INVESTIGATION ON FLEXURAL BEHAVIOUR OF GGBS CONCRETE INFILLED STEEL TUBULAR SECTIONS

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Abstract--- *This paper reports an investigation on flexural behaviour of GGBS concrete infilled steel tubular sections. A series of tests on concrete filled square beams and hollow tube were carried out. The experimental results showed that the load carrying capacity of concrete filled steel tubes (CFST) were much higher than that of hollow tubes. The deflection was higher for concrete filled steel tubular beam. The strain was less in concrete filled*steel *tube. Analytical study was carried out for all types of specimen using ANSYS software. FEA results agrees well with experimental results.*

Keywords: *Concrete filled steel tubes (CFST), Hollow sections, Normal mix concrete, GGBS concrete, Finite element analysis (FEA).*

1. INTRODUCTION

Concrete filled steel tubular (CFST) members utilize the advantages of both steel and concrete. They comprise of a steel hollow section of circular or rectangular shape filled with plain or reinforced concrete. They are widely used in high-rise and multistory buildings as columns and beam-columns, and as beams in low-rise industrial buildings where a robust and efficient structural system is required. The inherent buckling problem related to thin-walled steel tubes is either prevented or delayed due to the presence of the concrete core. Furthermore, the performance of the concrete in-fill is improved due to confinement effect exerted by the steel shell. The distribution of materials in the cross section also makes the system very efficient in term of its structural performance. The steel lies at the outer perimeter where it performs most effectively in tension and bending. It also provides the greatest stiffness as the material lies furthest from the centroid.

Ground granulated blast furnace slag (GGBS) is a by-product of iron manufacturing industry. Iron ore, coke and limestone are fed intothe furnace, and the resulting molten slag floats above the molten iron at a temperature of about 1500°C to 1600°C.The molten slag has a composition of 30% to 40% silicon dioxide (SiO_2) and approximately 40% CaO, which is close to the chemical composition of Portland cement. After the molten iron is tapped off, the remaining molten slag, which mainly consists of siliceous and aluminous residues is then rapidly water-quenched, resulting in the formation of a glassy granulate. This glassy granulate is dried and ground to the required size which is known as ground granulated blast furnace slag (GGBS).

2. OBJECTIVE OF THE STUDY

(a) To study the flexural behaviour of concrete filled steel tubes.
(b) To perform FEA on concrete filled steel tubes.

3. SCOPE OF THE STUDY

(a) To compare the flexural strength of steel hollow sections and concrete filled steel sections by conducting two point bending test.
(b) To find optimum replacement level of cement with GGBS in concrete.
(c) To find the variation in flexural strength of steel sections filled with conventional concrete and concrete with GGBS.
(d) To perform FEA and validating the test results.

4. EXPERIMENTAL INVESTIGATION

A total of 5 concrete filled steel tubular beam and hollow tubular beam specimens were tested. The width and breadth of the steel tubes were 100 mm and 100 mm respectively. The thickness of the steel tubes were 2 mm. All the specimens were 1500 mm in length.

Hot rolled steel tubular sections were used. The mix proportions of M_{20} grade of concrete were as follows: Cement: 437.77 kg/m^3; Water: 197 kg/m^3; Sand: 619.55 kg/m^3; and Coarse Aggregate: 1054.92 kg/m^3. The mix proportions of M_{40} grade of concrete were as follows: Cement: 415.57 kg/m^3; Water: 140 kg/m^3; Sand: 652.61 kg/m^3; and Coarse Aggregate: 1062.86 kg/m^3. M_{20} and

M_{40} grades of concrete were filled in hollow tubes which were designed earlier.

The concrete was filled in layers and was vibrated by a vibrator. The specimens were placed in curing for 28 days from casting. For each batch of concrete mix, six cubes were also casted and cured in conditions similar to the related specimens. The average cube strength of each specimen at the time of tests was listed in Table 1 and Table 4.

Fig. 1. Arrangement of beam test.

Two strain gauges were used for each specimen to measure strains at the mid-span. One strain gauge was fixed at top and another strain gauge was fixed at bottom of each specimen. Dial gauge was used to find the deflection at mid span as well as at the loading point of the specimen. At each load increment, the strain readings and the deflection measurements were recorded. All the specimens were loaded up to the failure. The load vs deflection graphs were shown in Chart-1, 2, 3, 4 and 5.

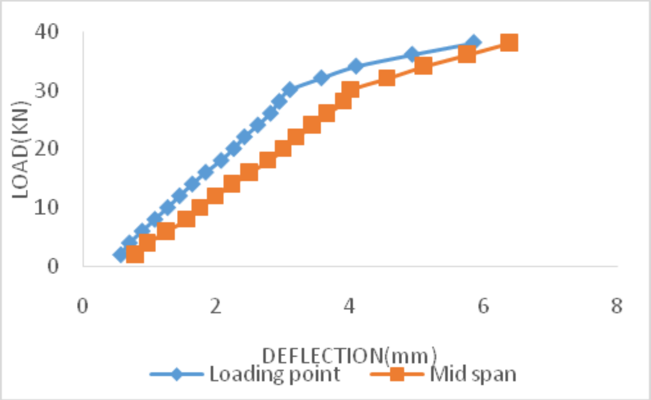


Chart-1: Load vs. Deflection graph of Hollow tube.

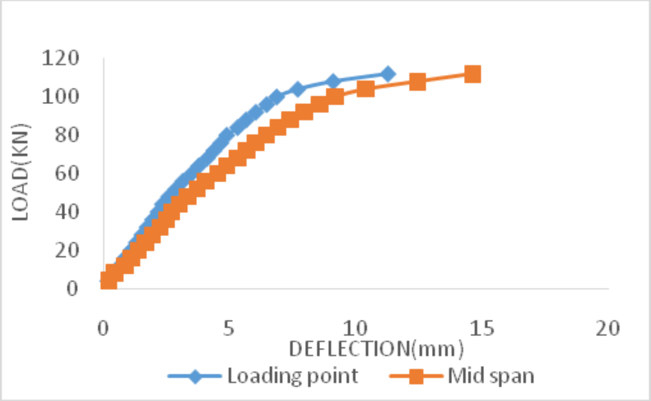


Chart-2: Load vs. Deflection graph of CFST beam infilled with conventional concrete (M_{20} grade).

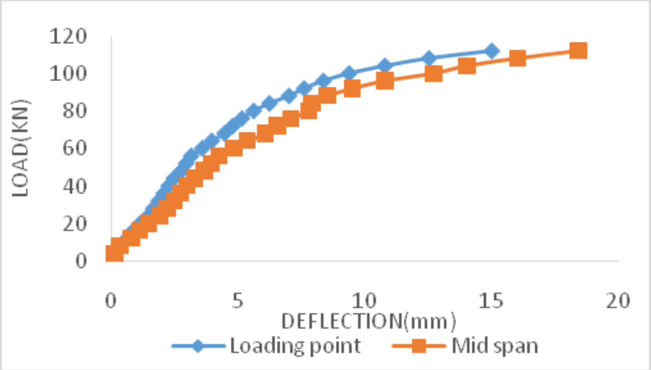


Chart-3: Load vs. Deflection graph of CFST beam infilled with GGBS concrete (M_{20} grade).

Table: 1. Compression cube strength results of M_{20} grade of concrete.

SL. NO.	TYPE OF CONCRETE	DAYS	COMPRESSIVE STRENGTH (N/mm²)
1	Conventional concrete	7	17.67
		14	19.45
		28	28.21
2	50% replacement of GGBS with cement	7	16.17
		14	20.21
		28	27.32

The cubes made up of conventional concrete (M_{20} grade) got higher compressive strength than that of cubes made up of GGBS concrete (M_{20} grade), because GGBS concrete will get strength gradually over a long period as shown in Table: 1.

Table: 2. Deflection values of beam specimens (M$_{20}$ grade of concrete).

SPECIMEN	LOAD (KN)	DEFLECTION (mm)	
		@ loading point	@ centre point
Hollow tube	38	5.84	6.38
CFST with conventional concrete	112	11.28	14.62
CFST with 50% replacement of GGBS with cement	112	14.97	18.4

In the above Table, it can be observed that the deflections were not same even though the ultimate load were same for CFST beams infilled with conventional as well as GGBS concrete.

Table: 3. Strain values of beam specimens (M$_{20}$ grade of concrete).

SPECIMEN	LOAD (KN)	STRAIN (*10^{-3})	
		TOP	BOTTOM
Hollow tube	38	6	5
CFST with conventional concrete	112	2	2
CFST with 50% replacement of GGBS with cement	112	3	2

The compressive strain as well as tensile strain were higher for hollow tube as compared to CFST beam infilled with normal mix concrete and GGBS concrete.

Table: 4. Compression cube strength results of M$_{40}$ grade of concrete.

SL. NO.	TYPE OF CONCRETE	DAYS	COMPRESSIVE STRENGTH (N/mm^2)
1	Conventional concrete	7	27.21
		14	33.42
		28	41.65
2	50% replacement of GGBS with cement	7	24.32
		14	30.24
		28	39.45

In the above Table, the cubes made up of 50% replacement of GGBS with cement in concrete got lesser compressive strength as compared to the cubes made up of conventional concrete. Partially replacement of GGBS with cement in concrete will take time to gain strength.

Table: 5. Deflection values of beam specimens (M$_{40}$ grade of concrete).

SPECIMEN	LOAD (KN)	DEFLECTION (mm)	
		@ loading point	@ centre point
CFST with conventional concrete	128	33.98	35.88
CFST with 50% replacement of GGBS with cement	140	41.45	48.26

The ultimate load and deflection were higher for CFST beam infilled with GGBS concrete. It was observed that the load bearing capacity of concrete filled steel tubular beam infilled with GGBS concrete (M$_{40}$ grade) have 48% higher strength than that of CFST beam infilled with normal mix concrete.

Table: 6. Strain values of beam specimens (M$_{40}$ grade of concrete).

SPECIMEN	LOAD (KN)	STRAIN (*10^{-3})	
		TOP	BOTTOM
CFST with conventional concrete(M$_{40}$ grade)	128	2	0
CFST with 50% replacement of GGBS with cement	140	4	2

Table: 6 showed that the compressive strain as well as tensile strain were higher for CFST beam infilled with GGBS concrete. Strain values were higher for hollow tube than that of concrete filled steel tubular beam infilled with conventional as well as GGBS concrete (M$_{40}$ grade).

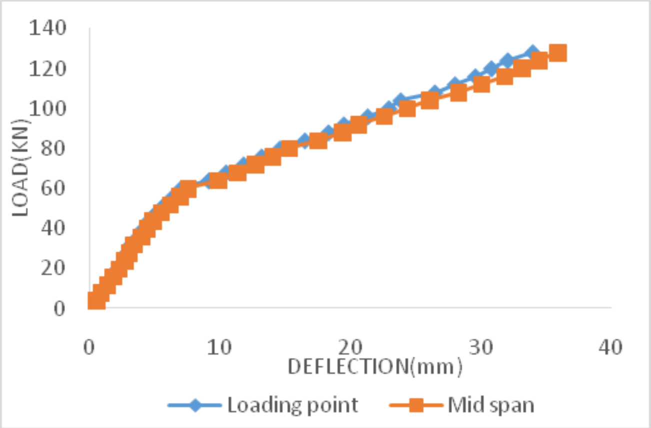


Chart-4: Load vs. Deflection graph of CFST beam infilled with conventional concrete (M_{40} grade).

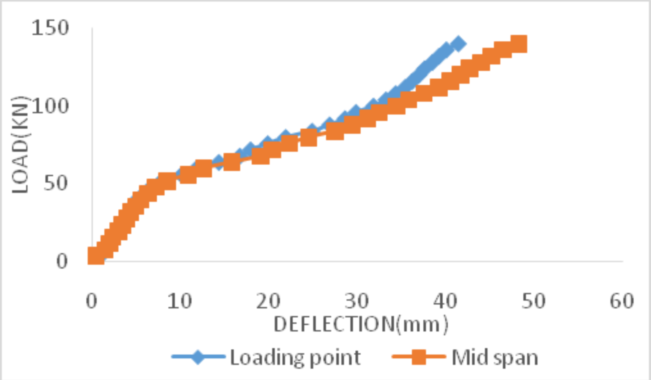


Chart-5: Load vs. Deflection graph of CFST beam infilled with GGBS concrete (M_{40} grade).

5. FINITE ELEMENT ANALISIS

The FE method has been extensively used to study the structural behaviourof steel-concrete composite section. However, to model the contact interactionbetween the outer surface of the concrete core and the inner surface of the steeltube, surface-to-surface contact technique method was used. The validity ofsuch FE model was justified by comparing the numerical results with theexperimental results. The modeling technique was then used to study othertypes of CFST beams. The pre- and post-processing work was performed by using ANSYS which is a graphical user interface module that allows the user to execute a FE analysis process from start to finish. The FE model can be viewed and checked interactively and the results (stress, strain, displacements, etc.) can be visualized graphically.

5.1 Finite element material model

5.1.1 Steel tube and Concrete core

In the present analysis, average stress strain curve obtained from material tests were used to model both steel and concrete core, assuming isotropy of the material. The behaviour of the steel tube is simulated by an elastic perfectly plastic model. The material properties were as follows: the mild steel have possessed yield strength (fy) of 410Mpa, Elastic modulus (E) of 200Gpa, Poisson's ratio 0.3 and density 7850 kg/mm^3. The concrete have Elastic modulus (E) of $5000\sqrt{fck}$, Poisson's ratio 0.2 and density 2500 kg/mm^3.The elastic properties are completely defined by giving the Young's Modulus (E) and the Poisson's ratio (ν).

5.2 Element, mesh, contact between steel and concrete

The choice of the element type and mesh size that provide consistent results with less computational time is also important in simulating structures with interface elements. Use of fine mesh size provides accurate results. Type of element for steel tube and concrete is selected from element library in ANSYS. Based on the geometric characteristics of concrete and steel an appropriate element type for the analysis is selected. In geometry modeler, the model was drawn using ANSYS workbench. A fine mesh of 30 mm sizing was used for concrete and steel. Surface to surface contact technique was used to model the interaction between the outer surface of theconcrete and the inner surface of the hollow steel tube. The CFST beam is analysed as full model.The boundary conditions applied for the nodes lying on the planes of symmetry. Beams were supported by rollers.

5.3 Methodology adopted

- Finite element method was extensively used to study the structural behaviour of steel concrete composite section. Finite element model was developed using ANSYS 14.5 version.

- The strength of CFST depends upon the material properties like characteristic strength of infill concrete Young's Modulus (E), Poisson's ratio (ν) and stress/stain values. Geometric properties like wall thickness (t), length (l), width (b), depth (d). Therefore, the material and geometric properties are taken as input parameters for modeling in ANSYS.

- Model is analyzed and ultimate moment, deflection values, strain, results are obtained from Finite element model.

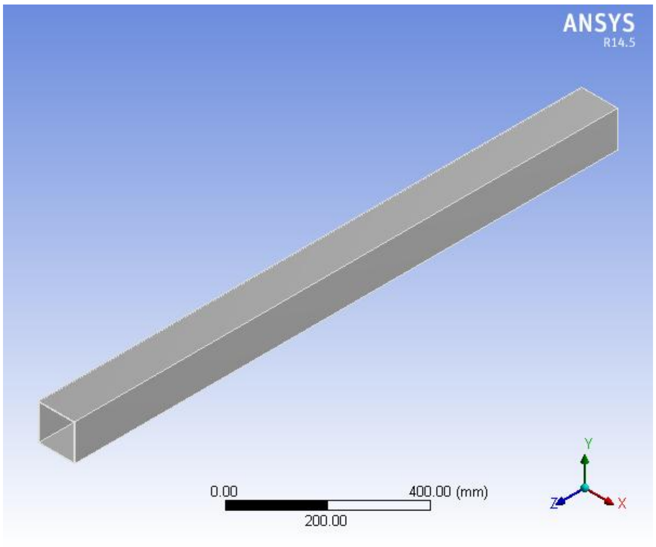


Fig. 2. FE model of Hollow tube.

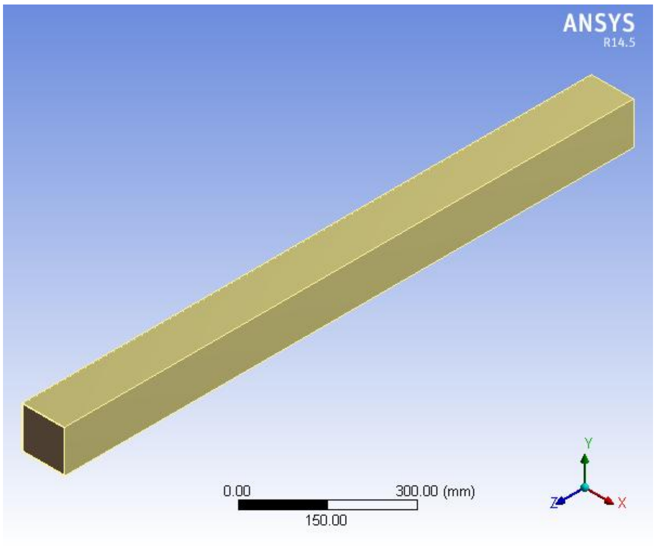


Fig. 3. FE model of concrete filled steel tube (CFST)

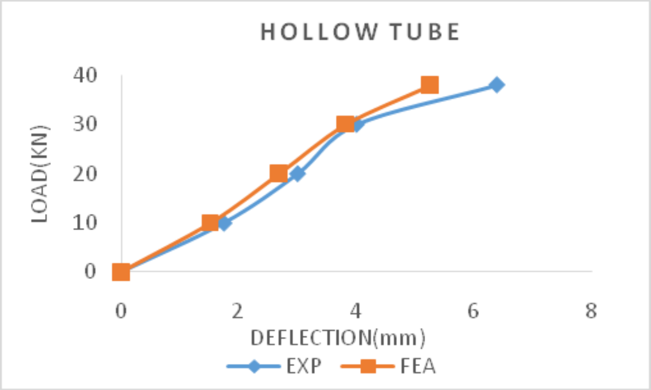
6. RESULTS AND DISCUSSIONS

The experimental and analytical values were calculated and compared. For the comparison the following parameters was selected:

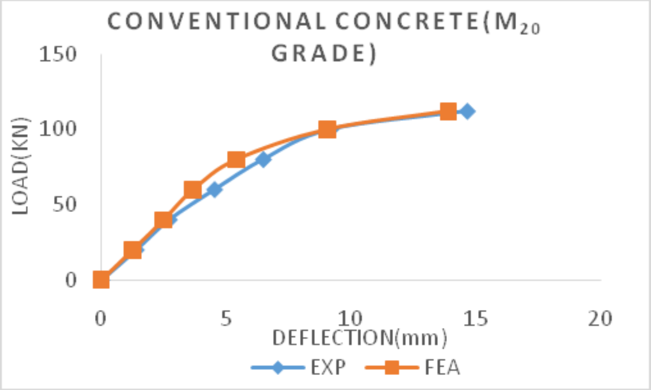
i. Load vs. Deflection graph
ii. Ultimate load
iii. Strain

The load vs. deflection behaviour of the square hollow tubular section was shown in Chart-6(a). The result from the test and FEA were impressed in this figure. Up to a load of 10 KN the agreement between both the results were pretty close. About 20 KN there was an insignificant deviation between the results. The behaviour of the filled tubular member with conventional concrete (M_{20} grade) was shown in Chart-6(b). The results of test and FEA were in fairly good agreement. After a load of 40 KN this behaviour was non-linear. The results from both tests and FEA were shown in Chart-6(c) for the CFST filled with 50% replacement of GGBS with cement in concrete. Up to 20 KN, both results shown a linear trend. Above 20 KN, the experimental solution shown an increase in deflection with respect to the FEA programme. In this region both results exhibit non-linear behaviour. In Chart-6(d), the FEA values were slightly higher than experimental values and in Chart-6(e), both the values were almost same. In Chart-6(d), after a load of 40 KN this behaviour is non-linear and in Chart-6(e), after a load of 60 KN the behaviour is non-linear.

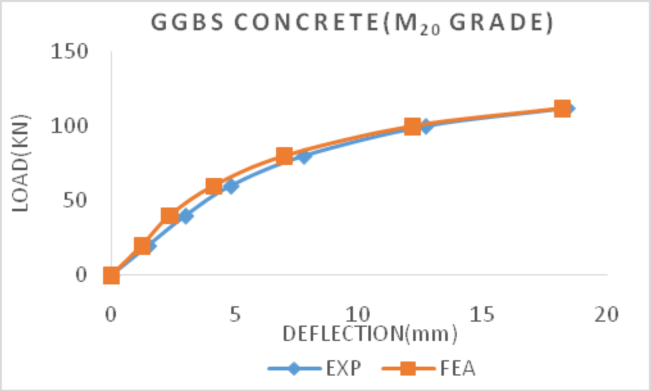
In Fig. 4, 5 and 6, deformed shape were shown for hollow tube, CFST beam (M_{20} grade) and CFST beam (M_{40} grade) beyond ultimate load respectively.



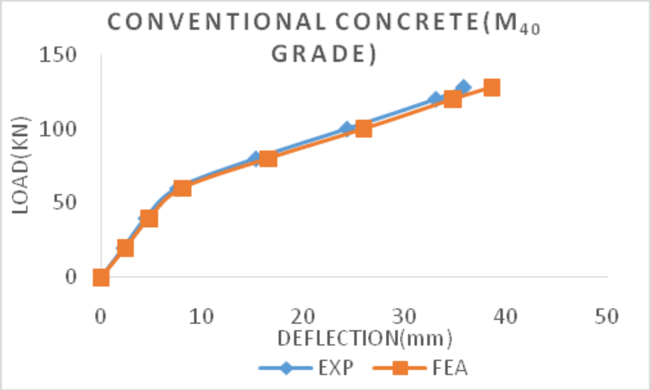
6(a)



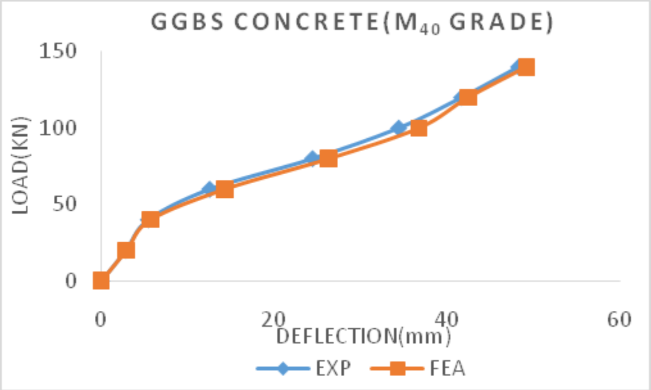
6(b)



6(c)



6(d)



6(e)

Chart-6: Load vs. mid-span deflection of the beam.

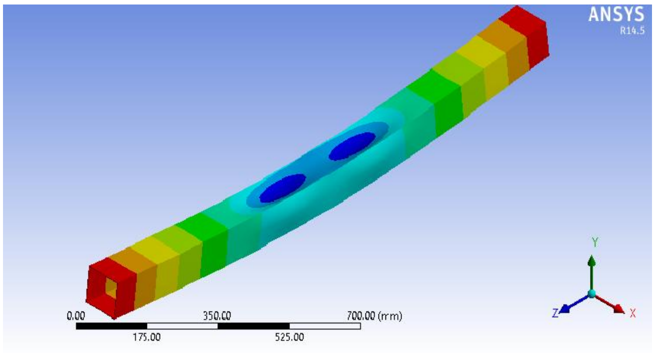


Fig. 4. Deformed shape of hollow tube beyond ultimate load.

After FEA analysis, holes were observed on hollow steel tube as shown in Fig. 10. The deflection in hollow tube was lesser than the concrete filled steel tubes.

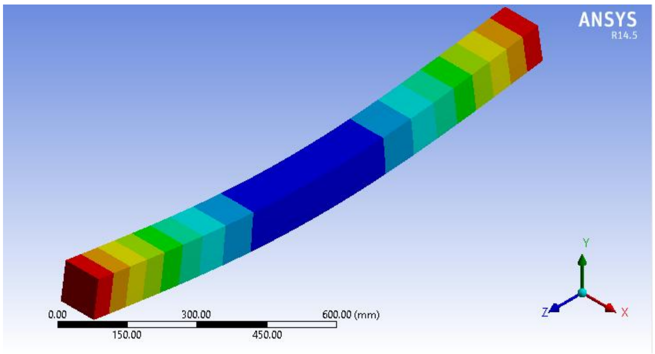


Fig. 5. Deformed shape of CFST beam (M_{20} grade) beyond ultimate load.

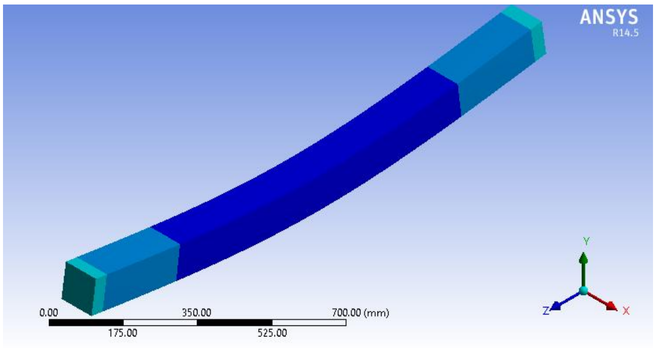


Fig. 6. Deformed shape of CFST beam (M_{40} grade) beyond ultimate load.

Concrete filled steel tubular (CFST) beams with M_{40} grade of concrete got higher strength than M_{20} grade of concrete. Ultimate loads of 128 KN and 140 KN were achieved for normal mix concrete and GGBS concrete respectively. Concrete filled steel tubular beam with GGBS concrete got higher ultimate load as compared to conventional concrete (M_{40} grade). Mid-span deflection as well as deflection at loading point were higher for

CFST beam replaced by 50% of GGBS with cement in concrete.

From this study, it can be concluded that, since the grain size of GGBS was less than that of ordinary Portland cement, its strength at early ages is low, but it continues to gain strength over a long period.

7. CONCLUSIONS

From the presented work it can be concluded that:

- It was found that the strength of concrete filled steel tubes (CFST) were 2.8 times higher than that of hollow tubes.
- The beams infilled with M_{40} grade of concrete have 25% higher strength than those beams filled with M_{20} grade of concrete.
- The load vs. lateral deflection curves for hollow as well as for CFST beams were found in good agreement with experimental values.
- The compressive strain and tensile strain of concrete filled steel tubes were 33% and 40% lesser than that of hollow tube.
- GGBS concrete with 50% cement replacement possess 48% higher strength than conventional concrete.
- Finite element analysis was shown to be a promising method to obtain data for the development of design aid for CFST beams.

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