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Performance of Hollow Sections with and Without Infill under Compression and Flexure

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Abstract:*Composite column are structural members, which are mainly subjected to forces and end moments. The steel tube serves as a formwork for casting the concrete, which reduces the construction cost. No other reinforcement is needed since the tube itself act as a longitudinal and lateral reinforcement for the concrete core. The Concrete filled steel tube member has many advantages compared with the conventional concrete structural member made of steel reinforcement. Concrete filled steel tubes are frequently used for columns, caissons, piers & deep foundations because of their large compressive stiffness. These composite sections have the rigidity and formability of reinforced concrete with the strength and speed of construction associated with structure, thereby making them economical. In the present study, an experiment is conducted on rectangular and square hollow structural steel with and without infill under compression and flexure. The infill material used in the hollow sections is conventional concrete and light weight concrete with chemical bond and mechanical bond. Compression and flexure tests are performed on the specimens and the behavior of the specimens are plotted. The behavior of hollow specimens with and without infill is observed from the experiment also effect of bonding between the concrete and steel is obtained. The results obtained from the experimental work are compared with numerical study by Finite Element Modeling using ANSYS.*

Keywords*:Concrete Filled Steel Tube Column, Compression, Flexure, Chemical Bonding, Mechanical Bonding, Araldite GY 257 IN, ARADUR 140, Angles*

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I. Introduction

A steel-concrete composite structural member contains both structural steel and concrete elements which work together..A concrete-filled steel tubular (CFST) column is formed by filling a steel tube with concrete. It is well known that concrete-filled steel tubular (CFST) columns are currently being increasingly used in the construction of buildings, due to their excellent static and earthquake-resistant properties, such as high strength, high ductility, large energy absorption capacity, bending stiffness, fire performance along with favorable construction ability etc. Recently, the behavior of the CFST columns has become of great interest to design engineers, infrastructure owners and researchers. Two types of composite columns, those with steel section encased in concrete and those with steel section in-filled with concrete are commonly used in buildings.

There exist applications in Japan and Europe where CFST are also used as bridge piers. Recently in Australia, Singapore, and other developed nations, concrete-filled steel columns have experienced a renaissance in their use. The major reasons for this renewed interest are the savings in construction time, which can be achieved with this method. Concrete filled steel tubular columns have been utilized in dwelling houses, tall buildings and many types of arch bridges. Steel hollow sections used as reinforcement in this composite structure. CFST columns have established an appropriate loading capacity, ductility and energy absorption capacity. The steel tube acts as the formwork for casting the concrete and hence, construction cost is reduced. There is no other reinforcement and the tube acts as longitudinal and lateral reinforcement for the concrete core. An evaluation of available experimental studies shows that the main parameters influencing the behaviour and strength of concrete filled steel tubular columns are slenderness, the diameter to wall thickness (D/t) ratio and the initial geometry of the column. The major benefits include:

- The steel column acts as permanent and integral formwork.
- The steel column provides external reinforcement.
- The steel column supports several levels of construction prior to concrete being pumped.

II. Experimental Investigation

The tests were performed in four series in each series consist of 12 specimens. First two series are for compression test consist of square and rectangular cross sections column. Other two series are for flexure test consist of square and rectangular cross sections beams. Square columns and beams having sizes 72 mm x 72 mm x 2.4 mm and having lengths 432 mm and 500 mm respectively. Rectangular columns and beams having sizes 95 mm X 50 mm x 2.4 mm having lengths are 300 mm and 500 mm respectively. Each Series consist of 12 specimens of which 3 specimens were cast for normal concrete with chemical bonding, 3 specimens were cast for normal concrete with mechanical bond, 3 specimens were cast for no-fines concrete with chemical bond, and last 3 specimens were cast without infill. The thicknesses of all hollow section used were 2.4 mm. Table 1 and table 2 shows the specimens used for compression and flexure tests.

Table 1. Specifications for composite column

Series No.	Concrete type	Bond type	c/s of column	Abbreviations used
Series I	Normal concrete	Chemical bond	Rectangular	NCR-C1
				NCR-C2
				NCR-C3
	Normal concrete	Mechanical bond	Rectangular	NMR-C1
				NMR-C2
				NMR-C3
	No-fines concrete	Chemical bond	Rectangular	NFCR-C1
				NFCR-C2
				NFCR-C3
	Hollow section		Rectangular	HR-C1
				HR-C2
				HR-C3
Series II	Normal concrete	Chemical bond	Square	NCS-C1
				NCS-C2
				NCS-C3
	Normal concrete	Mechanical bond	Square	NMS-C1
				NMS-C2
				NMS-C3
	No-fines concrete	Chemical bond	Square	NFCS-C1
				NFCS-C2
				NFCS-C3
	Hollow section		Square	HS-C1
				HS-C2
				HS-C3

Table 1. Specifications for composite column

Series No.	Concrete type	Bond type	c/s of beam	Abbreviations used
Series III	Normal concrete	Chemical bond	Rectangular	NCR-F1
				NCR-F2
				NCR-F3
	Normal concrete	Mechanical bond	Rectangular	NMR-F1
				NMR-F2
				NMR-F3
	No-fines concrete	Chemical bond	Rectangular	NFCR-F1
				NFCR-F2
				NFCR-F3
	Hollow section		Rectangular	HR-F1
				HR-F2
				HR-F3
Series IV	Normal concrete	Chemical bond	Square	NCS-F1
				NCS-F2
				NCS-F3
	Normal concrete	Mechanical bond	Square	NMS-F1
				NMS-F2
				NMS-F3
	No-fines concrete	Chemical bond	Square	NFCS-F1
				NFCS-F2
				NFCS-F3
	Hollow section		Square	HS-F1
				HS-F2
				HS-F3

Table 2. Specifications for composite beam

III. Results and Discussion

3.1 Observation on Compression Test

The observations made during the experimental work are as follows.

1. Failure of square composite column with normal concrete and chemical bond under compression. The failure is as shown in the fig.1

The heights of these types of columns used in the experiment were 432 mm. majority of the column failed due to buckling of the column near to middle portion. Especially in the normal concrete mostly failure took place at the middle of the column.

Fig.1 Failure of NCS-C

2. Failure of square composite column with normal concrete and mechanical bond under compression. The failure is as shown in the fig.2

Majority of these columns failed due to buckling of the column either at the top or at the bottom was observed. Especially in the normal concrete mechanical bonding failure took place at the top as well as at bottom of column.

Fig.2 Failure of NMS-C

3. Failure of square composite column with no-fines concrete and chemical bond under compression. The failure is as shown in the fig.3

The heights of these types of columns used in the experiment were 432 mm. Initially the failure of concrete took place in no-fines concrete infill later composite action took place. In composite column yielding of steel is observed at the middle portion.

Fig.3 Failure of NFCS-C

4. Failure of square hollow column under compression.

Majority of these columns failed due to buckling of the column either at the top or at the bottom was observed. Especially in the hollow square column buckling failure took place at the bottom of the column. The failure is as shown in the fig.4

Fig.4 Failure of HS-C

5. Failure of rectangular composite column with normal
concrete and chemical bond under compression. The failure is as shown in the fig. 5
The heights of these types of columns used in the experiment were 300 mm. majority of the column failed due to buckling of the column either at the top or at the bottom. Especially in the normal concrete mostly failure took place at the top of the column due to buckling.

Fig.5 Failure of NCR-C

6. Failure of rectangular composite column with normal concrete and mechanical bond under compression. The failure is as shown in the fig.6
The heights of these types of columns used in the experiment were 300 mm. majority of the column failed due to buckling of the column either at the top or at the bottom. Especially in the normal concrete mostly failure took place at the top of the column.

Fig.6 Failure of NMR-C

7. Failure of rectangular composite column with no-fines concrete and chemical bond under compression. The failure is as shown in the fig.7

The height of the column used in the experiment was 300 mm. Initially the failure of concrete took place in no-fines concrete infill later composite action took place. In composite column yielding of steel is observed at the middle portion.

Fig.7 Failure of NFCR-C

8. Failure of rectangular hollow column under compression.

Majority of these columns failed due to buckling of the column either at the top or at the bottom was observed. Especially in the hollow rectangular column failure took place at the bottom of the column. The failure is as shown in the fig.8

Fig.8 Failure of HR-C

3.2 Observation on Flexure Test

The flexure test is performed in the universal testing machine by applying concentrated load at the center of the specimen. The span of the composite specimen used for flexure test is 400 mm. the specimens were observed to fail at 110 kN. The crack pattern of the specimen occurred at the bottom of specimen. The observed failure pattern is as shown in the figure below.

Fig.9 Failure of the composite beam section

3.3 Load v/s Deflection Relationship between all types of square columns for compression test

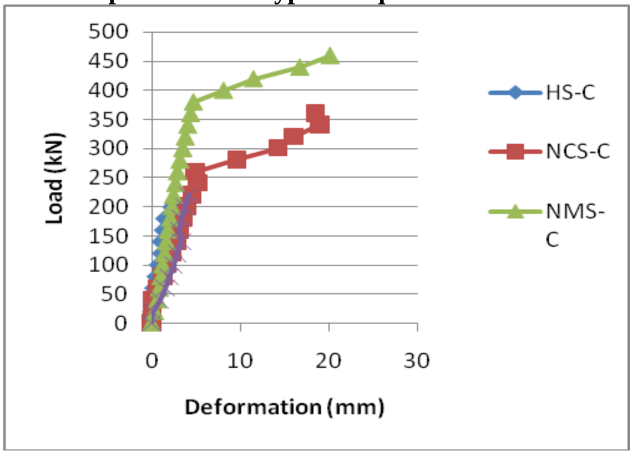

Fig.10 Load v/s deflection relationship for HS-C, NCS-C, NMS-C, NFCS-C

Table 3. Summary of compression test results

Infill type	Bonding type	Column Specifications		Ultimate Load (kN)	max .deformation (mm)
Hollow		Square	HSC1	182.05	2.32
			HSC2		
			HSC3		
		Rectangular	HRC1	129.58	2.06
			HRC2		
			HRC3		
Normal concrete	Chemical Bond	Square	NCSC1	358.61	20.84
			NCSC2		
			NCSC3		
		Rectangular	NCRC1	259.76	15.46
			NCRC2		
			NCRC3		
Normal concrete	Mechanical Bond	Square	NMSC1	456.78	19.91
			NMSC2		
			NMSC3		
		Rectangular	NMRC1	325.44	14.68
			NMRC2		
			NMRC3		

No-fines concrete	Chemical Bond	Square	NFCSC1	204.4	5.42
			NFCSC2		
			NFCSC3		
		Rectangular	NFCRC1	171.55	5.18
			NFCRC2		
			NFCRC3		

3.4 Load v/s lection
Relationship between all types of rectangular columns for compression test

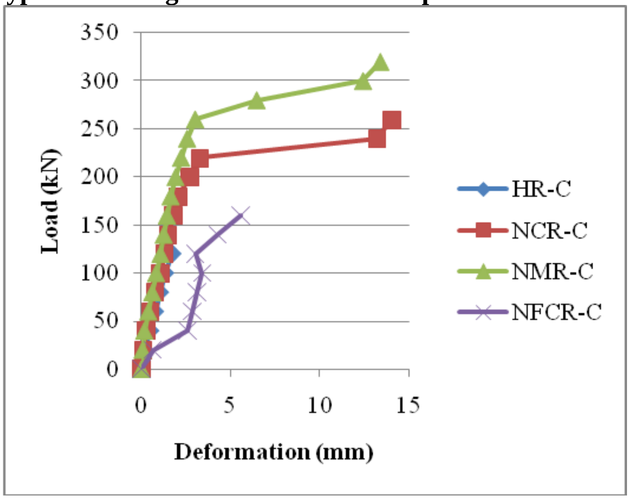

Fig.11 Load v/s deflection relationship for HR-C, NCR-C, NMR-C, NFCRC

3.5 Load v/s Deflection Relationship between all types of square beams for flexure test

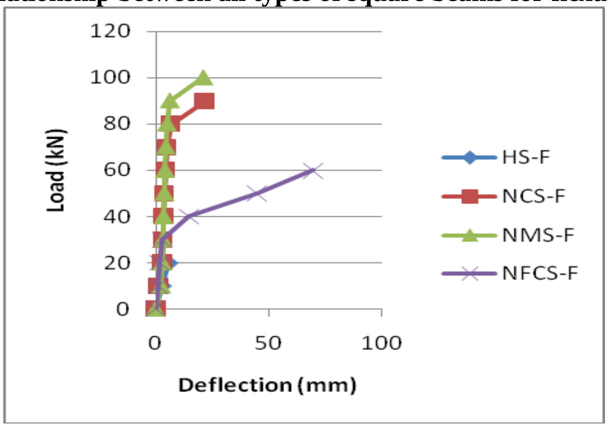

Fig.12 Load v/s deflection relationship for HS-F, NCS-F, NMS-F, NFCS-F

3.6 Load v/s Deflection Relationship between all types of rectangular beams for flexure test

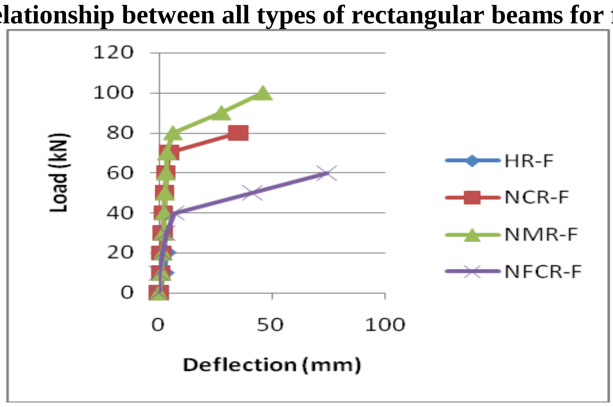

Fig.13 Load v/s deflection relationship for HR-F, NCR-F, NMR-F, NFCR-F

Table 3. Summary of compression test results

Table 4. Summary of flexure test results

Infill type	Bonding type	Beam Specifications		Ultimate Load (kN)	Max. Deflection (mm)
Hollow		Square	HSF1	25.23	12.24
			HSF2		
			HSF3		
		Rectangular	HRF1	21.90	3.44
			HRF2		
			HRF3		
Normal concrete	Chemical Bond	Square	NCSF1	88.7	33.40
			NCSF2		
			NCSF3		
		Rectangular	NCRF1	84.46	44.13
			NCRF2		
			NCRF3		
Normal concrete	Mechanical Bond	Square	NMSF1	103.71	31.40
			NMSF2		
			NMSF3		
		Rectangular	NMRF1	106.18	58.52
			NMRF2		
			NMRF3		
No-fines concrete	Chemical Bond	Square	NFCSF1	58.11	66.82
			NFCSF2		
			NFCSF3		
		Rectangular	NFCRF1	59.71	70.19
			NFCRF2		
			NFCRF3		

IV. Numerical Analysis

The nonlinear analysis of composite sections is done by using ansys workbench release 16.2.

Element type

In this step selection of materials has been done i.e. concrete and structural steel.

4.1 Concrete (Solid 65)

SOLID65 is used for the three-dimensional modeling of solids with or without reinforcing bars (rebar's). The solid is capable of cracking in tension and crushing in compression. In concrete applications, for example, the solid capability of the element may be used to model the concrete while the rebar capability is available for modeling reinforcement behavior. Other cases for which the element is also applicable would be reinforced composites (such as fiberglass), and geological materials (such as rock). The element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. Up to three different rebar specifications may be defined.

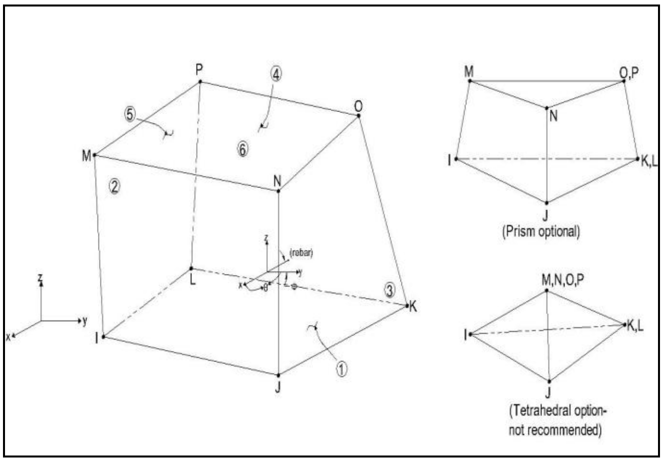

Fig.14 Solid 65 element

4.2 Steel (Link 8)

A link 8 element is used to model steel reinforcement. This element is a 3-D spar element and it has two nodes with three degrees of freedom translations in the nodal x, y and z directions. This element is capable of plastic deformation and element is shown in figure below,

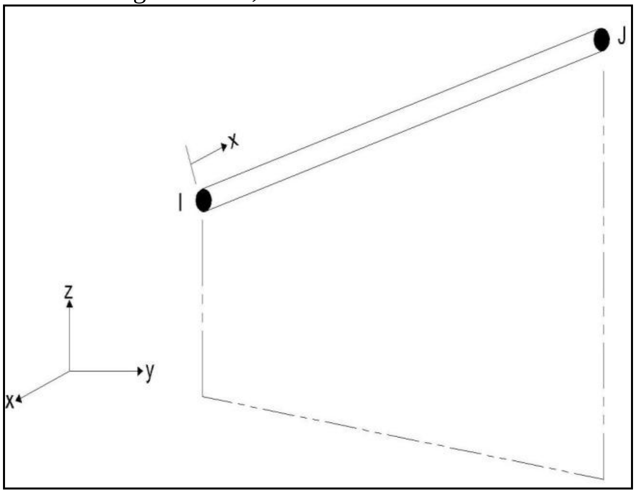

Fig.15 Link 8 element

Table 5. Compressiontest results for NCS-C

Column name	Experimental		Numerical	
	Load (kN)	Deformation (mm)	Load (kN)	Deformation (mm)
Normal chemical square	0	0	0	0
	40	0.16	40	0.1520
	80	0.57	80	0.5446
	120	1.03	120	0.9683
	160	1.49	160	1.406
	200	1.97	200	1.8429
	240	2.89	240	2.7015
	280	5.93	280	5.5564
	320	17.2	320	15.621
	340	19.15	340	17.183

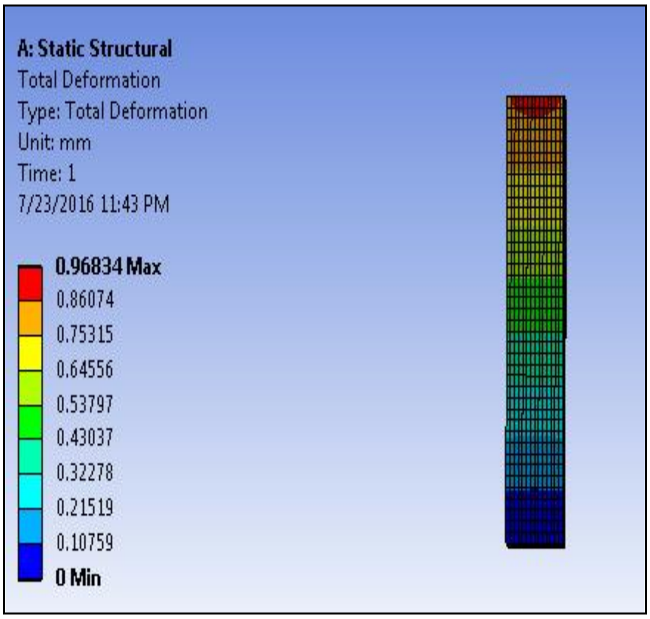

Fig.16 Deformation of NCS-C

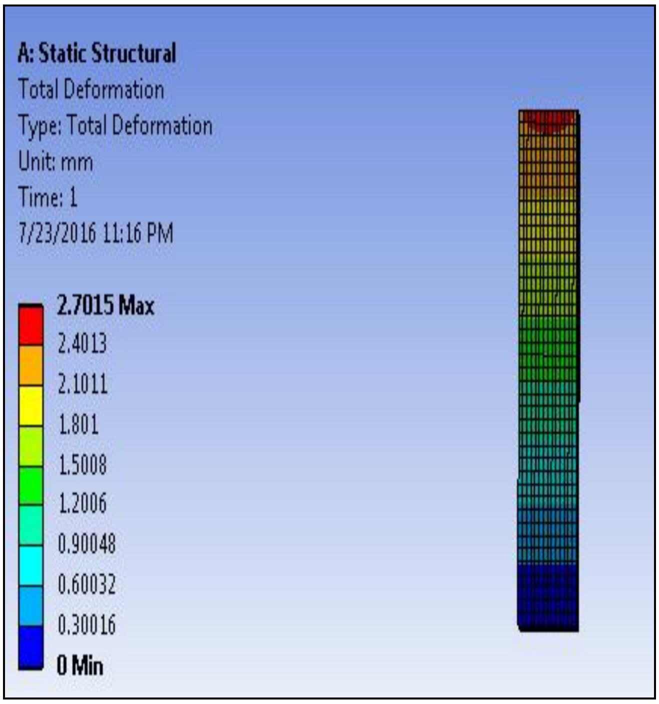

Fig.17 Deformation of NCS-C

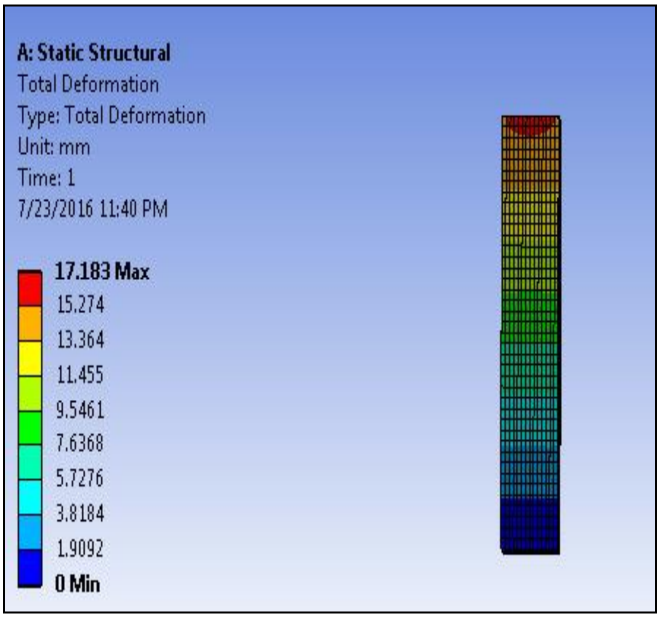

Fig.18 Deformation of NCS-C

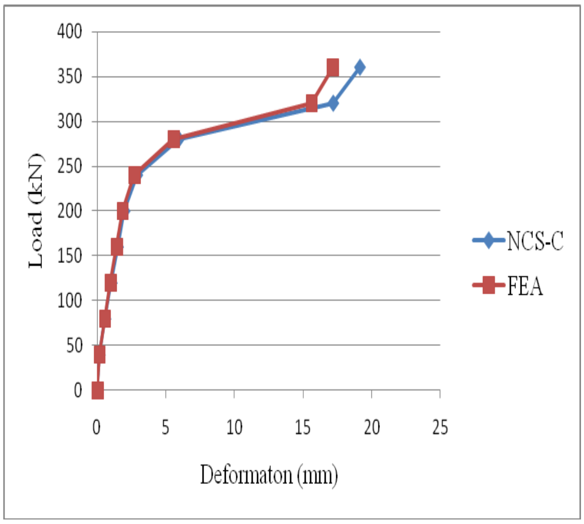

Fig.19 Comparison of experimental and FEA results of NCS-C under compression

Table 6. Flexural test results for NCR-F

Column Name	Experimental		Numerical	
	Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)
Normal chemical rectangular	0	0	0	0
	10	0.09	10	0.08858
	20	0.20	20	0.1890
	30	0.53	30	0.4977
	40	1.01	40	0.9863
	50	1.30	50	1.2679
	60	1.96	60	1.8323
	70	3.80	70	3.4098

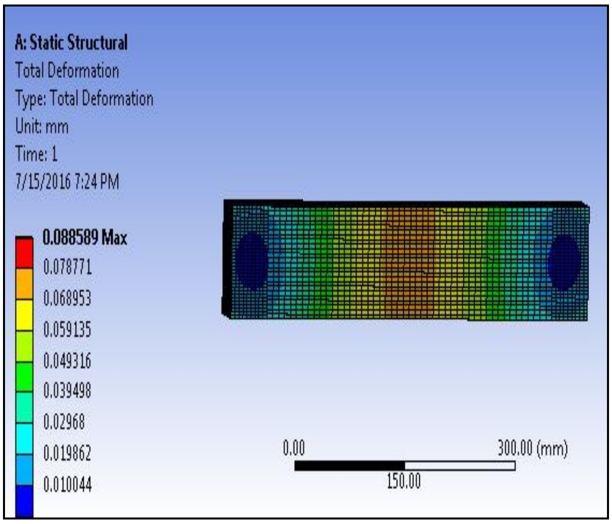

Fig.20 Deflection of NCR-F

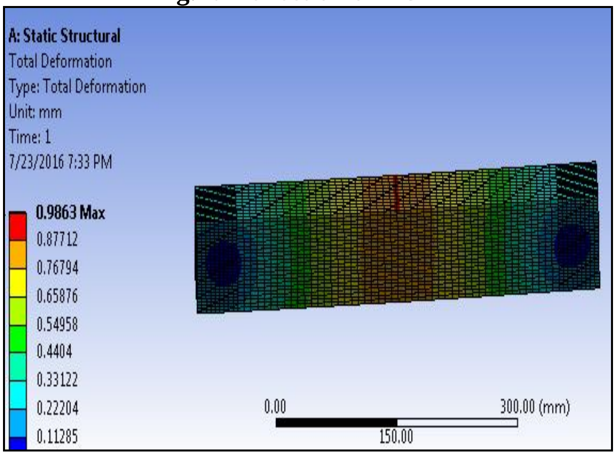

Fig.21 Deflection of NCR-F

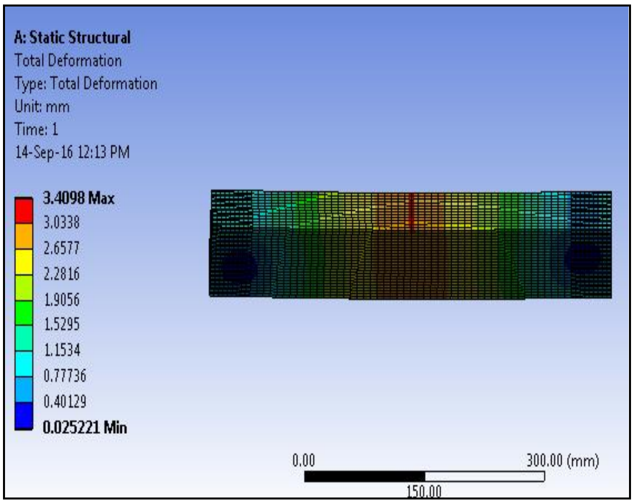

Fig.22 Deflection of NCR-F

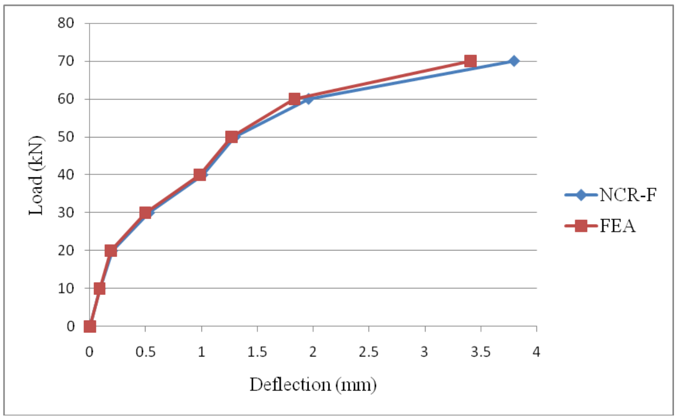

Fig.23 Comparison of experimental and FEA results of NCR-F under flexure

V. Conclusions

From experimental investigation of hollow as well as composite columns and beams following conclusions are derived,

1. The strength of the hollow section with infillednormal concrete is observed to be greater than the hollow section without infilled concrete and other forms of composite section in compression as well as in flexure.

The percentage increase in the compressive strength of the square composite section as compare to hollow section is as shown below,

- Composite columns with chemical bonding - 45 to 50%.
- composite columns with mechanical bonding - 60 to 65%
- Composite columns with No-fines concrete - 10 to 20%

The percentage increases in the flexural strength of rectangular composite section as compare to hollow section isas shown below,

- Composite section with chemical bonding -70 to75%
- Composite section with mechanical bonding –70 to 80%
- Composite columns with No-fines concrete – 55 to 65%

2. The compressive strength of square normal concrete composite section with mechanical bonding is maximum as compared to the other types of square and rectangular hollow sections, square and rectangular composite sections such as chemical bond with No-fines concrete and chemical bond with normal concrete

3. The flexural strength of rectangular normal concrete composite section with mechanical bonding is maximum as compared to the other types of square and rectangular hollowsections, square and rectangular composite sections such as chemical bond with No-fines concrete, chemical bond with normal concrete.

4. The experimental results of NCS-C and NCR-F are compared with the numerical analysis results of same composite sections. In comparison with the experimental results the numerical study shows similar variation.

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