Fatigue Analysis of Continuous Steel Concrete Composite Girders Strengthened With CFRP

Soorya M. Nair and Nithin Mohan

Abstract- Steel-concrete composite girders, when used over continuous spans, a loss of strength and composite action is experienced at the hogging moment region due to the development of tension in concrete and compression in steel. Limited works have been done to study address this weakness in the girders which are widely used in construction. Although Carbon fiber reinforced polymer (CFRP), is found to be capable of tackling this issue, most of the existing works studies the behavior of the girders under static loading condition. This paper presents an analytical investigation into the behavior of composite girders strengthened in hogging moment region using CFRP under fatigue loading conditions. Effect of various arrangements of CFRP laminates are also being compared for different geometries. CFRP was found effectively improve the strength of composite girders in the negative moment regions especially when provided as strips.

Keywords- Steel concrete composite, hogging moment region, CFRP strengthening, FEA, strip arrangement, full length arrangement, Fatigue loading

1 INTRODUCTION

Steel–concrete composite girders are popularly in used construction due to their small size, light weight, high bearing capacity, fast-track construction and better seismic, fire and corrosion resistance. In various uses, when they are provided along long spans a negative moment region is formed over the intermediate supports. At this region concrete develops tension and steel needs to carry compression against their basic properties. Composite action is not fully maintained at the region making it vulnerable.

CFRP is a relatively new material in the field has been established as a suitable material for retrofitting and rehabilitation of the deteriorating structures. Several researches have been conducted on strengthening the positive moment region of such composite girders with CFRP but only a few seems to address the weakness experienced by the negative moment region. And mostly the studies are based on the static loading condition. Sharif *et al.*(2015) carried out an experimental study by strengthening a 2 span continuous girder at negative moment using CFRP and found it to be effective in strengthening the negative moment region of the girders. Fa-Xing *et al*. (2018) experimentally investigated the seismic behaviour of simply supported steel–concrete composite I section and Box sections beams and proved that composite girders have favourable seismic performance.

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In view of the limited published work on the use of CFRP to strengthen composite girders at the negative moment zone and all of them considers the effect under static loading condition, this paper aims to present an analytical study of continuous composite girders with CFRP bonded to the top of the concrete slab in the negative moment region under fatigue loading. Effect of different arrangements of CFRP laminates are also being compared for different geometries.

2. FINITE ELEMENT ANALYSIS

Sharif *et al.* (2015) was chosen for validation. Continuous 2 span girders with each span having a length of 2500mm was modeled using ANSYS 16 software. Model of the girder and the corresponding deformation obtained are as shown in fig.1. and Fig.2.Results obtained from the model developed and the paper is compared and is represented in.Fig.3. 5% error was obtained during the validation

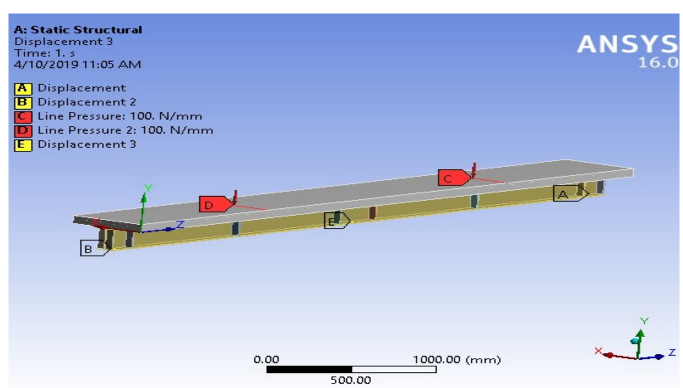


Fig.1. Loading arrangement in validated girder

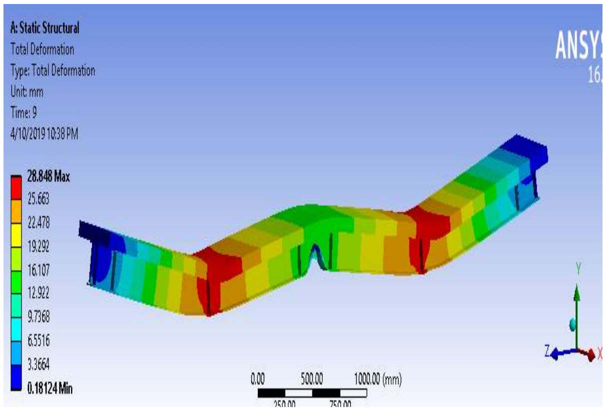


Fig.2. Deformation of the validated girder

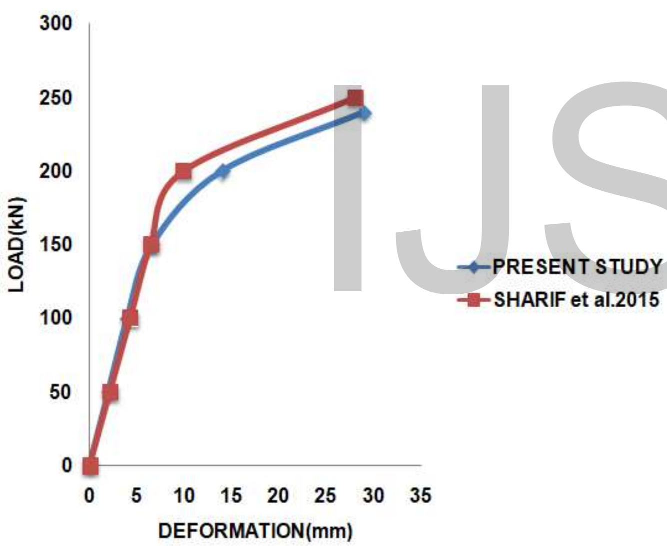


Fig.3. Comparison of results for girder validated

3. NUMERICAL STUDIES

3.1 Material Selection

The material property of CFRP given as input for the ANSYS model is given in Table 1. It was treated as an orthotropic material and thickness was kept as 2mm throughout the study

Table 1: Properties of CFRP used

Modulus of elasticity in x direction	Ex (kN/m^2)	230000
Modulus of elasticity in y direction	Ey (kN/m^2)	17900
Modulus of elasticity in z direction	Ez (kN/m^2)	17900
Poisson's ratio in x direction	υ_{xy}	0.22
Poisson's ratio in y direction	υ_y	0.3
Poisson's ratio in z direction	υ_z	0.22
Shear modulus in z direction	Gxy (kN/m^2)	11790
Shear modulus in z direction	Gyz (kN/m^2)	6880
Shear modulus in z direction	Gzx (kN/m^2)	11790

Table 2: Properties of concrete used

Young's modulus of concrete kN/m$_2$	25000
Poisson's ratio of concrete	0.2

Concrete having 25 Mpa compressive strength and properties as given in Table.1. was used. Bilinear relationship was used to define steel beams with yield strength 278MPa and rebars with 360MPa

3.2 Loading Condition

In analysis using the ANSYS workbench it is not possible to exactly determine the effects on the hogging moment region. The region was isolated to get better results. The specimens were studied in inverted condition as shown in Fig.4. in the rest of the study in order to replicate the loading condition. All specimens were subjected 3-point cyclic loading. The loading details are as given in Fig.5.

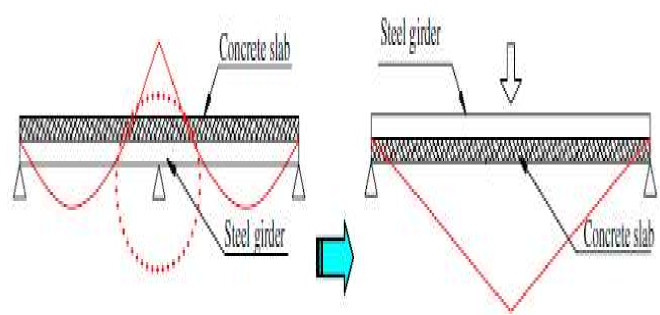


Fig.4.Loading arrangement used in tested specimen

Fig.5. Loading details

3.3 Modelling

ANSYS 16 Software was used to develop a non linear finite element model .The performance of plain and strengthened steel-concrete composite girders were studied. Element Solid 65 defined the properties of concrete. SOLID 186 was used for steel girder. LINK 180 was used for rebars and SHELL 181 was used to model the behaviour of CFRP laminates. A mesh size of 50mm was adopted. In the present study 2 random specimens SB-1 and SB-2 were included in the study. Each specimen has a span of 1250 mm. Schematic representations of the girders are as shown in Fig.6. To avoid failure at loading points load bearing stiffeners of 8mm thickness were provided

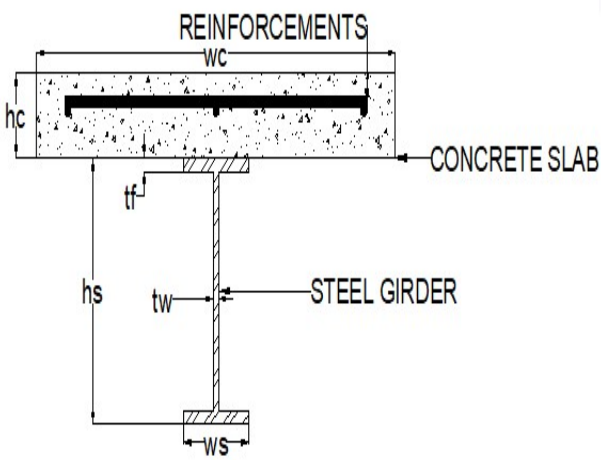


Fig.6.Typical cross section of the girder specimens

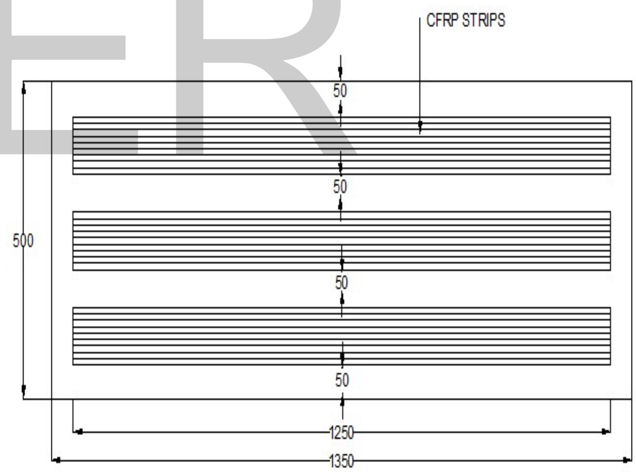
Table 3: Cross section details of the tested specimen (dimensions in mm)

Specimen	w_c	h_c	w_s	h_s	t_f	t_w
SB-1	350	65	90	200	11.3	7.5
SB-2	500	70	125	175	7.4	5.8

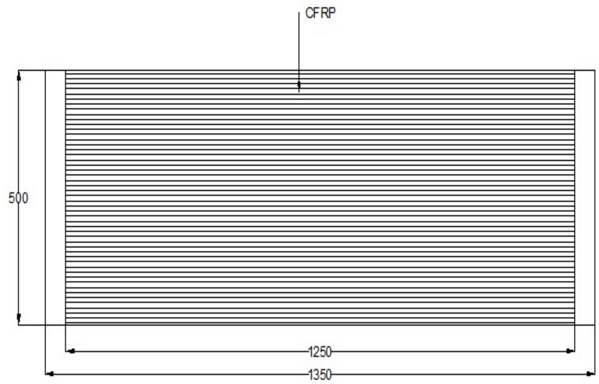
4. RESULT AND DISCUSSION

4.1 Effect of different arrangement of CFRP

Specimen SB-1, SB-2 were used in this study. 3 mm thick CFRP sheets were attached to the concrete slab in 2 different ways: (i) plates along the full width of the slab (FW) and (ii) As strips, which were provided at 50mm spacing. The no of strips were decided based on the width of the slab. For the first specimen 4 strips of 62.5mm width were provided and second one was strengthened using 6 strips each having width of 50mm.These arrangements have been schematically represented using Fig.7.And the specimens were subjected to cyclic loading.



(a)



(b)

Fig.7. Arrangement of CFRP: (a) strip form and (b) plate

Loading arrangement as shown in Fig.5. was provided. Load v/s displacement based hysteresis curve was generated for both the specimen. Skeleton obtained by connecting the ultimate loading points for each tension or compression load cycle, in the same direction on the hysteresis were also made to make the comparison of results easier

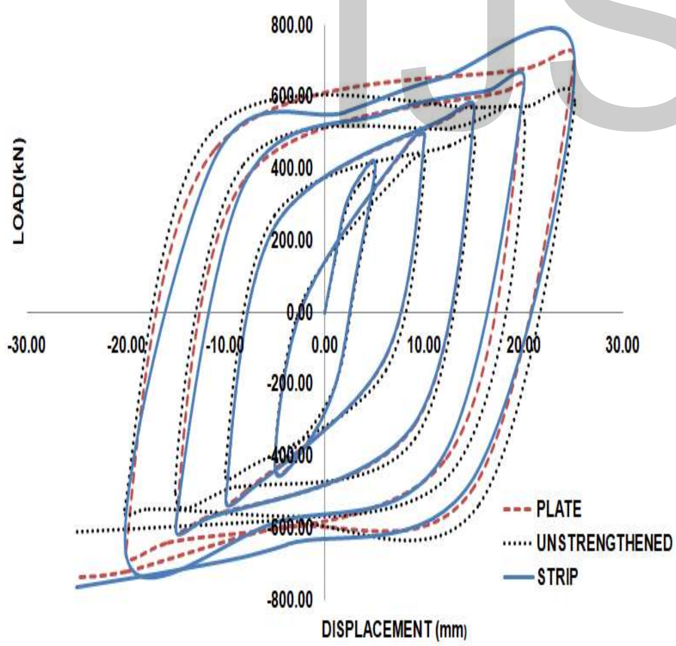


Fig.8. Comparison of hysteresis curve of SB-1 strengthened with CFRP

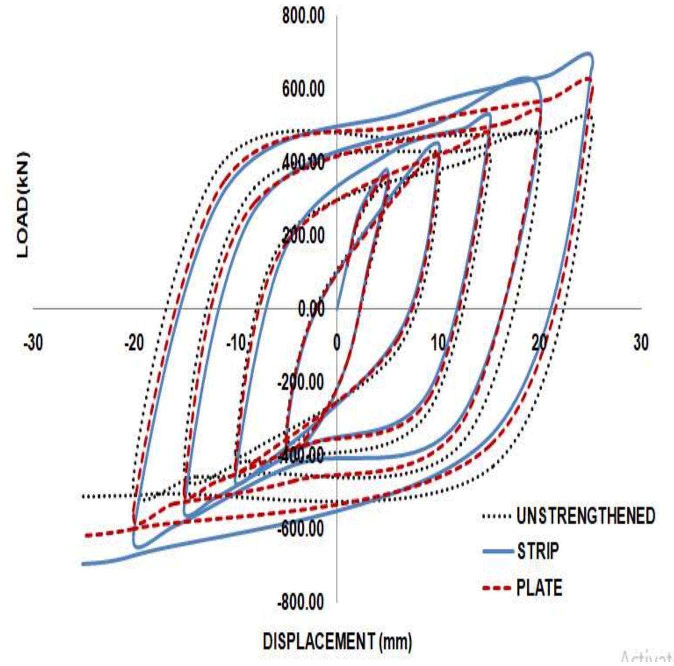


Fig.9. Comparison of hysteresis curve of SB-2 strengthened with CFRP

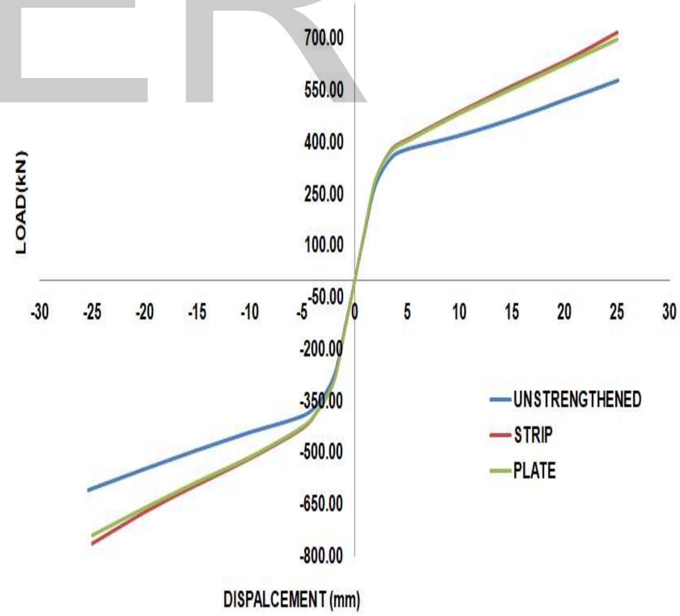


Fig.10. Comparison of skeleton curves of SB-1 strengthened with CFRP

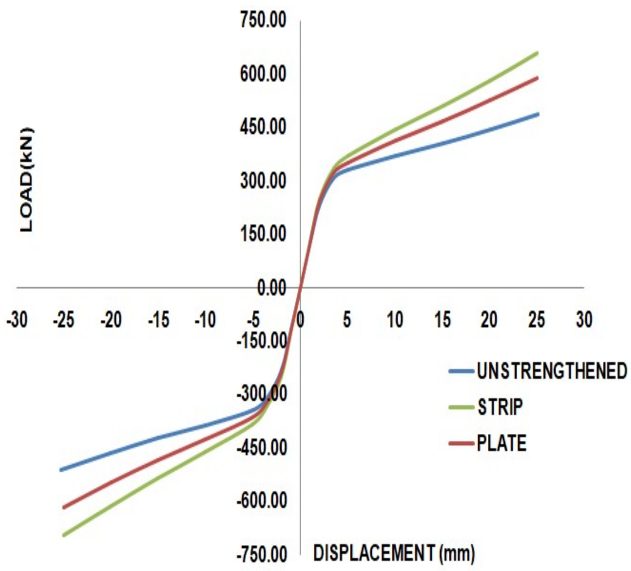


Fig.11. Comparison of skeleton curves of SB-2 strengthened with CFRP

Fig.8. and Fig.9. Shows the comparison of hysteresis curves of specimen SB-1and SB-2 for strengthened and un strengthened conditions. During cyclic loading, the hysteresis curves for the strengthened beams were bigger while compared to the un strengthened girders. From Fig.10. and Fig.11.,it could be inferred that the ultimate load is found to be more when strengthened with CFRP under fatigue loading. The results were found to be better when CFRP was provided as strips on the girder slab. Skeleton curves comparing the ultimate load under tension and compression cycles also supports the conclusions.

5. CONCLUSIONS

The following conclusions were derived from the study of steel concrete composite girder.

The ultimate load carrying capacity of steel concrete composite girders was found to improve with the use of CFRP composites. Hysteresis curve was plumper for strip arrangement than full length and hence the energy absorption too will be more for the same. Overall the steel - concrete composite girders were found to have favourable energy absorption properties under fatigue loading. Strengthening was found to improve the performance of the girders under fatigue loading especially when provide as strips rather than plates

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