FLEXURAL STRENGTH OF CONCRETE-FILLED STEEL TUBULAR BEAM WITH PARTIAL REPLACEMENT OF COARSE AGGREGATE BY GRANITE

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ABSTRACT

Composite members consists of steel and concrete have the advantages of both materials, steel has high tensile strength and ductility, while concrete has the advantages of high compressive strength and stiffness. The main objective this research is to determine the load carrying capacity of steel tubular beams filled with different types of concrete (normal and partial replacement of coarse aggregate by granite) under bending action in construction works. The benefits of using partial replacement of coarse aggregate by granite is not only to enhance strength but also to preserve the natural resources of sand and also keeps these powder particles from being airborne into the atmosphere causing health hazard to humans, in particular children. It is widely recognized that the innovative use of two or more material in structures generally leads to more efficient economical systems for resisting forces. In this area utilizing of concrete filled steel tubes are new idea which increasingly finding application in design practice. Current design codes and standards provide little information on the flexural behaviour of Concrete Filled Steel Tubes (CFST). There are significant differences in d/t limits recommended in various codes for CFST under bending. This paper presents an experimental investigation of the flexural behaviour of square concrete filled steel tubes (SCFST) subjected to pure bending, where the depth to thickness ratio (d/t) is 23.8 & 27.8. The paper compares the behaviour of empty and concrete-filled, hot rolled rectangle hollow sections under pure bending. The behaviour of such concrete filled steel tubular beams with partial replacement of coarse aggregate by granite under flexural loading is presented. The effects of steel tubes, compressive strength of concrete and the confinement of concrete are examined. Six specimens were tested with strength of concrete as 20 MPa. The beams were 88.9X88.9 and 114.3X114.3 mm in size and 1200 mm in length. From the test results it was observed that the ultimate load carrying capacity of steel tubular beams filled with partial replacement of coarse aggregate by granite is almost the same as that of conventional concrete. In general, filled steel tube enhances strength, ductility and energy absorption especially for thinner sections. The steel shell provides confinement for concrete core thus increases the ductility and strength of core. The use of concrete filled steel tubular sections in structural frames has increased in different countries such as United States, and Australia during the past ten years.
1. INTRODUCTION
Composite members consisting of rectangle steel tubes filled with concrete are extensively used in structures involving very large applied moments. Composite concrete filled steel tubes (CFST) have been used increasingly as columns, beams and beam-columns in braced and un-braced frame structures. Their use worldwide has ranged from compression members in low rise, open floor plan construction using cold-formed steel rectangular tubes filled with pre-cast or cast-in-situ concrete, to large diameter cast-in-situ members used as the primary lateral resistance columns and beams in multi-storey buildings. Concrete filled steel columns and beams have been used is some of the world’s tallest structures. In addition, concrete filling is widely used in retrofitting of damages steel bridge piers in the Northridge earthquake in 1994 in the USA. The two main types of composite column are the steel-reinforcement concrete beam, which consists of a steel section encased in reinforced or unreinforced concrete, and the concrete-filled steel tubular (CFST) beams, which consists of a steel tube filled with concrete. CFST beams have many advantages over steel reinforcement concrete beams. The major benefits of concrete filled beams are:

- Steel beam acts as permanent and integral formwork
- The steel beam provides external reinforcement.
- The steel beam support several levels of construction before concrete being pumped.

Although CFST beams are suitable for all tall buildings in high seismic regions, their use has been limited due to a lack of information about the true strength and the inelastic behaviour of CFST members. Due to the traditional separation between structural steel and reinforced concrete design, the procedure for designing CFST beam using the American Concrete Institute’s (ACI) code,[1] is quite different from the Load and Factor Resistance Design (LFRD) method suggested by the American Institute of Steel Construction’s (AISC).[2]. The CFST structural members have a number of distinctive advantages over conventional steel reinforced concrete members. These members also have excellent behaviour under bending loading, compared with hollow tubes. The use of CFST members in moment resisting frames eliminates the use of additional stiffening elements in panel zones and zones of high strain demand. In general, concrete filling tube is an efficient way to delay premature local buckling and to enhance ductility of tubular structures built with hot-rolled hollow sections. The parametric and experimental studies provide information for developing formulas when calculating the ultimate strength of the composite beam-columns. Concrete filling not only delays local buckling but also prevents the detrimental effect of vocalization on the bending capacity of circular hollow sections (CHS). The basic samples were composed in two layers consisting of high-performance concrete as the top layer and normal strength concrete. The results confirm a significant improvement of structural properties of composite beams in comparison with the beams prepared by normal concrete and the same case in comparison with the HPC.

This paper presents the comparison between two different composite beams and hollow beam sections.

- Concrete filled steel tubular beams with conventional (normal) concrete.
- Concrete filled steel tubular beam with partial replacement of coarse aggregate by granite (25%).

2. CONCRETE FILLED STEEL TUBULAR SECTIONS
The use of concrete filled steel tubular sections as structurally integrated stay-in-place formwork for concrete structures maximizes the advantages of both steel and concrete, while simplifying the
construction procedure, particularly when using closed tubular sections. In this case, rectangular tubes are filled with concrete and used as flexural members. The tube provides lightweight permanent formwork and non-corrosive reinforcement simultaneously. Concrete-filled rectangular steel tubes have been extensively studied in bending and under axial loads. Square tubular sections have an advantage over other sections when used in bending members, for a given cross-sectional area, they have a large uniform flexural stiffness in all directions. Filling the tube with concrete will increase the ultimate strength of the member without significant increase in cost. The main effect of concrete is that it delays the local buckling of the tube wall and the concrete itself, in the restrained state, is able to sustain higher stresses and strains than when is unrestrained. The uses of CFST provide large saving in cost by increasing the floor area by a reduction in the required cross-section size. This is very important in the design of tall buildings in cities where the cost of letting spaces are extremely high. These are particularly significant in the lower storey of tall buildings where short columns and beams usually exist.

3. PREVIOUS RESEARCH

A series of tests had been carried out by O’Shea and Bridge [3] on the behaviour of circular thin walled steel tubes. The tubes had diameter to thickness (d/t) ranging between 55 and 200. The tests included; bare steel tubes, tubes with un-bonded concrete with only the steel section loaded, tubes with concrete in filled with the steel and concrete loaded simultaneously and tubes with the concrete infill loaded alone. The test strengths were compared to strength models in design standards and specification. The results from the tests showed that the concrete infill for the thin-walled circular steel tubes has little effects on the local buckling strength of the steel tubes. Lapko et al. (2005),[4] conducted experiments on reinforced concrete composite beam; the tests were prepared in full scale with the cross-section of 120×200 mm and the effective span of 2950 mm. However, O’Shea and Bridge found that concrete infill can improve the local buckling strength for rectangular and square sections. Increased strength due to confinement of high-strength concrete can be obtained if only the concrete is loaded and the steel is not bonded to the concrete. For steel tubes with a d/t ratio greater than 55 and filled with 110-120 MPa high-strength concrete, the steel tubes provide insignificant confinement to the concrete when both the steel and concrete are loaded simultaneously. Therefore, they considered that the strength of these sections can be estimated using Eurocode 4 (EC4), [5] with confinement ignored. The influence of local buckling on behaviour of short circular thin-walled CFSTs has been examined by O’Shea and Bridge. Two possible failure modes of the steel tube had been identified, local buckling and yield failure. These were found to be independent of the diameter to wall thickness ratio. Instead, bond between the steel and concrete infill determined the failure mode. A design method has been suggested based upon the recommendations in EC4. Elchalakani et. al [6] conducted series of experiments in composite members consisting of circular steel tubes filled with concrete are extensively used in structures involving very large applied moments, particularly in zones of high seismicity. Composite circular concrete filled tubes (CFT) have been used increasingly as columns and beam-columns in braced and un-braced frame structures. The CFT structural members have a no distinctive advantages over conventional steel reinforced concrete members. These members also have excellent hysteresis behaviour under cyclic loading, compared with hollow tubes. In spite of the bulk literature written over the last four decades on the technique of concrete filling of circular steel tubes, little of it was devoted to the large deformation flexural behaviour of these members. The yield stress of the steel tube does not seem to have a significant influence on curvature ductility. The elastoplastic behaviour of the connection panels was also analytically examined. This panel was modelled by superposing tri-linear relations for the steel tube and concrete filling. The analytical method was verified by the experimental results in this study. As a result, the analytical results were found to be in agreement with the experimental results up to the maximum shearing capacity of concrete, although the analytical results tend to slightly underestimate the experimental results over the displacement range above the maximum shearing capacity of concrete. Teng et.al ,[7] told that the calculation of ultimate bearing capacity is a significant issue in the design of Concrete Filled Steel Tubular (CFST) arch bridges. Based on the space beam theory, this paper provides a calculation method for determining the ultimate strength of CFST
structures. The moment carrying capacity of this method and the applicability of the stress-strain relationships were validated by comparing different existing confined concrete uni-axial constitutive relationships and experimental results. Comparison of these results indicated that this method using the confined concrete uni-axial stress-strain relationships can be used to calculate the ultimate strength and CFST behaviour with satisfactory accuracy. Wang et al.,[8] conducted many experiments were done to find out appropriate methods of rubber application. However, with small portion of aggregates replaced, the loss in compressive strength was not significant. Experiments under the laboratory environments commonly presented that the use of rubber in the concrete cement mix reduced drying shrinkage, brittleness, and elastic modulus, which might improve the overall durability and serviceability of cement concrete. Structures include buildings of all types (both residential and non residential) as well as roads and bridges. This review summarizes the behaviour of circular and rectangular concrete-filled steel tube beam–columns and braces, particularly focused on their behaviour when subjected to cyclic seismic loading. The article concludes with a summary of publications in which current CFST design provisions are outlined for several non-seismic and seismic specifications throughout the world. The British Standards Code of practice for design of composite bridges – BS5400 (Steel 1979),[9] does not permit to use the concrete other than normal weight concrete of a density less than 2300 kg/m³. Other codes such as Eurocode 4 (Common 1985) and the European recommendations (Composite Structures 1981) permit using lightweight concrete of strength not less than 20 MPa. Tests conducted by Ghannam et al. (2004),[10], on steel tubular columns of square, rectangular and circular sections filled with normal and lightweight aggregate concrete were conducted to investigate the failure modes of such composite columns. The interest of this research is due to a low specific gravity and thermal conductivity of the lightweight concrete for replacing the normal concrete and lightweight aggregate concrete. The columns filled with lightweight concrete exhibit local buckling when the column reached failure load and an overall buckling took place. Such negative effect (local buckling) does not significantly reduce the load-carrying capacity of the column. Also, a low specific gravity and thermal conductivity of lightweight aggregate concrete is a good possibility to replace normal concrete and lightweight aggregate concrete. Han, Yao and Zhao (2004),[11], found a mechanics model in this research paper also conducted an experimental on concrete-filled steel CHS beam-columns. The parametric and experimental studies provide information for developing formulas when calculating the ultimate strength of the composite beam-columns. Based on the tests conducted by Hunaiti (2003),[12], on battened composite sections at the age of 5 years, the bond between the steel section and concrete shows considerable strengthening, when compared with results at the age of one year. The results show that the bond strength at the age of 5 years is about two and one-half times of that of one year. This is mainly due to steel rusting at the surface of contact with concrete, which increases mechanical keying due to micro-irregularities, thus enhancing the bond of two materials.

4. EXPERIMENTAL PROGRAM

A total of 6 beam specimens of square section (B1-B6) were tested for this research. All specimens were tested with strength of concrete as 20 MPa and a (d/t) ratio 23.8 & 27.8. The beams were 88.9 x 88.9 mm & 114.3 x 114.3 mm in size of 1200 mm in length. The beam specimens were classified into two different groups. Each group consists of two specimens filled with conventional (normal) concrete (B2 and B5), and partial replacement of coarse aggregate by granite (25%) (B3 and B6). The third group of the beam specimens was tested as hollow sections for reference beam (B1 and B4). All the specimen properties are given in Table 1. All the specimens were cast from square hollow steel tube and filled with different types of concrete. The average values of yield strength and ultimate tensile strength for the steel tube (carbon steel – Gr.B, A53M) were found to be 241 MPa and 414 MPa respectively. In the present experimental work, the parameters of the test specimens are the size of the specimen and strength of concrete. The concrete mix was obtained using the following dosages: 350 kg/m³ of Portland cement (7 bags), 510 kg/m³ of sand, 1150 kg/m³ of coarse aggregate (waste pieces from granite industries) with maximum size 12 mm, and 175 litres of water. In order to characterize the mechanical behaviour of concrete, three
cubic, three prismatic and three cylindrical specimens were prepared from each concrete and tested. The mean values of the strength related properties of concrete at an age of 28 days are summarized in Table 2. During preparation of the test specimens, concrete was cast in layers and light tamping of the steel tube using wooden hammer was performed for better compaction.

Table 1 Specimen properties

<table>
<thead>
<tr>
<th>Beam Type</th>
<th>Specimen Size Designation (bxd) mm</th>
<th>Thickness t (mm)</th>
<th>d/t ratio</th>
<th>Length L (mm)</th>
<th>Steel Strength, fy (Mpa)</th>
<th>Concrete cube, fcu (Mpa)</th>
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<tr>
<td>B- 1</td>
<td>88.9x88.9</td>
<td>3.2</td>
<td>27.8</td>
<td>1200</td>
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<td>27.8</td>
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<td>B- 3</td>
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<td>241</td>
<td>24.8</td>
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<tr>
<td>B- 4</td>
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<td>241</td>
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<td>1200</td>
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Table 2 Concrete properties

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<tr>
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<th>fcr (MPa)*</th>
<th>fct (MPa)*</th>
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<td>Conventional (Normal) Concrete</td>
<td>26.03</td>
<td>3.16</td>
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<td>Partial Replacement of Coarse Aggregate by Granite 25 %</td>
<td>24.8</td>
<td>3.17</td>
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* average of three cubes, prisms and cylinders respectively.

Table 3 Ultimate load carrying capacity of beams

<table>
<thead>
<tr>
<th>Beam Type</th>
<th>Specimen Size Designation (bxd) mm</th>
<th>Thickness t (mm)</th>
<th>Ultimate Load (kN)</th>
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<tr>
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<td>B- 2</td>
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<tr>
<td>B- 6</td>
<td>114.3x114.3</td>
<td>4.8</td>
<td>350.7</td>
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Table 4 Load vs Deflection

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<th>Deflection (mm)</th>
<th>Beam- B1</th>
<th>Beam- B2</th>
<th>Beam- B3</th>
<th>Beam- B4</th>
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<td>116.4</td>
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<td>320</td>
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<td>100.2</td>
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<td>310</td>
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</table>

5. TEST SETUP AND PROCEDURE

The specimens are tested to find out the basic mechanical properties. The cube specimen was placed over the Compression Testing Machine and the load was gradually applied till the failure of the specimen. The ultimate load was noted down as collapse load and crushing strength was calculated. The beam is placed on Universal Testing Machine (1000 KN) to find out the Flexural Strength for various proportions. The split tensile strength tests were carried out with concrete cylinders in Compression Testing Machine for each type of concrete. The hollow steel tubular beam and other composite beam specimens were tested in Electronic Universal Testing Machine (1000 KN) using hydraulic loading with horizontal position to determine the central deflection of the hollow steel tubular beam and other beams with cyclic loading. An initial load of 2 kN is given to the specimen to hold it in correct position. At every 5 kN load, the deflection and the strain in compression and tension zones are observed and tabulated. The diagrammatic sketch of the beam setup is as shown in Figure 1 and schematic diagram of tested beam as shown in Figure 2.

Figure 1 Experimental Test Set up
6. CONCLUSION

From the above results it can be observed that the partial replacement of coarse aggregate by granite is a very attractive proposition for composite sections. However, the success of the method depends on several factors. The results obtained from the tests on composite beams presented in this paper allow the following conclusions to be drawn.

- The ultimate load of steel tubular beams in-filled with normal concrete is about 51 to 67% of hollow beams as shown in Table 3 and Figure 3.
- The strength of CFSTs with partial replacement of coarse aggregate by granite – beams is almost same as that of normal concrete as shown in Table 4 and Fig.3.
- It may be said that the partial replacement of coarse aggregate by granite will also reduce the disposal of this waste on valuable fertile land.
- Usage of this waste material in concrete filled steel tubular beams, not only a waste minimizing technique, also it saves cost and reduction of size of beams to increase the working space.
Flexural Strength of Concrete-Filled Steel Tubular Beam with Partial Replacement of Coarse Aggregate by Granite

- It can be concluded that the partial replacement of Coarse Aggregate for normal conventional concrete will not only reduce the cost of concrete but at the same time it will save large quantity of coarse and fine aggregates.
- Also it is observed that when square steel tube beams with (bigger thickness) and smaller (d/t) ratio are used, the load carrying capacity of the beam will highly increase as shown in Fig. 3.
- From the experimental results of the current investigation, it can be concluded that the failure mechanism of the beam sections result in an excessive deflection with no lateral disturbances or any other form of instability.

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REFERENCES