

# Experimental and computational study of concrete filled steel tubular columns under axial loads

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## Abstract

The paper presents an experimental and computational study on the behaviour of circular concentrically loaded concrete filled steel tube columns till failure. Eighty-one specimens were tested to investigate the effect of diameter and  $D/t$  ratio of a steel tube on the load carrying capacity of the concrete filled tubular columns. The effect of the grade of concrete and volume of flyash in concrete was also investigated. The effect of these parameters on the confinement of the concrete core was also studied. Diameter to wall thickness ratio between  $25 < D/t < 39$ , and the length to tube diameter ratio of  $3 < L/D < 8$  was investigated. Strength results of Concrete Filled Tubular columns were compared with the corresponding findings of the available literature. Also a nonlinear finite element model was developed to study the load carrying mechanism of CFTs using the Finite Element code ANSYS. This model was validated by comparison of the experimental and computational results of load–deformation curves and their corresponding modes of collapse. From the experimental and computational study it was found that for both modes of collapse of concrete filled tubular columns at a given deflection the load carrying capacity decreases with the increase in % volume of flyash up to 20% but it again increases at 25% flyash volume in concrete.

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## 1. Introduction

Composite concrete-filled steel tubes (CFTs) have been used increasingly as columns and beam–columns in braced and unbraced frame structures. Their use worldwide has ranged from compression members in low-rise, open-floor plan construction, using cold-formed steel circular or rectangular tubes filled with precast or cast-in-situ concrete, to large-diameter cast-in-situ members used as the primary lateral-resistance columns in multi-story braced and unbraced frames. Concrete filled steel box columns, fabricated from four welded steel plates, and concrete-filled steel fabricated circular pipes have been used in some of the world's tallest structures. In addition, concrete-filled steel box columns are commonly used as bridge piers.

Concrete-filled steel tubular structural members have a number of distinct advantages over equivalent steel, reinforced

concrete, or steel-reinforced concrete members. Steel members have the advantages of high tensile strength and ductility, while concrete members have the advantages of high compressive strength and stiffness. Composite members combine steel and concrete, resulting in a member that has the beneficial qualities of both materials. The steel tube serves as a form for casting the concrete, which reduces construction cost. No other reinforcement is needed since the tube acts as longitudinal and lateral reinforcement for the concrete core. In addition, the placement of longitudinal steel at the perimeter of the section is the most efficient use of the material since it provides the highest contribution of the steel to the section moment of inertia and flexural capacity. The continuous confinement provided to the concrete core by the steel tube enhances the core's strength and ductility. The concrete core delays local buckling of the steel tube by preventing inward buckling, while the steel tube prevents the concrete from spalling.

Experimental research on concrete filled tubular metallic columns has been ongoing throughout the world for many years, with significant contributions having been made

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particularly by researchers in the past few years. Neogi et al. [1] investigated numerically the elasto-plastic behaviour of concrete filled tubular metallic columns pinned at both ends, loaded either axially or with some eccentricity about one axis. Complete interaction between the steel and concrete was assumed so triaxial and biaxial effects were not considered. To compare the experimental results with the numerical solution eighteen eccentric loaded columns were taken. They found good agreement between the experimental and theoretical behaviour of columns with  $L/D$  ratios greater than 15. Moreover they also inferred that triaxial effects were small for such columns, whereas for columns with smaller  $L/D$  ratios there was a gain in strength due to the triaxial effect.

A series of tests were carried out by O'Shea and Bridge [2] to study the behaviour of circular thin-walled concrete filled steel tubes having  $D/t$  ratio ranging between 55 and 200. These tests were conducted on bare steel tubes, tubes with unbounded concrete with only the steel section loaded, tubes with concrete infill with the steel and concrete loaded simultaneously and tubes with concrete infill loaded alone. The obtained load carrying strengths were compared with the strengths calculated using the design standards and specifications. The results showed that the concrete infill for the thin-walled circular steel tubes has little effect on the local buckling strength of the steel tubes.

O'Shea and Bridge [3] also tried to estimate the strength of CFTs under different loading conditions. The loading conditions examined include axial loading of the steel only, axial loading of the concrete only, and simultaneous loading of the concrete and steel both axially and at small eccentricities. All the tested specimens were short with a  $L/D$  ratio of 3.5 and  $D/t$  ratio between 60 and 220. The used concrete had a compressive strength of 50, 80 and 120 MPa. From these experiments, O'Shea and Bridge concluded that the degree of confinement offered by a thin-walled circular steel tube to the internal concrete is dependent upon the loading condition. The confinement effect was highest when only the concrete was loaded axially and the thin-walled steel was used as pure circumferential restraint. They also concluded that Eurocode 4 can be used for the design of thin-walled steel tubes filled with very-high-strength concrete if care is taken in the formulation of the design equations.

Kilpatrick et al. [4,5] also examined the applicability of Eurocode 4 for the design of CFTs which use high strength concrete and compared 146 columns from six different investigations with Eurocode 4. The concrete strength of the columns ranged from 23 to 103 MPa. The mean ratio of measured/predicted column strength was 1.10 with a standard deviation of 0.13. The Eurocode safely predicted the failure load in 73% of the columns analysed.

Brauns [6] declared that the confinement effect exists at high stress level and when structural steel acts in tension and concrete in compression and that the ultimate limit state of material strength was not attained for all parts simultaneously. In his study of the constitutive relationships for material components, the stress state in composite columns was

Table 1

Details of basic ingredients of control concrete mix

| Quantities of basic ingredients (kg/m <sup>3</sup> ) | Grade of concrete |      |
|------------------------------------------------------|-------------------|------|
|                                                      | M30               | M40  |
| Cement                                               | 342               | 410  |
| Fine aggregate                                       | 720               | 638  |
| Coarse aggregate                                     | 1173              | 1187 |
| Water                                                | 205               | 205  |

determined by considering the dependence of the modulus of elasticity and Poisson's ratio on the stress level in concrete.

Recently the behaviour of circular concrete-filled steel tubes (CFT) with various concrete strengths under axial load was also presented by Georgios Giakoumelis and Dennis Lam [7]. In their study they examined the effects of steel tube thickness, the bond strength between the concrete and the steel tube, and the confinement of concrete. Measured column strengths were compared with the results predicted using Eurocode 4, Australian standards and American codes. All three codes predicted lower values than that measured during the experiments. Eurocode 4 gave the best estimation for both CFT with normal and high-strength concrete. They also found that the effect of concrete shrinkage was critical for high-strength concrete and negligible for normal strength concrete.

Since the Finite Element Method has reached a state of maturity, numerical simulation can be carried out as an alternative to experiments to understand the behaviour of CFTs. Therefore in this paper an attempt has been made to understand the axial compression process of CFTs having  $D/t$  values between 25 and 39 between two parallel rigid plates under quasi-static loading with Finite Element simulations. But to develop and validate the computational Finite Element model experiments were also performed and the results are compared with the computations. On the basis of the experimental observations a finite element computational model using ANSYS code has been presented for the prediction of load–deformation curve of the CFTs and their deformed shapes. For the in situ conditions it is difficult to achieve full compaction in CFT columns, or it may require expensive technology to do so. To eliminate this problem an attempt is also made to design and develop a concrete, which gets compacted without the use of any vibrators. Since flyash is the waste product of thermal power plants and can be used to make the concrete more economical, therefore in making the concrete flyash is also used.

## 2. Experimental details

### 2.1. Concrete properties

Concrete of design strength of 30 and 40 MPa was produced using commercially available materials with mixing using vibrators and simple curing techniques. Mix design of both grades was carried out in accordance to the British standards. The mix designs are shown in Table 1. These grades of concrete are designated as controlled concrete. Standard cube tests were used to determine the compressive strength of the concrete.

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