Shear Retrofitting of Steel Beam with CFRP Straps

Ankit Kadam1, Prof. Vishwajeet Kadlag2, Dr. Ashok Kasnale3

Department of Civil Engineering,
Dr.D.Y.Patil school of Engineering and Technology, Charholi bk., via. Lohegaon,Pune - 412 10

Abstract*:*A technique has been developed that employ thin Carbon Fibre Reinforced Polymer (CFRP) straps for shear improvement of steel beams. Use of Carbon Fibre Reinforced Polymer (CFRP) strips as externally bonded reinforcement, is a technically sound and basically efficient method of strengthening and upgrading of steel beam. Externally bonded CFRP strips help in improving the structure performance by reducing deflections and/or cracking and increasing ultimate strength. The final capacity of the strengthened beam is controlled by either compression crushing of concrete, rupture of CFRP and flexural shear cracking. To ensure maximum improvement, the-straps need to fully penetrate the compression flange of the beam and the amount of flange area removed for the straps should be minimized. The study conducted experimental to evaluate the effectiveness of strengthening steel beams by the use of CFRP sheets configurations. The research involved the testing of five experimental composite beams to analyze the variation in yield load, ultimate load and deformation characteristics. When the steel beam wrapped with CFRP sheets in the lower and upper portion of bottom flange as well as in the bottom portion of web there was an increase the yield load and ultimate load. Validation of the steel beam with FRP surface treatment techniques, adhesive curing, and support conditions under loading, and failure modes with finite element (FE) simulation structural elements is required to be studied.

Keywords: *Carbon Fibre Reinforced Polymer (CFRP), flexural shear cracking, finite element (FE) analysis.*

I. INTRODUCTION

Studies on attractive structures have significantly increased recently. Different methods exist for strengthening various structures. Using Fiber Reinforced Polymer (FRP) is more popular than other materials for strengthening structures because of their high tension strength, low weight, and more resistance against corrosion. Normally, two type of FRP has been produced: (a) Glass Fiber Reinforced Polymer (GFRP) and (b) Carbon Fiber Reinforced Polymer (CFRP). Applying CFRP had been recognized as more fitting than GFRP for enhancing different structures because of its higher strength. Strengthening steel structure by means of CFRP materials have been escalating lately.

1.1 Retrofit Of Steel Members With FRP

There is comparatively little work investigating the use of bonded FRP materials for the retrofit of steel members. Most available research focuses on the use FRP for the flexural strengthening of corroded bridge girder sand addressed the use of bonded FRP materials on only the tension flange of simple girders. The rationale is that the bottom flanges of bridge girders typically see the greatest level of corrosion, largely due to debris accumulation. Most investigations of the use of CFRP strips attached to the tension flange of I-girders have demonstrated modestly improved flexural capacity relative to the CFRP applied although little improvement to girder stiffness. In such applications, Lenwarietal. Demonstrated that the stress intensity at the ends of CFRP plates governs the deboning behavior and represents the dominant limit state for this application. Investigated the behavior of steel beams, damaged intentionally at their tension flange to simulate corrosion, and then repaired with CFRP plates .Damage varied upto a loss of 75% of the tension flange. The test results showed that the elastic flexural stiffness of damaged beam can be partially restored (upto50%); whereas the strength of damaged beams carefully restored to their original, undamaged state using the particular CFRP plates investigated.

II. LITERATURE REVIEW

1 *Strengthening Of Steel Structures With Fiber-Reinforced Polymer Composites*

It stated that over the past two decades, fiber-reinforced polymer (FRP) composites have gradually gain broad receipt in civil engineering application due to their unique compensation including their high strength-to-weight ratio and exceptional corrosion resistance. In particular, numerous potential of by means of FRP in the intensification in addition to construction of concrete structures have been explored. More lately, the use of FRP to strengthen existing steel structures has received much attention. This document starts with a critical conversation of the use of FRP in the intensification of steel structures where the compensation of FRP are appropriately exploited. The paper then provides a critical review and interpretation of existing research on FRP-strengthened steel structures. Topics covered by the review include steel surface preparation for adhesive bonding, assortment of a suitable adhesive, bond performance between FRP in addition to steel and its appropriate modeling, flexural strengthening of steel beams, fatigue strengthening of steel structures, strengthening of thin-walled steel structure alongside local buckling, and strengthening of hollow or concrete-filled strengthen tube through external FRP confinement. The paper concludes with explanation on future research needs.

2 *Fiber Reinforced Polymers For Structural Retrofitting: A Review*

This paper presents a representative overview of the current state of using FRP materials as a retrofitting technique for the structures not designed to resist seismic action. Many structures located in seismically active zone are not capable of withstanding seismic action according to current codes and provisions. Furthermore, recent earthquakes in urban areas have clearly established an urgency to improve and strengthen these seismic deficient structures. Significant amount of research work has been approved out in recent years to develop various strengthening and rehabilitation techniques to get better the seismic presentation of structures. Several intensification methods like addition of new structural elements; external post tensioning, steel plate bonding etc. have been applied in the past with varying degree of achievement. Among these methods, seismic retrofit with FRP materials has gained notable acceptance from the civil engineering community in recent years. Retrofitting with FRP materials is a strictly sound in addition to cost effective repair technology and is now extensively being used as a seismic retrofitting method all over the world. It summarizes the scopes and uses of FRP materials in seismic strengthening of RC structures in addition to masonry retrofitting as healthy as the seismic retrofitting schemes for steel structures.

3 *Shear Strengthening Of Steel I-Beams By Using CFRP Strips*

In this study shows that carbon fiber reinforced polymer (CFRP) strips have been used for flexural strengthening of steel beams, but in this research, application of CFRP strips as shear reinforcements was innovated. In this novel method, study on the requirement of applying CFRP on one or both sides of the web, and using different values of CFRP area on the web were the two main objectives. In this investigate, five specimens were selected. The first specimen (B1) was not strengthened. The second in addition to third beams (B2 and B3) were upgraded on both sides of web with the CFRP ratios of 0.72 and 0.48, respectively. The fourth and fifth specimens (B4 and B5) were strengthened on one side of web with the CFRP ratios of 0.72 and 0.48, respectively. Both numerical simulation and experimental test were used in this research. The results show that by using CFRP strips on web, could appropriately increased the load bearing capacity up to 51%. Also, the CFRP ratios of 0.72 and 0.48 for both sides of web have produced the same load capacity. Using less CFRP in the shear zone with the same load capacity of the steel I-beams was one of the significant achievements of this research.

III. STRENGTHENING OF STEEL STRUCTURES

3.1 Appropriate Use of FRP in the Strengthening of Steel Structures

The method of FRP confinement is attractive not only in the strengthening of steel tubular structures, but also in the construction of new tubular columns. The combination of adhesive bonding with shape flexibility makes bonded wet lay-up FRP laminates an attractive strengthening method in a number of applications. Needless to say, steel plates can also be adhesively-bonded but bonding is less attractive for steel plates due to their heavy weight and inflexibility in shape. Furthermore, for the same tensile capacity, a steel plate has a much larger bending stiffness than an FRP laminate so a steel plate leads to higher peeling stresses at the interface between the steel plate and the steel substrate. It is also easier to anchor FRP laminates to a steel member by wrapping FRP jackets around the steel member.

Table shows the properties of pultruded CFRP plates supplied by SIKA; these three types of CFRP plates are referred to herein as high strength, intermediate modulus and high modulus plates respectively and their stress–strain curves are illustrated in Figure. 3.1. By contrast, for the confinement of steel tubes, particularly when ductility

Table 1: Properties of SIKA CFRP Plates

Product	Elastic Modulus (GPa)	Tensile Strength (MPa)	Ultimate Strain (%)
Sika Carbon Dur S (High Strength CERP)	165	2800	1.70

Sika Carbon modulus M (Intermediate modulus CERP)	210	2400	1.20
Sika Carbon Dur H (High modulus CERP)	300	1300	0.45

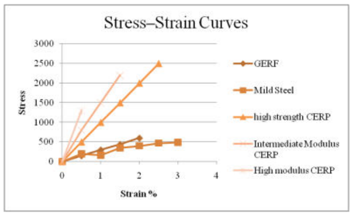

Figure.1. Typical FRP and Mild Steel Stress–Strain Curves

3.2 Degradation and FRP Strengthening

Degradation of steel structures, such as old industrial buildings and bridges, and increased load requirements have led to the need for structural rehabilitation and strengthening. Application of bolted or welded steel plates to the original structure is sometimes used as a strengthening technique. This technique has some negative aspects, such as the increase in permanent loads, difficulty of movement, and problems due to corrosion and fatigue.

Fiber Reinforced Polymer (FRP) materials have a high strength-weight ratio, do not give rise to problems due to corrosion, are extremely manageable and are commonly used for strengthening structural reinforced concrete members, but they have only been infrequently studied and used for strengthening steel elements and, above all, steel-concrete composite elements. Several studies on the FRP strengthening of concrete structures have resulted in the first design guidelines for concrete structures strengthened with externally applied FRP. Although externally bonded FRP strengthening for metal structures is a rapidly developing technique, guidelines for the reinforcement of steel structures with FRP do not currently have a comparable degree of reliability.

3.3 Strengthening Steel Beams Using FRP under Fatigue

The collapse of structural elements due to fatigue is extremely expensive and may be catastrophic in terms of human life and damage. The fatigue process can be defined as the accumulation of damage at a localized region as a result of cyclic loads, which leads to the formation of a crack that eventually propagates through the material.

IV. VALIDATION OF SOFTWARE

4.1 Paper 1 – October 2012 E. (Agcakoca and M. Aktas)

In recent year, little research work has been published on the impact of the high-modulus carbon fiber-reinforced polymer strips ratio on the strengthening of steel composite I beam. Based on the study development lengths were set at 900, 1800, and 3600mm for beams with lengths of 3000, 6000, and 12000 mm, respectively. Variations in the specimens' load-carrying capacities were investigated by using various quantities of HMCFRP.

4.2 Testing and Numerical Verification

A two-step experiment was performed in this part of the study. In the first step, a steel Ibeam specimen was constructed and tested that matched the load-carrying capacity of a concrete composite steel I-beam. The concrete slab components were replaced by their steel counterparts and used for further studies, avoiding problems associated with manufacturing concrete parts and issues with numerical modeling during this parametric study on concrete composite I-beams.

The beam specimens had a length of 3,000mm, and the distance between the supports was 2,900mm. The distance between the loading point and the end of the HM-CFRP material was 1,050mm, the distance between loading points was 800mm, and the load was applied using a 400kN piston. A 200 × 200 × 1000mm spreader beam was used to apply equal loads to all of the beam's loading points. Two 20 × 30 × 900mm steel bars were utilized to ensure load transfer from the spreader to the beam.

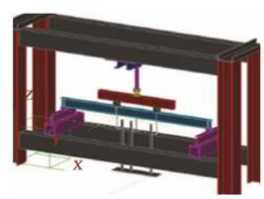

Figure.2. Loading Considered

Table 2: Result For Load Carrying Capacity Of Model

Sr. No	Descriptions		E. Agcakoca and M. Aktas Result
1	Reference Beam	Max Load KN	84
		Max Moment KN-m	44.13
2	Strengthening Beam	Max Load KN	121
		Max Moment KN-m	63.52

V. RESULT AND DISCUSSION

1 Static Analysis of CFRP at Bottom Flange

✓ **Single Strip Flange**

Table 3: Load Vs defection for Single Strip Application Of CFRP At Bottom Flange

Sr. No	Load	10	20	30	40	50
	KN	mm	mm	mm	mm	mm
1	5	0.1	0	0	0.4	0
2	10	0.2	0.32	0.46	0.52	0.67
3	15	0.3	0.43	0.57	0.64	0.8
4	20	0.4	0.54	0.68	0.76	0.93
5	25	0.5	0.65	0.79	0.88	1.06
6	30	0.6	0.76	0.9	1	1.19
7	35	0.65	0.87	1.01	1.12	1.32
8	40	0.8	0.98	1.12	1.24	1.45
9	45	0.9	1.09	1.23	1.36	1.58
10	50	1	1.2	1.34	1.48	1.71
11	55	1.15	1.31	1.45	1.6	1.84
12	60	1.2	1.42	1.56	1.72	1.97
13	65	1.3	1.53	1.67	1.84	2.1
14	70	1.4	1.64	1.78	1.96	2.23
15	75		1.75	1.89	2.08	2.36

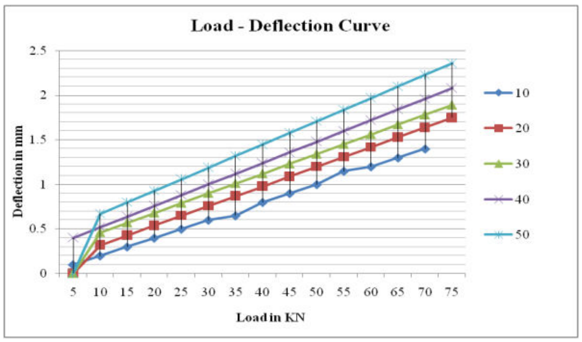

Figure.3. Load Vs defection for Single Strip Application Of CFRP At Bottom Flange

Figure 4 shows load Vs deflection for single strip application of CERP at bottom flange in steel beam. it observed that as per load carrying capacity increase deflection is also increase that is load carrying capacity is directly proportional to deflection . in 50 mm strip is more deflection as compare to other.

✓ **Double Strip Flange**

Table 4: Load Vs defection for Double Strip Application Of CFRP At Bottom Flange

Sr. no	Load	4	6	8	10	12	14	16
	KN	mm	mm	mm	mm	mm	mm	mm
1	5	0	0	0	0.4	0	0	0
2	10	0.12	0	0.42	0.535	0.58	0.65	0.65
3	15	0.2	0.28	0.522	0.67	0.72	0.79	0.82
4	20	0.28	0.38	0.624	0.805	0.86	0.93	0.99
5	25	0.36	0.48	0.726	0.94	1	1.07	1.16
6	30	0.44	0.58	0.828	1.075	1.14	1.21	1.33
7	35	0.52	0.68	0.93	1.21	1.28	1.35	1.5
8	40	0.6	0.78	1.032	1.345	1.42	1.49	1.67
9	45	0.68	0.88	1.134	1.48	1.56	1.63	1.84
10	50	0.76	0.98	1.236	1.615	1.7	1.77	2.01
11	55	0.84	1.08	1.338	1.75	1.84	1.91	2.18
12	60	0.92	1.18	1.44	1.885	1.98	2.05	2.35
13	65	1	1.28	1.542	2.02	2.12	2.19	2.52
14	70	1.08	1.38	1.644	2.155	2.26	2.33	2.69
15	75	1.16	1.48	1.746	2.29	2.4	2.47	2.86
16	80		1.58	1.848	2.425	2.54	2.61	3.03

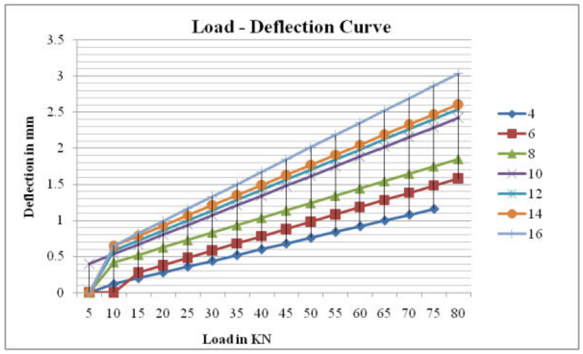

Figure.4. Load Vs defection for Double Strip Application Of CFRP At Bottom Flange

Figure 5 shows load Vs deflection for double strip application of CERP at bottom flange in steel beam. it observed that as per load carrying capacity increase deflection is also increase that is load carrying capacity is directly proportional to deflection. In 16 mm strip is more deflection as compare to other.

2 Static Analysis of CFRP at Web

✓ Single Strip Web

Table 5: Load Vs Defection For Single Strip Application Of CFRP At Both Sides Of Web

Sr No	Load	10	20	30	40	50	60	70	80	90	100	110	120	130
	KN	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
1	5	0.2	0	0	0	0	0.2	0	0	0.3	0	0.5	0.56	0
2	10	0.25	0	0.4	0	0	0.4	0	0.25	0.4	0.4	0.55	0.65	0
3	15	0.3	0	0.5	0	0.01	0.6	0.1	0.3	0.6	0.5	0.69	0.85	0.9
4	20	0.32	0.3	0.6	0.5	0.02	0.7	0.2	0.4	0.9	0.8	0.78	0.9	0.98
5	25	0.35	0.35	0.75	0.58	0.025	0.8	0.25	0.5	1	0.95	0.89	1.2	1
6	30	0.37	0.38	0.8	0.6	1.15	1.1	0.29	0.6	1.6	1.15	0.96	1.3	1.02
7	35	0.4	0.41	0.85	0.8	1.2	1.15	0.3	0.7	1.8	2	1	1.4	1.08
8	40	0.42	0.5	0.95	0.9	1.25	1.2	0.32	0.8	2	2.4	1.25	1.5	2.2
9	45	0.44	0.55	1.1	1.1	1.3	1.25	0.35	0.9	2.3	2.6	1.35	1.6	2.3
10	50	0.46	0.6	1.05	1.2	1.5	1.3	0.4	1	2.42	2.65	1.45	1.7	2.4
11	55	0.5	0.68	1.2	1.3	1.6	1.35	0.48	1.1	2.4	2.75	1.55	1.8	2.5
12	60	0.58	0.7	1.18	1.42	1.68	1.4	0.58	1.18	2.45	2.76	1.65	1.9	2.6
13	65	0.62	0.74	1.25	1.5	1.7	1.45	0.6	1.2	2.5	2.8	1.75	2	2.7
14	70	0.7	0.79	1.3	1.6	1.95	1.5	0.68	1.25	2.55	2.85	1.85	2.1	2.8
15	75	0.78	0.82	1.56	1.7	2	1.6	0.478	1.3	2.6	2.9	1.95	2.2	2.9
16	80	0.82	0.9	1.9	1.8	2.05	1.7	0.8	1.4	2.65	3	3.1	2.3	3
17	85	0.86	0.95	1.92	1.9	2.1	1.8	0.85	1.5	2.7	3.2	3.15	2.4	3.1
18	90	0.92	1.08	1.95	1.95	2.15	1.9	0.9	1.6	2.75	3.22	3.2	2.5	3.2
19	95	1	1.2	2	1.98	2.2	2	0.98	1.7	2.8	3.25	3.25	2.6	3.3
20	100	1.15	1.8	2.2	2	2.21	2.2	1	1.8	2.85	3.3	3.3	2.7	3.4
21	105		1.95	2.25	2.15	2.3	2.3	1.2	1.9	2.9	3.35	3.2	2.8	3.5
22	110			2.27	2.2	2.4	2.4	1.3	2	2.92	3.45	3.25	2.9	3.55
23	115					2.42	2.5	1.4	2.1	2.95	3.55	3.3	3	3.6
24	120						2.65	1.48	2.2	2.98	3.8	3.35	3.1	3.65
25	125						3	1.5	2.3	3	3.85	3.4	3.2	3.7
26	130						3.2	1.55	2.4	3.02	4	3.45	3.3	3.75
27	135						3.25	1.6	2.5	3.02	4.4	3.55	3.4	3.8
28	140							1.8	2.6	3.04	4.45	3.75	3.5	3.85
29	145								2.75	3.2	4.5	3.78	3.6	3.9
30	150									3.3	4.55	3.81	3.7	3.95
31	155									3.4	4.6	3.8	3.8	3.45
32	160									3.5	4.65	3.79	3.9	4
33	165										4.7	3.78	4	4.2
34	170										4.75	3.82	4.1	4.3
35	175											4.02	4.2	4.4
36	180												4.3	4.5

37	185													4.6
38	190													5.3

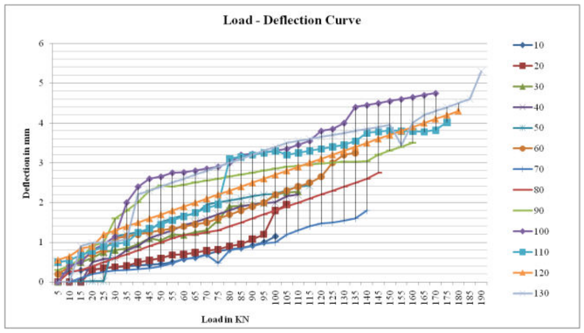

Figure.5. Load Vs defection for Single Strip Application Of CFRP At Both Sides of Web

Figure 6 shows load Vs deflection for single strip application of CERP at both sides of web in steel beam. it observed that as per load carrying capacity increase deflection is also increase that is load carrying capacity is directly proportional to deflection. In 130 mm strip is more deflection as compare to other.

✓ **Double Strip Web**

Table 6: Load Vs defection for Double Strip Application Of CFRP At Both Sides of Web

Sr. no	Load	10	15	20	25	30	35	40	45	50	55
	KN	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
1	5	0.35	0	0	0	0	0.4	0	0	0.4	0
2	10	0.45	0.37	0	0.2	0	0.6	0	0	0.7	0.6
3	15	0.55	0.49	0.68	0.3	0.18	0.8	0	0	0.9	0.8
4	20	0.65	0.61	0.6	0.5	0.02	1	0.2	0.5	1.1	1
5	25	0.75	0.73	0.71	0.7	0.3	1.2	0.45	0.7	1.3	1.2
6	30	0.85	0.85	0.82	0.9	0.4	1.4	0.7	0.9	1.5	1.4
7	35	0.95	0.97	0.93	1.1	0.5	1.6	0.85	1.1	1.7	1.6
8	40	1.05	1.09	1.04	1.3	0.6	1.8	0.95	1.3	1.9	1.8
9	45	1.15	1.21	1.15	1.5	0.7	2	1.05	1.5	2.1	2
10	50	1.25	1.33	1.26	1.7	0.8	2.2	1.15	1.7	2.3	2.2
11	55	1.35	1.45	1.37	1.9	0.9	2.4	1.25	1.9	2.5	2.4
12	60	1.45	1.57	1.48	2.1	1	2.6	1.35	2.1	2.7	2.6
13	65	1.55	1.69	1.59	2.3	1.2	2.8	1.45	2.3	2.9	2.8
14	70	1.65	1.81	1.7	2.5	1.4	3	1.6	2.5	3.1	3
15	75	1.75	1.93	1.81	2.7	1.6	3.2	1.7	2.7	3.3	3.2
16	80	1.85	2.05	1.92	2.9	1.9	3.4	1.8	2.9	3.5	3.4
17	85	1.95	2.17	2.03	3.1	2.2	3.6	1.9	3.1	3.7	3.6
18	90	2.05	2.29	2.14	3.3	2.5	3.8	2	3.3	3.9	3.8
19	95	2.15	2.41	2.25	3.5	2.8	4	2.3	3.5	4.1	4
20	100	2.25	2.53	2.36	3.7	3.1	4.2	2.6	3.7	4.3	4.2
21	105	2.35	2.65	2.47	3.9	3.4	4.4	2.9	3.9	4.5	4.4
22	110		2.77	2.58	4.1	3.7	4.6	3.2	4.1	4.6	4.6
23	115			2.69	4.3		4.8	3.5	4.3	4.7	4.8
24	120			2.8				4	4.5	4.8	5
25	125			2.91				4.2	4.7	4.9	5.2
26	130			3.02				4.6	4.9	5	5.4
27	135									5.1	5.5
28	140									5.2	5.6
29	145										5.65
30	150										5.7

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 04 Issue: 08 | August -2020 ISSN: 2582-3930

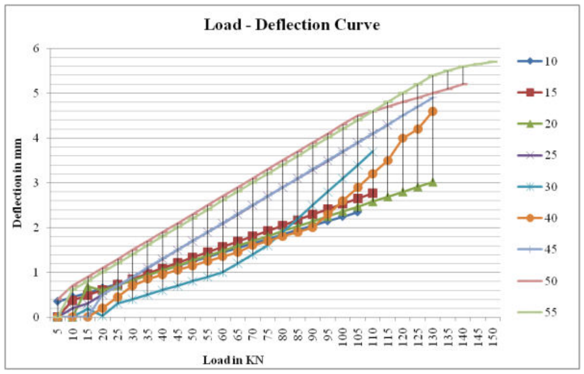

Figure.6. Load Vs defection for Double Strip Application Of CFRP At Both Sides of Web

Figure 7 shows load Vs deflection for double strip application of CERP at both sides of web in steel beam. it observed that as per load carrying capacity increase deflection is also increase that is load carrying capacity is directly proportional to deflection. In 55 mm strip is more deflection as compare to other

3 Validation Comparison

Table 7: Result For Load Carrying Capacity Of Model In Research Paper

Sr. No	Description		E. Agcakoca and M. Aktas Result	Abaqus Result	& Difference
1	Reference Beam	Max Load KN	84	82.56	1.714
		Max Moment KN-m	44.13	48.65	9.291
2	Strengthening Beam	Max Load KN	121	127.41	5.031
		Max Moment KN-m	63.52	65.78	3.436

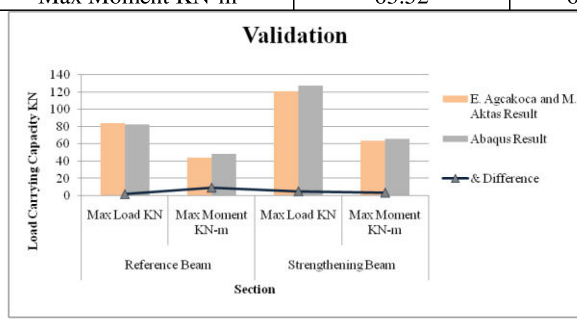

Figure.7. Load Carrying Capacity Of Model In Research Paper

Figure 8 shows load carrying capacity of model in research paper. Comparison of researcher results and our ABAQUS calculated results are showing graph and percentage difference are plotted in line graph. Both the results are approximately same below 10% it concluded in validate results in ABAQUS software.

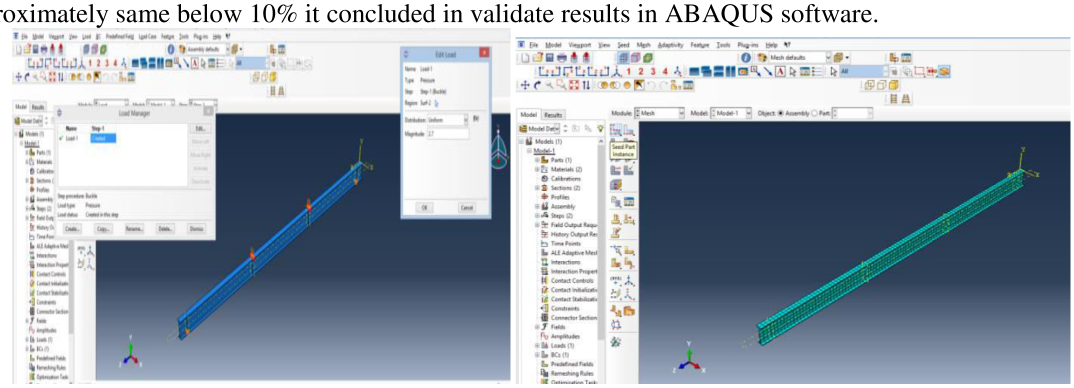

Figure.8. Result For Load Carrying Capacity Of Model In Research Paper

VI. CONCLUSION

Following conclusion can be listed below:

1. Load Deflection Curve

✓ Flange

- Load deflection Single strip CFRP application of bottom flanges are maximum deflection is 2.36 mm and ultimate load is 73.926 KN. In this result load carrying capacity increase also increase in deflection.
- Load deflection double strip CFRP application of bottom flanges are maximum deflection is 3.03 mm and ultimate load is 77.79 KN. In this result load carrying capacity increase also increase in deflection.

✓ Web

- Load deflection single strip CFRP application of both sides of web are maximum deflection is 5.3 mm and ultimate load is 188.05 KN. In this result load carrying capacity increase also increase in deflection.
- Load deflection double strip CFRP application of both sides of web are maximum deflection is 5.7 mm and ultimate load is 144.22 KN. In this result load carrying capacity increase also increase in deflection.

2. Validation

- The analytical results giving load carrying capacities of steel beam section provided loading, is found to be almost similar to that of the result obtained in the research paper using software and a percentage variation in load carrying capacity is found to be approximately. Hence, it can be concluded that the results of ABACUS are validated with the results obtained by using software in research paper.

3. General Conclusion Design

- Strengthening mechanisms using CFRP at both flanges and web with plates are the most suitable against all the standard failure modes.
- The precise location of the CFRP can often be more critical than length and shape in achieving the optimum strength effect.
- CFRP strengthening was found effective in enhancing the flexural strengthening of the beam.

VII. REFERENCES

1. A.H. Al-Saidy, F.W. Klaiber, et.al, "Parametric Study On The Behavior Of Short Span Composite Bridge Girders Strengthened With Carbon Fiber Reinforced Polymer Plates", *Construction and Building Materials,* Vol. 22, Pp.729–737, 2008.
2. Asma Nabila binti Abd Kader, S. A. Osman, and M. Y. M. Yatim, "A State-Of-The-Art Review on Retrofitting Beam-Column Joint Using GFRP with NSM Technique under Seismic Loading", *International Journal of Engineering and Technology,* Vol. 11, No. 1, February 2019.
3. Faikha V. P, Nandhu Ramesh, et.al. "Flexural Strengthening of Steel Beams using CFRP Sheets", *International Research Journal of Engineering and Technology (IRJET),* Vol. 06, Issues. 05, May 2019.
4. J.G. Teng, T. Yu, D. Fernando, "Strengthening of steel structures with fiber-reinforced polymer composites", *Journal of Constructional Steel Research,* Vol. 78 (2012) Pp. 131–143, 2012.
5. Jun Deng, Marcus M. K. Lee, "Fatigue performance of metallic beam strengthened with a bonded CFRP plate", *Composite Structures,* Vol. 78, Pp. 222–231, 2007.
6. Jun Deng, Marcus M. K. Lee, Stuart S. J. Moy, "Stress analysis of steel beams reinforced with a bonded CFRP plate", *Composite Structures,* Vol. 65, Pp. 205–215, 2004.
7. KambizNarmashiri, MohdZamin Jumaat1 and N. H. Ramli Sulong, "Shear strengthening of steel I-beams by using CFRP Strips", *Scientific Research and Essays,* Vol. 5(16), Pp. 2155-2168, August 2010.
8. Md. Mofizul Islam, Rubieyat Bin Ali, MoushtakimBillah, "Strengthening Techniques of Steel Structure: An Overview", *World Scientific News,* Vol. 118 Pp. 181-193, 2019.
9. Mr. V. Venkata Ramana, Mrs P. Meher Lavanya, et.al. "Shear retrofitting of RC Beams", *International Journal of Academic Research,* Vol. 4, Issue-2 No. 1, February 2017.
10. Neil A. Hoult1 and Janet M. Lees, "Efficient CFRP Strap Configurations for the Shear Strengthening of RC T-beams", *ASCE Journal of Composites for Construction,* Vol. 13 (1) Pp.45-52, 2009.
11. PierluigiColombi, Carlo Poggi, "An Experimental, Analytical and Numerical Study of the Static Behavior of Steel Beams Reinforced By Pultruded CFRP Strips", *Composites: Part B*, Vol. 37 Pp. 64–73, 2006.
12. Priyanka Sarker, Mahbub Begum and Sabreena Nasrin, "Fiber Reinforced Polymers for Structural Retrofitting: A Review", *Journal of Civil Engineering (IEB),* Vol. 39 (1), Pp. 49-57,