Flexural Behaviour of Composite Beam-Column Connections

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Abstract: The present study includes an experimental investigations for the behavior of composite beam-column connections at static condition. The goals were to evaluate the effect of using cold-formed steel sections (CFS) which encasing in concrete as a replacement to steel bars of beam segment, while steel tube filled with concrete (CFST) used as column segment.. Results show an improve in cracking load, ultimate strength, and stiffness for composite specimens compared with specimen that using steel bars reinforcement under static condition.
Keywords: beam-column connection, cold-formed steel plate, thickness of CFS

1. Introduction

Beam-column connection define as the portion of column within the depth of beam that frame to column **(ACI-Code 352-02)** as shown in Figure 1. Beam-column connections are critical zone to transfer the loads effectively between the related elements at the structure **(Uma and Sudhir 2006)**. Sudden change in geometry and complexity in stresses distribution of joints are the main causes of its critical behavior. The connections have limited force carrying capacity, so; its subjected to greater forces through earthquake and blast, connections has harshly failure and that lead to disastrous collapse of the building. Repairing damaged of connections is so difficult, therefor the failure must be avoided. Thus, connection regions must have sufficient strength and the energy dissipation to resist every interior force resulting from frame members **(Rajaram et al. 2010).**

Figure1. showing sample of beam-column connection

2.Significance Of The Study

This project is an attempt to replacement the steel bar of concrete beam by cold-formed steel section (CFS), and using square steel tube filled with concrete for column segment **(Thejeel 2020)**. In general, composite constructions used the advantages of both concrete and steel. Concrete has low cost, high fire resistance, and with easy place. While, steel material has high ductility, strength and stiffness. Steel members commonly used in building technology due to its numerous advantages **(Abdulridha et al. 2018)**.

3.Review Of Related Studies

Since 1960s, many studies have been directed to consider and many parameters have been studied on beam-column connections. **Chen et al. (2009)** used steel cross-section configuration, which embedded in the beam-column connections to improve the shear strength and ductility. **Lu et al. (2012)** investigate using additional diagonal bars on beam-column intersection and found this addition show control of crack capacity and which improve the seismic performance. **Almry & Ali (2019)** tested beam-column connection under static and repeated load, and find that using hybridisation technique at different region of joint enhanced the behaviour of connection.

4.Objectives Of The Study

- Investigating the flexural behavior of composite beam-column connections under static load.
- Studying the effect of using CFS as reinforcement for beam segment and using steel tube as reinforcement for column segment.
- Provided bond between cold-formed steel tube and concrete.

5. Experimental Programme

5.1. Description of the Specimens

Three beam-column connection specimens were constructed. one of connections used steel bars to reinforced the reference connection. The other connections used cold-formed steel plate (CFS) encasing concrete for beam segment, while square steel tube filled with concrete (CFST) for column segment. CFS section used to reinforced concrete beam as equivalent replacement of steel bars. The dimensions and details of beam and column explained in table 1 and figure2 -4.

Table.1. showing the information of beam-column connections

Specimens	Beam reinforcement	column reinforcement	Thickness of CFS Section
N-N-S	Bars	Bars	-
CF1-ST-S	CFS	CFST	4mm
CF4-ST-S	CFS	CFST	3mm

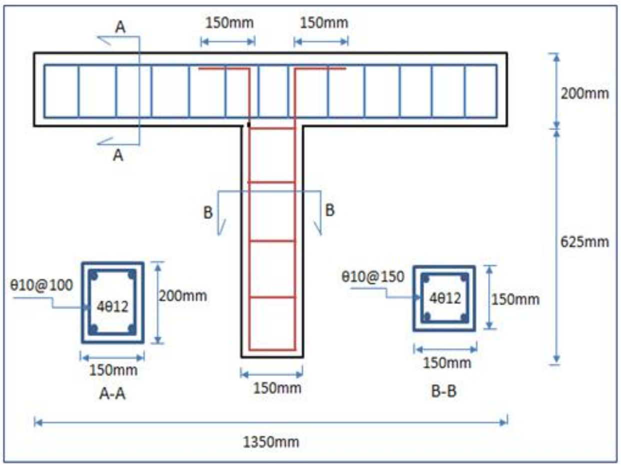

Figure 2. showing the details of test specimen N-N-S

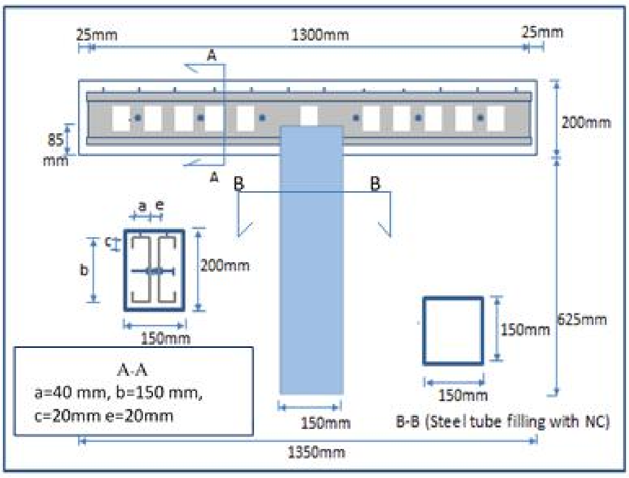

Figure 3. showing the details of test specimen CF-ST1-S and CF-ST4-S

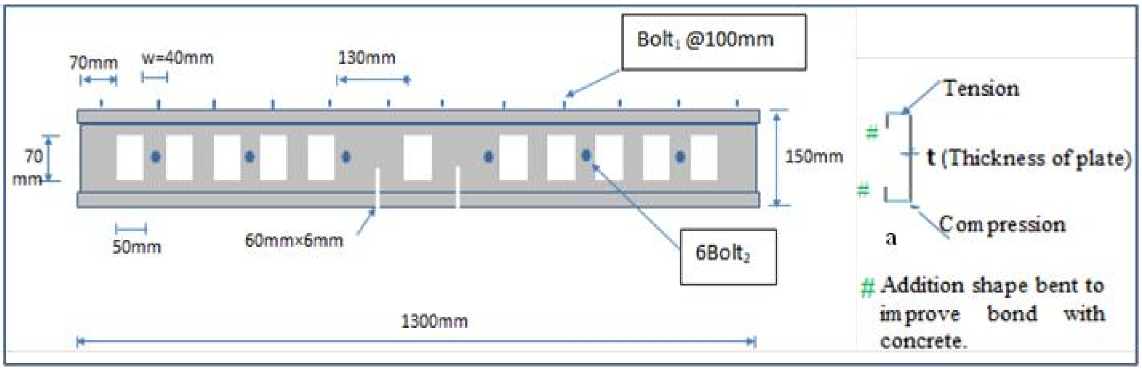

Figure 4. showing the details of CFS channel

5.2.Properties of Material

Concrete with about 32 MPa compressive strength was used to cast all the specimens. For the reference specimen, ø10 and ø12 steel bars are used, with yield strengths (fy) by about 545 and 502 MPa, respectively. CFS with 4 mm thicknesses (fy=330 MPa) and steel tube with dimension 150 x 150 x 4mm (fy=339 MPa) were used.

5.3. CFS channel dimensions

The equivalence between bar and required CFS was based on carry the same load as follows:
(Ab . fy) bar = (Ap . fyp) CFS plate
Ap = cross section area of CFS = width of CFS (a) × thickness of CFS (t)
Ab = area of bar = $\frac{\pi}{4} db^2$
The details of CFS sections was shown in Figure 5.

5.4. Steel Preparation and casting of connections

The CFS plate bended to the cross sections by using press break machine. Gaps (60mm*6mm) which required to attach CFS sections with CFST, and the opening in the shear zone, are provided using a computer numerical control machine. Two type of bolt using with CFS to provided bond between concrete and fixed sections to each other .
The casting of connection happened by following ways, for reference specimen the steel bars sited in the mold and casted by normal concrete (NC). While for the other connections, firstly, steel tubes filling with NC; then the CFS sections fitted on CFST at specific gaps then the contact areas were welded. The frame (CFST and CFS sections), for easy casting, was placed horizontally to casting beam by normal concrete as shown in Figure 5-6.

Figure 5. showing arrangement of CFS channels

Figure 6. showing the casting of specimens

5.6. Test procedure

The connection was supported on the fixed supported at end of column. Two point load utilized at the free ends of the connection by hydraulic compression machine as static loads. Linear variable differential transformers (LVDT) employ at the free ends of the beams to measure the vertical displacement, as shown in figure 7.

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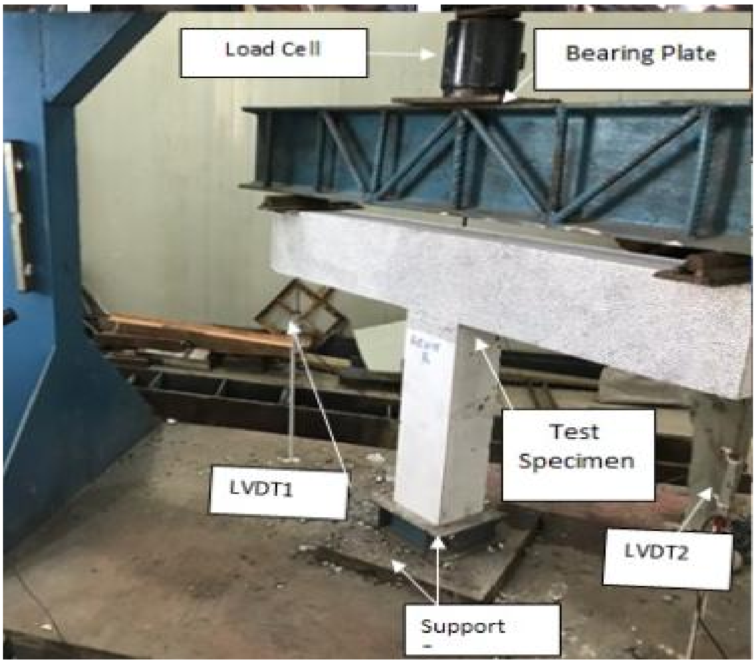

Figure 7. showing the Specimen under testing.

7.Data Analysis and Interpretation

Table.2. showing the Results of tested connections

Specimens	**Pcr kN**	$\frac{Pcr(i)-Pcr(r)}{Pcr(r)} \times 100\%$	**Pu (kN) ultimate load**	$\frac{Pu(i)-Pu(r)}{Pu(r)} \times 100\%$*
N-N-S	25	-	117	-
CF-ST1-S	40	60	179	52.9
CF-ST4-S	37	48	147	25.6

*r: Reference specimen, i: other specimens.

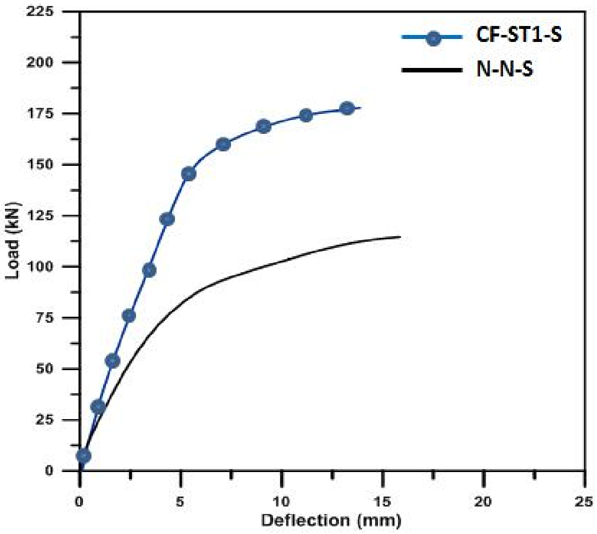

Figure 8. showing the load-deflection curve of specimens CF-ST1-S and N-N-S

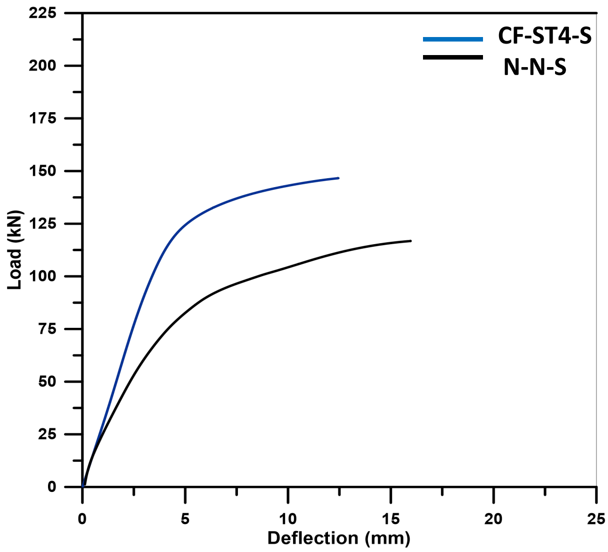

Figure 9. showing the load-deflection curve of specimens CF-ST4-S and N-N-S

Interpretation of table-2 and figure 8 and 9.

It is revealed from the above table that the experimental results including cracking loads (Pcr), ultimate load (Pu) and their growing percentage as compared with the reference connections. the specimens used cold-formed steel plates to reinforcement beam segment have an increase in the first cracking load reach to 80% and load capacity reach to 52.9% as a compare with reference specimen which using conventional steel bars. Where, the concrete strength which improved by the confinement effect which provided by CFS and CFST. In addition, the local buckling was prevented by the encasement of concrete.

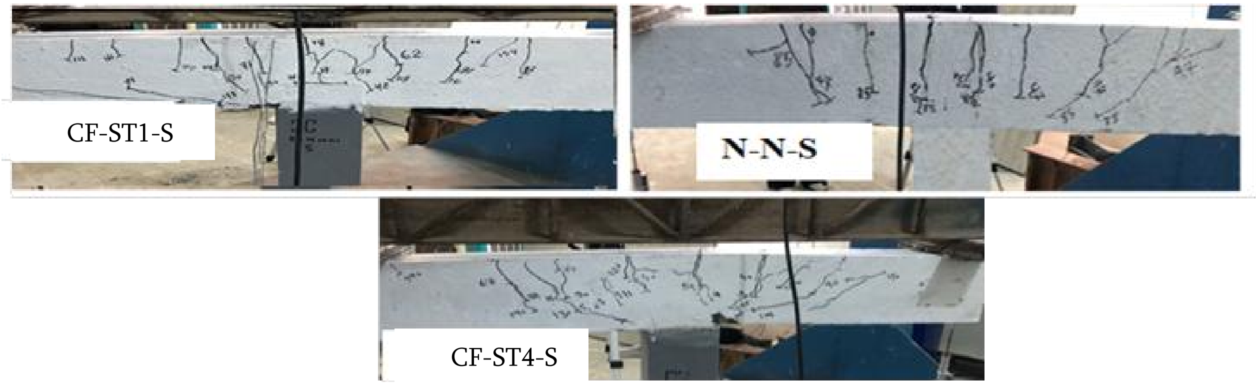

Figure 10. showing the cracking pattern of the tested specimens

Interpretation of figure -10.

The behavior of the composite connections using CFS and CFST to reinforcement concrete was similar to the behavior of reference specimens under static loading. Whereas, first flexural crack formed on the top of beam-column intersection. By increasing the load, additional flexural cracks appeared and its extended and widened until they reached the compressive zone of section where they move towards column face. The failure mode included basically by developed the cracks as the load increased to ultimate load.

8. Finite element FE

This research includes the analysis of beam-column connections tested by using powerful nonlinear finte element method package ABAQUS that provides a relatively acceptable numerical procedure for investigating the behavior of beam-column connections. The 8-node continuum (C3D8R) is obtainable in ABAQUS, is used for concrete, steel tube, bearing plate, and bolts as presented at Figure 11. This element has the capability to symbolize large deformation in addition to the nonlinearities of material and geometrical. 4-nodes doubly curved shell element with reduced integration (S4R) as adopted by. is suitable element to model the cold-form steel plate section. While 2-node linear 3-D truss element called (T3D2) presented in ABAQUS and used for the steel bars. The numerical load-deflection curves for the all beam-column connections compared with the experimental results showed shown in Figure 12-14.

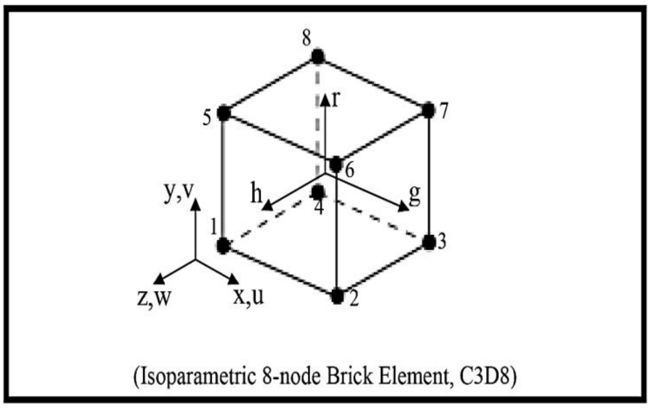

Figure 11. showing the (C3D8) in ABAQUS

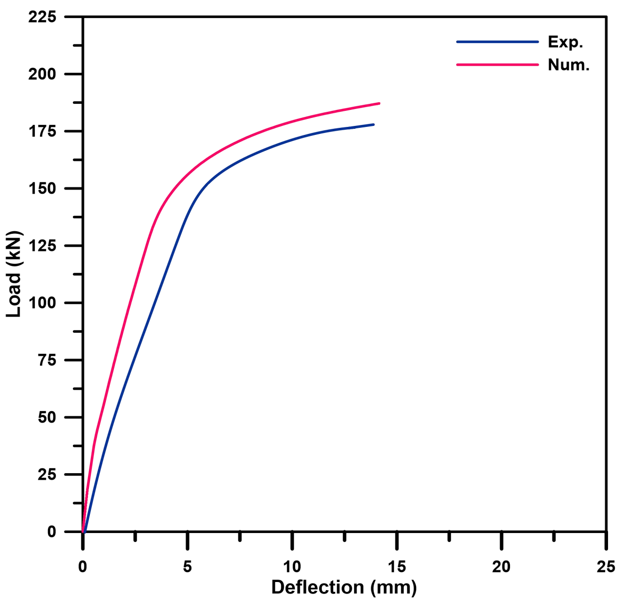

Figure 12. showing the load-deflection response by exp. and num. results of CF-ST1-S connection

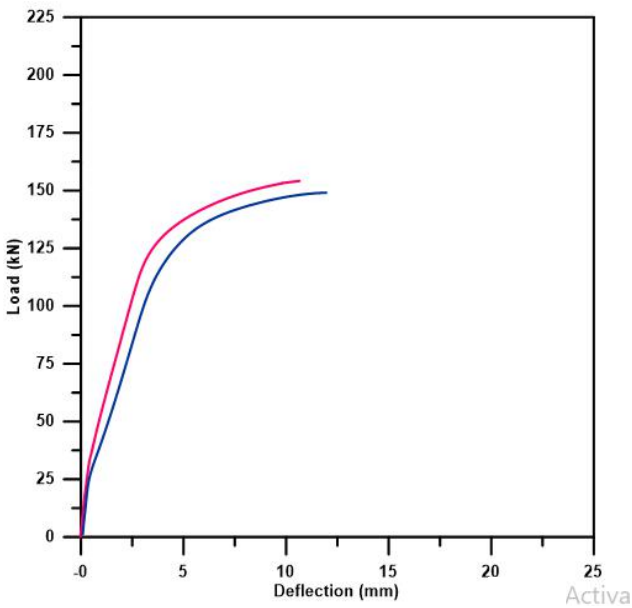

Figure 13. showing the load-deflection response by exp. and num. results of CF-ST4-S connection

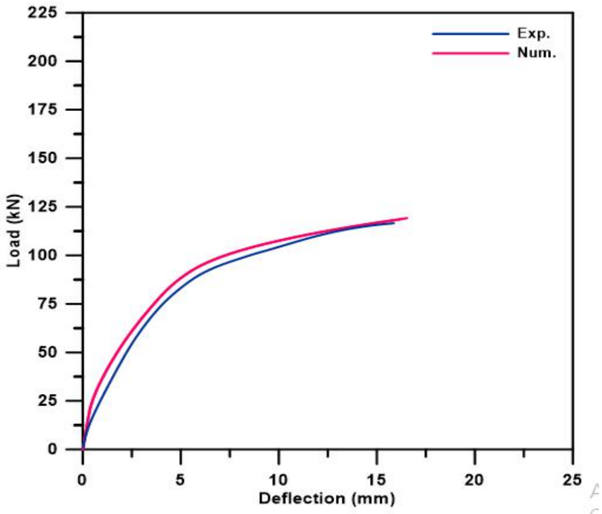

Figure 14. showing the load-deflection curve by experimental and numerical results of N-N-S connection

Interpretation of figure 12-14.

Accuracy of the adopted finite element models by using ABAQUS computer program are studied . The numerical load-deflection curves for the all beam-column connections compared with the experimental results showed that the FE results showed rather stiffer structure as shown in Figure 13-15

9.Conclusion

Using cold-formed steel plate and steel tube to reinforced beam-column connections are improved cracking and ultimate load. Where the local buckling of CFS prevented by encasement in concrete, at the same time, the concrete strength enhanced due to confinement effect. On the other hand, using CFS in beam segment of connection can improve the mechanism of crack.

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