FLEXURAL BEHAVIOUR OF CONCRETE FILLED STEEL TUBE BEAMS

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ABSTRACT

Concrete filled steel tubes (CFST) member have many advantages compared with the ordinary structural member made of steel or reinforced concrete. One of the main advantages is the interaction between the steel tube and concrete. Concrete delays the steel tube's local buckling, whereas the steel tube confines the concrete and thereby increases the concrete's strength. CFSTs are economical and permit rapid construction because the steel tube serves as formwork and reinforcement to the concrete fill, negating the need for either. The deformation capacity of the system is increased by the combined action of the concrete fill with the thin, ductile steel tube. The concrete fill significantly increases inelastic deformation capacity and the compressive stiffness and load capacity of the CFST member.

In building construction concrete filled steel tubes are very widely used for columns in combination with steel or reinforced concrete beam.

In this work totally 9 specimens were tested out of which 3 specimens were empty steel tubes and remaining 6 specimens were concrete filled with different bonding techniques. As it is prefabricated time consumption will be less in construction practice and due to confinement more ductility is expected which is very useful in earthquake resistant structures. Load carrying capacity of CFST almost doubled in comparison with empty steel tubes.

Ultimate load carrying capacity of concrete filled steel tube beams almost doubled compared to empty steel tubes. Compared to empty steel tubes, strength increase of 67.19%, 97.48% and 114.84% was observed in normal CFST, CFST with sand blasting and CFST with diagonal shear connector beams respectively. Average ultimate load of EST was 105.66kN whereas average load of CFSTB, CFSTBWSB and CFSTBWDSC was 176.66, 208.66 and 227kN respectively. The maximum load was taken by the specimen CFSTBWDSC – 03 which was 231kN, it may be because of presence of diagonal shear connector inside the tube.

INTRODUCTION

Building construction has been carried out from ancient times. Construction of building turned out to be a need due to the various climatic variations. Shelters were one means by which humans could adapt themselves to a variation in weather conditions.

Earlier human shelters were very simple and it lasted just for few days or months. As time passed, they started building temporary structures which were evolved into refined forms as igloo. Gradually durability of structures began to improve, particularly after the beginning of agriculture, when people stayed in one place for longer duration of time. Structures slowly started having symbolic value and functional value, when people began to notice the difference between architecture and structural aspects. The history of buildings has been improving day by day. One is by increasing the durability of the materials used. Initially materials used in building were perishable, like leaves, branches, and animal skin. Later, materials which had additional durability like clay, stones, timber (wood), and other synthetic materials, like brick, concrete, metals, and plastics were used.

Another evolution is the height and span of building which were constructed; this was made possible by the development of stronger materials and knowledge of how materials behave under situations and how to use them to greater advantage. The present state of building construction is very much complex.

Excavations at a number of sites in Europe at around 12,000 BC showed circular type rings made of stones that are supposed to have formed part of shelters. And in 3000 BC in Mesopotamia, the first fired bricks were implemented. Columns made up of single stones supporting stone beams appeared for the first time in royal temples connected with the pyramids in 2600 BC.

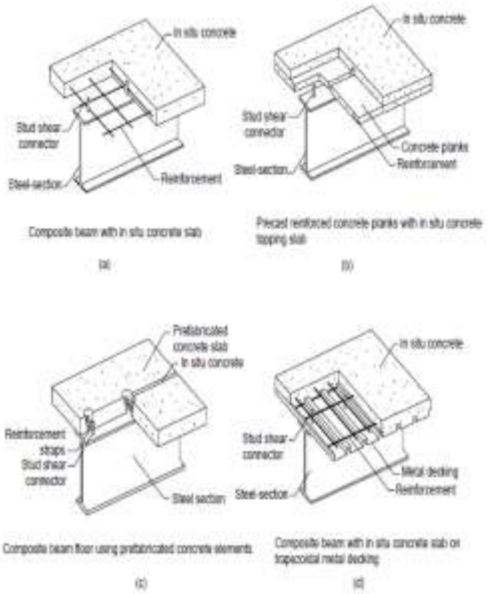

Figure: Different forms of composite beam and slabs

Types of Structures

Based on materials used for construction, structures are classified into:

1. Masonry structures
2. Timber and metal structures
3. Steel structures
4. Reinforced concrete structures
5. Composite structures

LITERATURE REVIEW

Investigations Carried Out on Flexural Behaviour of Concrete Filled Steel Tube Beams

The following parameters were investigated by different authors and are as listed below:

Flexural Strength:

For brittle materials the ability to counteract deformation under external loads acting in transverse direction is called as flexural strength. In bending test, the transverse load applied on specimen might cause fracture or bending and the ability to resist this to maximum possible range is usually called as flexural strength of the specimen.

Load vs. Deflection curve:

Load vs. Deflection curve is a curve which is obtained with various load data values and its corresponding deflection values. A graph obtained by the above provides load vs. deflection curve.

Load carrying capacity:

The maximum load which a section can accept by an external media is the load carrying capacity of the particular section.

Tests were carried out at the University of Western Sydney by Wheeler and Bridge on, the tube specimens and the flexural stiffness of specimens were measured. Experimental work on flexural behaviour of composite members was similar to the theoretical stiffness of the steel tubes under pure flexure. Han also observed a similar change in flexural behaviour of specimen in his experimental work. Han modified the design method appropriately however the change in stiffness was not as effective as observed by Wheeler and Bridge (2003). Additionally in the experimental work, the change in flexural stiffness decreases with increase in diameter of the section. In the experimental work by Shawkat et al the concrete filled tubes which had larger depth to span ratios, there was cracking on tension side of the specimens and multiple cracks at the mid span. This effect was noted down by Wheeler and Bridge in their work. Both the issues emphasises that size of the specimens effect on flexural behaviour of concrete filled tubular members [1].

In the experimental work carried out, the moment capacity and the behaviour of unfilled and concrete filled hollow sections were noted down.The sections were subjected to cyclic reversible loading. Here the filler materials were of two types, normal concrete and fly ash concrete. The effect of filler materials used, slenderness of section, load vs deflection, moment-strain curve, ductility, stiffness degradation and energy absorption of concrete –filled RHS beams were studied. Totally 9 specimens were considered. 3 were rectangular hollow sections, 3 were concrete filled steel tubes and the other six were fly ash filled steel tubes. The sizes of RHS section was 100x50x3.2 mm. They concluded that the increase in ultimate moment capacity was due to the filler material strength. The ultimate moment capacity for concrete-filled RHS members based on CIDECT standard was found to be in good agreement with the experimental moment capacity of Rectangular hollow steel beams filled with normal concrete and fly ash concrete. Experimental results prove that void filling increases energy absorption capacity of the section and also reduces the stiffness degradation. It also increases the ductility factor. The study showed that fly ash concrete could be used as infill material for a satisfactory mechanism [2].

In this experimental work the behavior of concrete filled steel tubes under pure bending was studied. Twelve rectangular hollow tubes with different sizes 150x150; 200x150 and 250x150 mm were used. High strength concrete (56.3MPa to 90.9MPa) was used as infill for the hollow tubes for composite action. Yield stresses of hollow tubes were 438Mpa, 495Mpa and 409Mpa respectively. They concluded that the post yielding behaviour was good enough with ductility performance. A comparison of the experimental values and values calculated from design formulas in EC4, ACI and AISC were made. The codes underrated moment capacities of the specimens considered. EC4 provides better moment carrying capacity than ACI and AISC and the difference is about 11%. THE ACI and AISC codes underrated the flexural strength of the specimens by 15 and 18%, respectively. On evaluating the codes with the collected data, test results show an increase in flexural strengths by 9, 12 and 15%, respectively [3].

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EXPERIMENTATION

Brief procedure of experimental work carried out for this thesis work is explained in this part.

Specimens

This experimental work was conducted to check the flexural behaviour of empty steel tube and concrete filled steel tube beams. Main objective was to find out the ultimate flexural strengths of empty and concrete filled steel tube beams. All specimens were of uniform cross section 120mmx60mm of thickness 3.2mm and of length 1000mm. Steel tubes were confirming to Indian Standard code IS 4923 : 1997.

All specimens were tested under two point loading with simple supports in Universal Testing Machine (UTM) of capacity 60 tonnes.

Specimen Details

Total 12 number of specimens used in this work.

1. Empty steel tubes (EST) – 3 numbers.
2. Concrete filled steel tube beams (CFSTB) – 03 numbers.
3. Concrete filled steel tube beams with sand blasting inner surface (CFSTBWSB) – 03 numbers.
4. Concrete filled steel tube beams with 10mm diameter HYSD bars as diagonal shear connectors (CFSTBWDSC) – 3 numbers.

Casting of Specimens

Empty steel tubes were available in 06 metre length. Each length was cut into 6 pieces of 1 metre length.

Figure: Empty steel tubes

Sand-Blasting of Specimens

For 3 numbers of specimens, inner surface of tubes were roughened to develop the bond between steel and concrete with epoxy resin araldite and manufactured sand (M-sand) particles of grain size retaining on 3.35mm sieve.

First inner surface was cleaned for dust and corrosion particles then a layer of Araldite was applied on inner surface and then M-sand particles were sprinkled on that surface. Then the steel tube was left for 24 hours undisturbed.

Figure: Application of epoxy and M-sand particles

Figure: Sand blasted specimens

Welding of Shear Connectors

For 3 numbers of specimens, 2 numbers of 10mm diameter HYSD bars were welded at the ends of tubes diagonally as shear connector.

Figure: Shear connector welded specimens

Providing End Plugs

End plugs were provided at one end of steel tubes to fill concrete from other side. Polythene sheet was used with araldite.

Concreting of Specimens

Totally 9 specimens were filled with M25 grade of concrete. To ensure full compaction, TULASI concrete with collapsible slump was used. Concreting has been done at TULASI RMC plant.

Figure: TULASI RMC plant

Curing of Specimens

Concrete filled tubes were cured by immersing one end of the tube in water and constant application of water at the other end for 28days.

Test Setup

All specimens were tested under two point static loading as simply supported condition with a span of 800mm. All specimens were tested in Universal Testing machine (UTM) of capacity 60tonnes.

Dial gauge was used to measure the deflection at mid span of the beam. The load was introduced at the rate of 2.5kN/minute. Deflections were noted down at every 2.5kN interval. Load was applied upto a point when the needle comes back and final load was noted down as ultimate load of the beam and at that load, final reading of dial gauge was noted down before releasing the load.

RESULTS AND DISCUSSION

Theoretical Results

Data: Yield Stress of tubes = 310Mpa

Effective Span=800mm

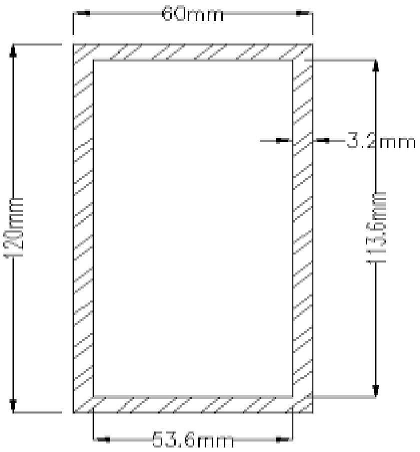

Figure: Cross-Section of the TATA tube

Sectional Modulus (Z_y)

$I_{N.A} = \{BD^3/12\}-\{bd^3/12\}$

$I_{N.A} = \{60X120^3/12\}-\{53.6X113.6^3/12\}$

$I_{N.A} = 2.0918X10^6\ mm^4$

Sectional Modulus (Z_y) = $I_{N.A}$ / y

$Z_y= 2.0918X10^6 / (120/2)$

$Z_y=34.8643\ X10^3\ mm^3$

Plastic Modulus (Z_p)

Plastic Modulus (Z_p) = Summation (A X y)

Plastic Modulus (Z_p) = 2 x [(60x3.2) x (56.8 + (3.2/2)) + { 2 x (3.2x56.8) x (56.8/2) }]

Plastic Modulus (Z_p) = $43.075\ X10^3\ mm^3$

Shape Factor

Shape Factor(S) = Plastic Modulus / Sectional Modulus

Shape Factor(S) =$43.075\ X10^3\ mm^3$ / $34.8643\ X10^3\ mm^3$

Shape Factor(S) = 1.2355

Moment Calculation

Moment for 2point loading is wL/3

Therefore Moment (M) = wL/3

Where M is the moment, w is the load in kN and L is the span of the specimen.

To determine the load, the equation is cross-multiplied as below

Load (w) = (Moment x 3)/ Span

A. *Collapse Load*

Collapse load (Wu) = (Plastic Moment x 3)/ Span

Plastic Moment (M_p) = Permissible yield stress x Plastic Modulus (Z_p)

Plastic Moment (M_p) = $310x43.075\ X10^3$ $=13.35325\ X10^6$

Collapse load (Wu)= $13.35325\ X10^6$/ 800

Collapse load (Wu)=50.073kN

B. *Service Load*

Service load (Ww) = (Elastic Moment x 3)/ Span

Elastic Moment (M_e) = 0.66xPermissible yield stress x Sectional Modulus (Z_y)

Elastic Moment (M_e) = $0.66x310x34.843\ X10^3$ $=6.48079\ X10^6$

Service load (Ww)= $6.48079\ X10^6$/ 800

Service load (Ww)=26.733kN

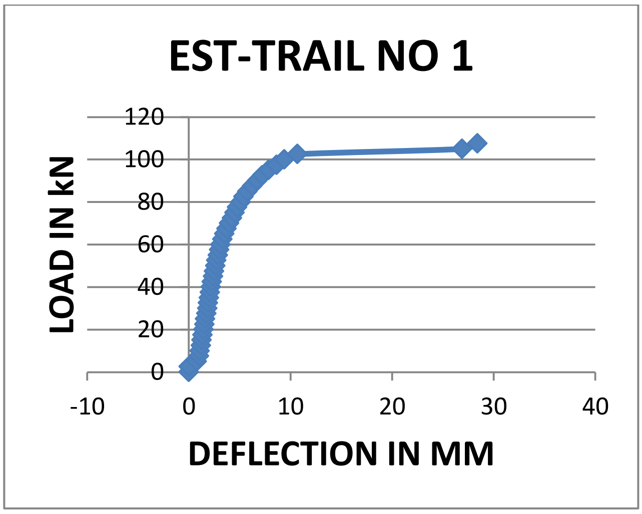

Figure: Load vs. deflection curve for EST – 01

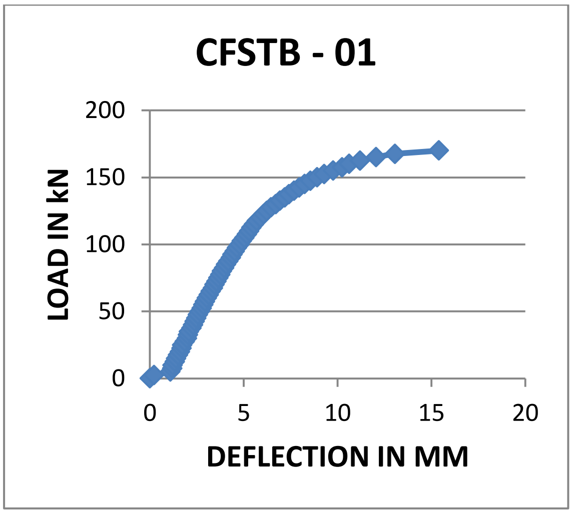

Figure: Load vs. deflection curve for CFSTB – 01

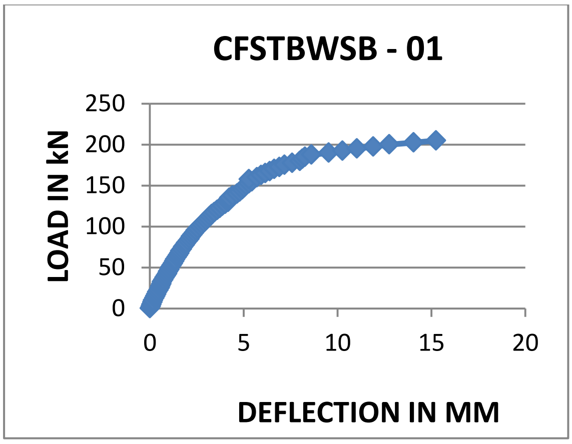

Figure: Load vs. Deflection curve for CFSTBWSB – 01

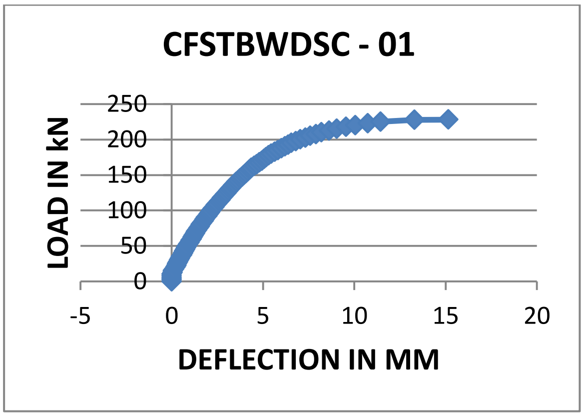

Figure: Load vs. Deflection curve for CFSTBWDSC – 01

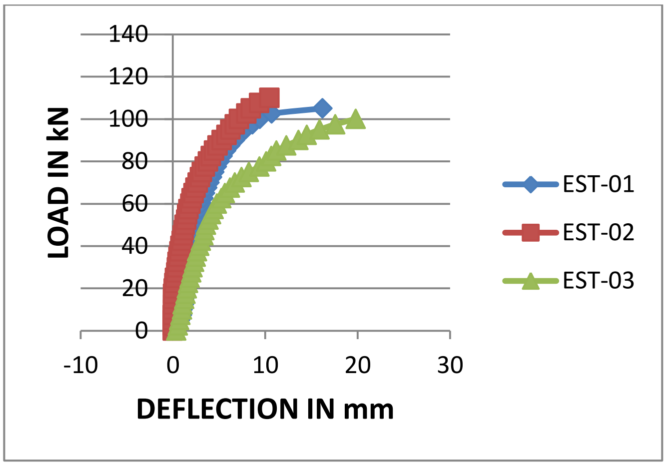

Figure: Load vs. Deflection curve for EST – 01, 02, 03

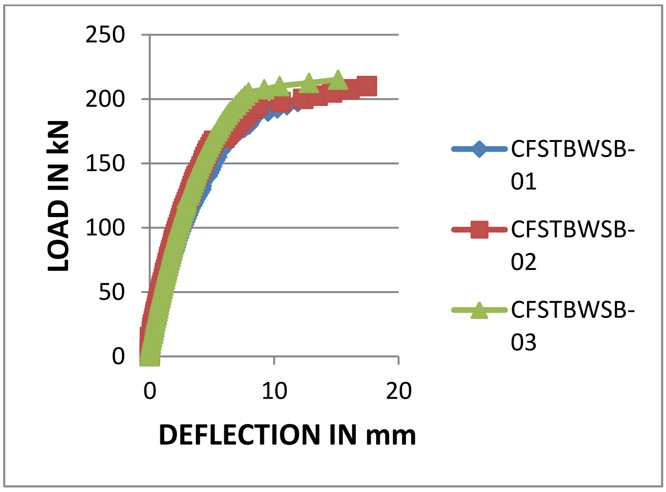

Figure: Load vs. Deflection curve for CFSTBWSB – 01, 02, 03

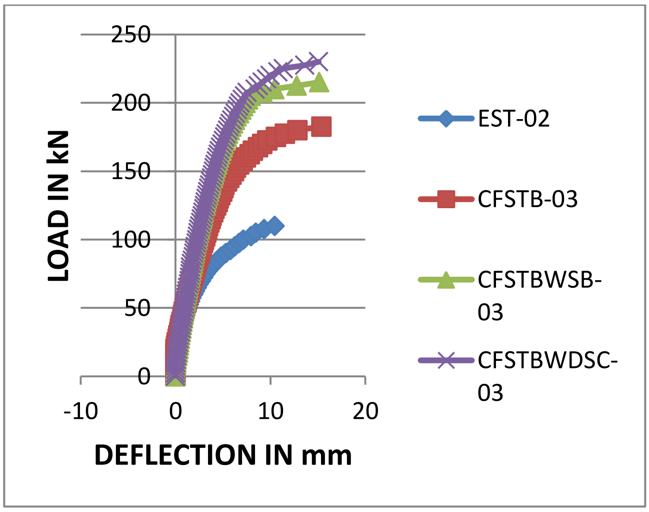

Figure: Load vs. Deflection curve for each type of specimen

1.1.1 Ultimate Load of all Specimens

To compare all specimens, ultimate load, ultimate deflection and allowable deflection is tabulated and presented graphically.

Table: Summary of results obtained from experimental investigation

Sl. No	Beam Type	Ultimate Load (Kn)	Average Ultimate Load (Kn)	Percentage of Strength Increase	Ultimate Experimental Moment (Kn-M)	Ultimate Deflection (Mm)
1	EST-01	106	105.66	---	14.13	16.2
2	EST-02	110			14.67	10.47
3	EST-03	101			13.46	19.8
4	CFSTB-01	170	176.66	67.19	22.67	15.4
5	CSFTB-02	177.5			15.67	15.8
6	CFSTB-03	182.5			24.33	15.4
7	CFSTBW SB-01	205	208.66	97.48	27.33	15.25
8	CFSTBW SB-02	208			27.73	17.47
9	CFSTBW SB-03	213			28.4	15.16
10	CFSTBW DSC-01	228	227	114.84	30.4	15.15
11	CFSTBW DSC-02	222			29.6	16.73
12	CFSTBW DSC-03	231			30.8	15.09

CONCLUSIONS

From the experimental results, failure patterns, load deflection characteristics and analytical results, following conclusions have been drawn.

1. All the specimens failed almost in same pattern. Local buckling of steel tubes occurred at the compression zone and at point load.
2. Flexural load carrying capacity of concrete filled steel tubes doubled when compared to empty steel tubes.
3. Much difference between different bonding techniques was not seen in any of the specimen.
4. Almost all type of filled specimens failed at same load, but the maximum load was taken by the specimen CFSTBWDSC – 03, it may be because of presence of diagonal shear connector inside the tube.
5. There was no slip of concrete at the edges of beams observed in any specimen. This shows that the bond between steel and concrete is good enough.
6. The filled specimens are opened to check the behaviour, failure and crack pattern of in filled concrete. Very minute cracks were developed in flexure zone and crack spacing was also more.
7. It can be concluded that the smaller cross section of concrete filled steel tubes

can carry much more load than normal reinforced concrete beams within the allowable crack width.

8. As concrete is confined by steel tube all around, sudden failure of beams may not occur.

9. Overall performance of concrete filled steel tubes are good and can be concluded that filling of concrete to empty steel tubes increases the load carrying capacity to maximum extent.

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