements for control beam

TABLE 1

BEAM DESIGNATION AND THE TYPE OF THE BEAM

Sl. No	Beam No	a/d	Beam details	Shear reinforcement: Steel stirrups	Shear reinforcement: CFRP	No. of layer
1	SB1	2.57	Control	6mm ϕ @ 100 mm c/c	---------------	-----------
2	WSB1	2.57	Retrofitted	6mm ϕ @ 100 mm c/c	U-wrapping of strips 100 mm @125 mm c/c	one ply 90^0
3	SB2	1.85	Control	6mm ϕ @ 120 mm c/c	---------------	-----------
4	WSB2	1.85	Retrofitted	6mm ϕ @ 120 mm c/c	U-wrapping of strips 100 mm @125 mm c/c	one ply 90^0
5	SB3	1.71	Control	6mm ϕ @ 125 mm c/c	---------------	-----------
6	WSB3	1.71	Retrofitted	6mm ϕ @ 125 mm c/c	U-wrapping of strips 100 mm @125 mm c/c	one ply 90^0

III. III STRENGTENING RC BEAMS WITH CFRP

Before the application of wrap, the substrate is prepared. A smooth convex surface of concrete is prepared before wrapping. This is important since the CFRP layer is very thin. Also, CFRP becomes ineffective if it is not in contact with the surface of concrete. Care is taken to avoid wrinkles, voids and sheet deformation. Moreover, sharp edges and corners were rounded off using sand blasting technique.

After preparation of the surface a low viscosity primer was applied on the concrete surface to improve bond between the fibre sheet and the concrete. Fibre sheets were cut to required sizes (i.e 100 x 500 mm). The strengthening scheme adopted in the present study is shown in Fig 1.

The mechanical properties of the materials used for manufacturing the test specimens are listed in tables 2 & 3.

TABLE II

ENGINEERING PROPERTIES OF CFRP USED IN THE PRESENT STUDY

Typical Properties	High strength	High modulus	Ultra-high modulus
Density (Kg/m^3)	1800	1900	2000-2100
Young's modulus (GPa)	230	370	560-620
Tensile strength (GPa)	2.48	1.79	1.03-1.31
Tensile elongation (%)	1.1	0.5	0.2

TABLE III

PROPERTIES OF THE REINFORCING BARS, OBTAINED BASED ON THE EXPERIMENTAL INVESTIGATIONS

Specimen ID	Elastic modulus E (MPa)	Actual diameter (mm)	Yield stress f_y (MPa)	Ultimate strength f_u (MPa)	Elongation (%)
12 mm	2.00×10^5	11.94	470	620.26	24
6 mm	1.99×10^5	6.24	387	555.86	14.5

IV. IV DISCUSSION OF TEST RESULTS

As a first step, it is proposed to compare the first crack and ultimate loads, of control and the corresponding wrapped beams, obtained from the tests. While testing the control specimens, since the testing frame was congested, the first crack load could not be ascertained exactly. Hence, the load-deflection and the strain gauge (gauges located nearer to the flexure zone) readings are considered. These loads are presented in table 4. From this table, it is noted that while there is no significant improvement in the first crack and ultimate strengths, the failure mode has changed with reference to the second and third control beams (for which (a/d) were 1.85 and 1.71, respectively). As expected, all the beams first cracked in the flexure zone, the dominance of the crack leading to failure occurred at later stages of loading depending on the (a/d) ratio and the presence or absence of the wraps. While the failure occurred in beams *SB2* and *SB3* due to propagation of dominant crack from the shear zone, the failure of the respective wrapped beams occurred due to propagation of cracks (almost vertically) in the flexure zone albeit more or less under one of the load points. In the case of wrapped beams, at the time of failure, it is noted that the wrap along with thin layer of concrete became separated (in the compression zone) on one or both the faces finally leading to an explosive failure due to crushing of concrete in the compression zone. In fact, in the case of beam *WSB1*, a lateral bending was also observed after the separation of the wrap. These observations along with the fact that there is no significant increase in strengths of beams suggest that, perhaps, the wraps in the shear zone should be continuous and that the orientation of the fibers of CFRP in the flexure zone should be parallel to the neutral plane of the beam. However, it is noted that the nature of failure mode has changed from one of shear to almost flexure by wrapping scheme used in the present study.

The load deflection graphs of control and wrapped beam are shown in Fig. 3. The load-deflection curves are bilinear. Table IV also shows that the first crack strength is 20 – 60% while that of ultimate strength is between 5 – 18% depending on the failure mode of the control beam. A careful study of load-deflection curves of control and wrapped beams (see Table V) shows that the stiffness values of all three beams have almost doubled both before and after cracking. Thus, while there may not be significant increase in strengths but the serviceability control can be better exercised through wrapping.

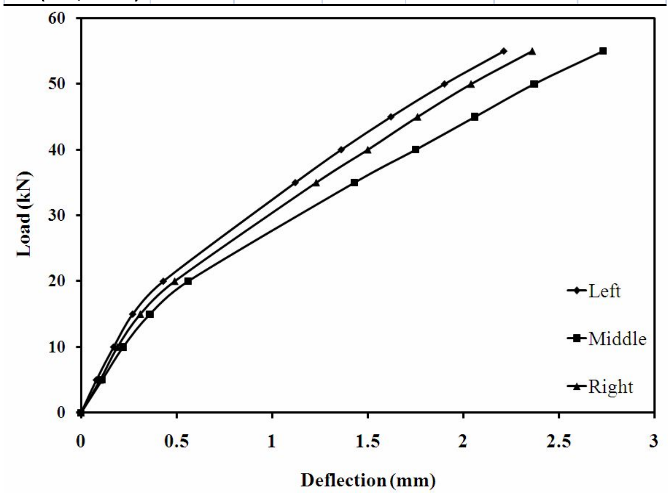
However, the strain recordings (on stirrups) are taken continuously. Strain variations in electrical resistance strain gauges (located nearer to point loads) for control beams & wrapped beams (sg2 – North Face; sg5 – South Face; both gauges) are shown in figure 4.

TABLE IV
EXPERIMENTAL FIRST CRACK AND ULTIMATE LOADS AND THE NATURE OF FAILURE

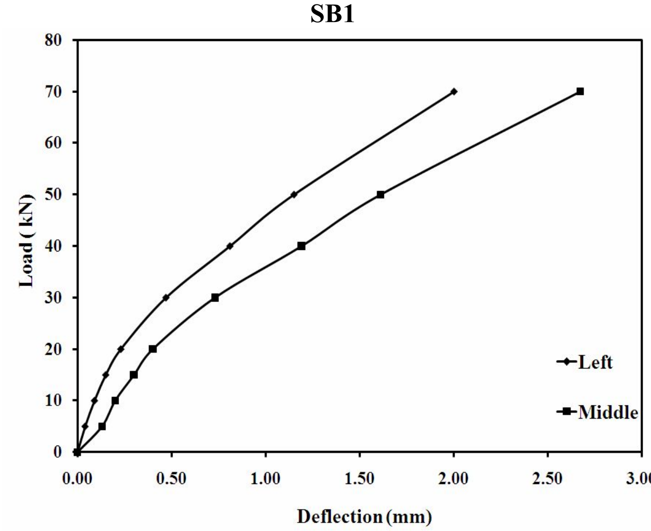
Sl. No.	Beam designation	Load at initial crack P_{cr} kN		Ultimate load kN	Nature of failure
		Deflection graph	Strain graph		
01	*SB1*	10–15	10 – 15	100.92	Flexural failure
02	*WSB1*	20 (60%)	20	106.08 (5.11%)	Failure due to bursting of concrete in compression near load point
03	*SB2*	18	18	134.92	Shear compression Failure
04	*WSB2*	20–25 (25%)	20 - 25	157.08 (16.42%)	Failure due to bursting of concrete in compression zone under one of the load point
05	*SB3*	25	25	149.08	Diagonal Shear Failure
06	*WSB3*	30 (20%)	30	176.08 (18.11%)	Failure due to explosive bursting of concrete in compression zone under one of the load points

TABLE V
STIFFNESS VALUES (BASED ON INITIAL AND SECOND SEGMENTS OF P-δ CURVES

	SB1	WSB1	SB2	WSB2	SB3	WSB3
K1(KN/mm)	48.39	83.33	50	100	50	100
K2(KN/mm)	15.63	24.02	24.79	34.59	23.53	48.91



SB1



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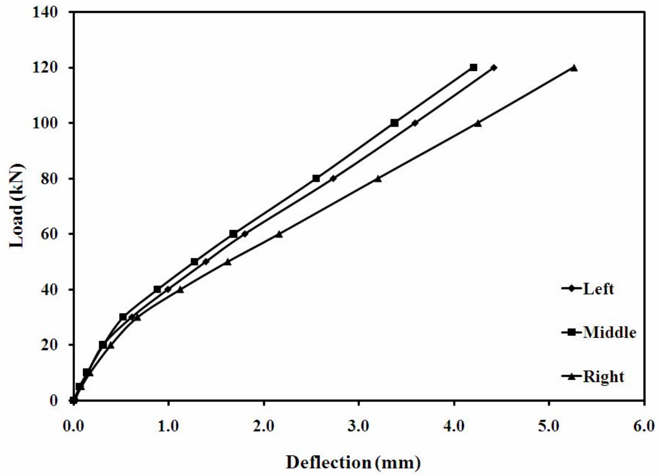

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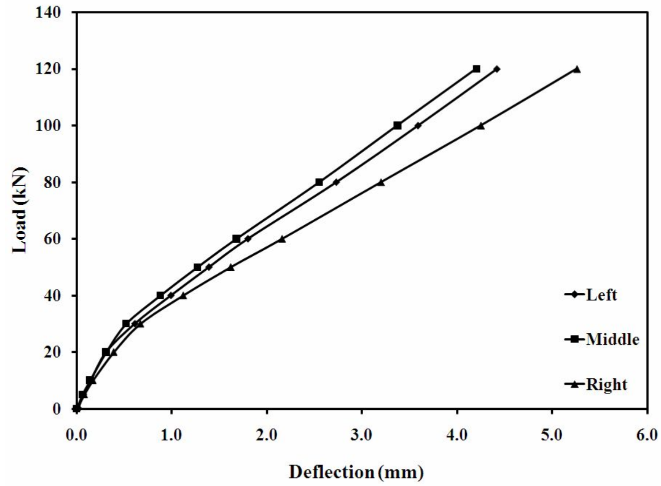
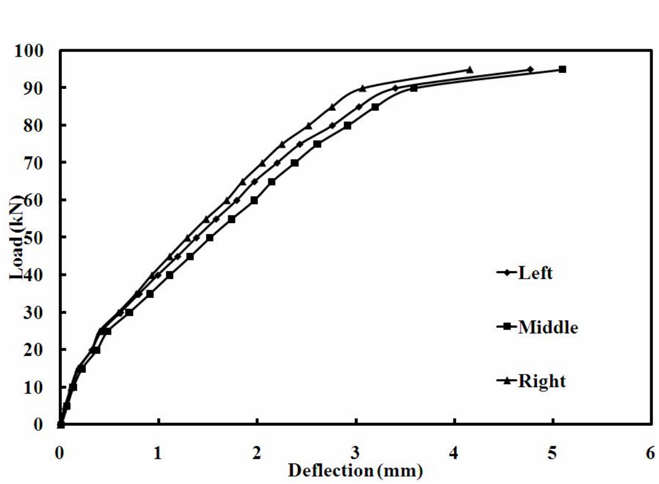
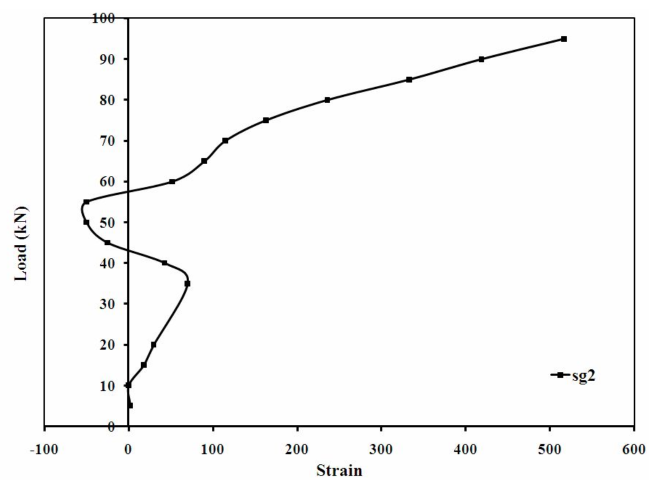


WSB3

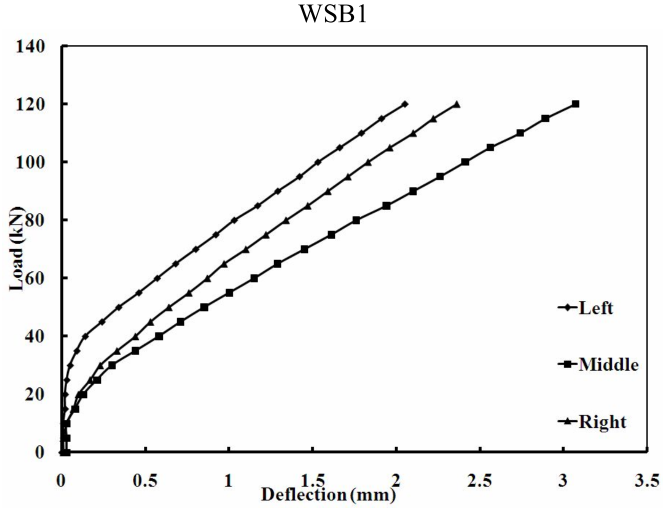
Fig. 3. Load – deflection plot for the control beams & Wrapped beams.



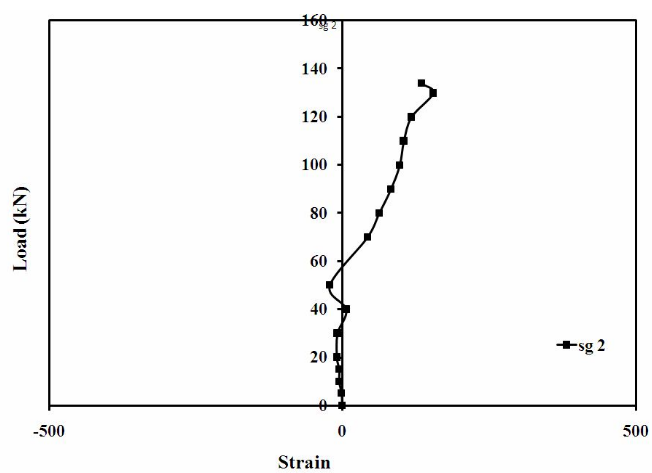
WSB1



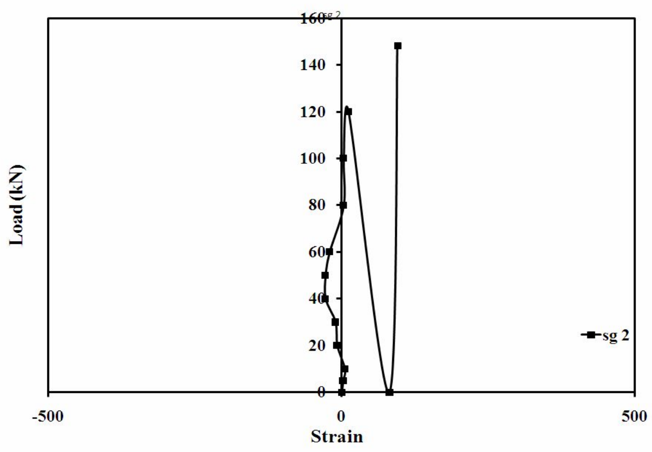
SB1



WSB2



SB2



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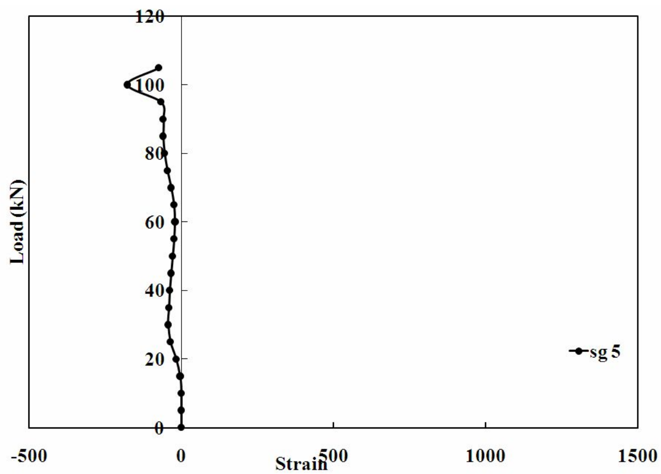
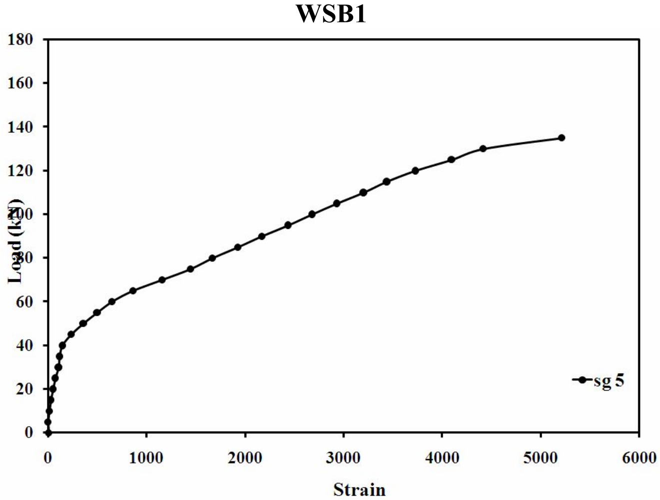
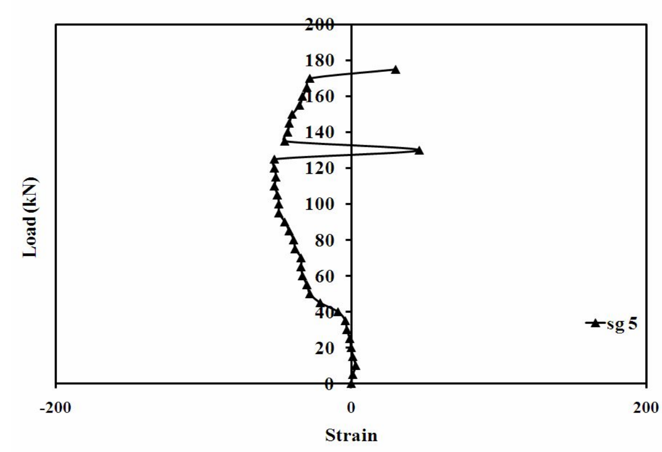


WSB1



WSB2



WSB3

Fig. 4. Strain variations in electrical resistance strain gauges (located nearer to point loads) for control beams (sg2 – North Face; sg5 – South Face; both gauges on stirrup)

V. CONCLUSION

Based on the experimental studies on six reinforced concrete beams under two-point loading with varying shear span to depth ratio, and, without- and with- CFRP wraps, the following general conclusions have been drawn:

1. The control beams, designed to fail in a particular failure mode have behaved as expected.
2. The wrapping scheme adopted in this work (i.e. discrete CFRP strips, with fibers oriented at 90^0 to the neutral plane) has resulted in change of failure mode from shear to almost flexural mode. The CFRP wrapping and the concrete is intact up to the failure of the beam which clearly indicates the composite action due to CFRP sheet.
3. The enhancement in first crack strength is 20 – 60% while that of ultimate strength is between 5 – 18% depending on the failure mode of the control beam.
4. The load-deflection behaviour of wrapped and unwrapped beams, considered in this investigation can be idealised by a bi-linear curve (at least up to the working load level).
5. While the increase in strength is marginal, there is significant improvement in the stiffness gained by wrapping (it is almost doubled depending on the region of the load-deflection curve). This observation indicates that the wrapping scheme, tested in this investigation, can be used to satisfy the serviceability requirements and to an extent alter the failure mode.

VI. REFERENCES

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