CONCRETE FILLED STEEL TUBULAR COLUMNS

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INTRODUCTION

Concrete filled steel tubular columns consist of a well compacted high grade concrete (minimum M25 grade) within mild steel tubes. Column sections utilizing square and circular shapes are shown in Fig. 1.

Filled steel tubes offer structural advantages due to efficient shape of the steel section (which offers a large moment of inertia) and full composite action of steel and concrete. The tubular section contributes a large part of the flexural rigidity of the column. The concrete being confined within the tube has an enhanced crushing strength due to triaxial effect of confinement. The column needs neither reinforcement nor formwork. The tube protects the concrete from impact and abrasion. Concrete filled steel tubular columns have an advantage over reinforced concrete columns and concrete encased steel sections in that the load carrying capacity is not reduced when carrying long term load. The elastic modulus of concrete is reduced under long term loading and hence the load carrying capacity is also reduced in case of columns where the concrete contribution to flexural rigidity is
large. It is shown in this paper that in case of filled tubular columns the load carrying capacity is not reduced under long term loading.

Concrete filled steel tubular columns are efficient structural members that can be used as bridge piers. In 1966 the four level motor way bridge at Almondsbury in U.K. was constructed using 42" (1070 mm) diameter tubes with core concrete of M30 grade and steel thickness of 50 mm. Interest in this type of construction is being revived in U.K. and U.S.A. due to development of design methods and codes. The construction is greatly facilitated due to development of high strength, high performance concrete (upto 100 MPa), admixtures and self compacting concrete.

Hollow tubes supporting off shore platforms are vulnerable to fatigue caused by wave forces. Concrete filled tubes are also liable to fatigue failure at the pier-platform junction or where the capping plates are welded to the tubes. At the junction the tube is to be strengthened either by studs or shotpeening.

DESIGN METHODS

European codes have adopted design method originally proposed by Basu & Sommerville later modified by Virdi & Dowling. This method is incorporated in the Model Eurocode of 1981 published by European Committee of Constructional Steel Research (ECCS). The latest Eurocode EC4 published in 1997 uses a modified approach consisting of a bilinear interaction diagram in place of the diagram used in ECCS method.

The combination of load and moment causing failure can be calculated assuming that the eccentricity 'e' (moment/load) is constant. This assumption, known as proportional loading case is made in case of pin ended columns. This assumption is valid for bridge piers where the load is transferred through capping plates and the eccentricity of the load can be accurately estimated.
In case of columns in building frames where the moment is shared both by column and beams, it is generally assumed that the moment is constant and not proportional to the loading. The results presented in this paper are based on the assumption of proportional loading.

Calculations for permanent loading are done assuming that the long term elastic modulus of concrete is half the value of short term modulus. Results are presented for two cases (1) assuming all the load is short term and (2) all load is permanent.

SQUARE AND CIRCULAR COLUMNS

The ultimate strength of concrete filled steel tubular columns depends upon the strength of concrete and steel. The strength of concrete is enhanced due to confinement but reduced due to creep. The plasticity of the steel is also to be considered in the strength assessment. Basu & Sommerville showed that for square or rectangular columns the enhancement of the concrete strength due to confinement is negligible. The design equations for circular columns, on the other hand incorporate parameters to account for enhanced strength, creep of concrete and plasticity of steel. In the ECCS method these equations provide for modified design stresses in concrete and steel to account for the effects of confinement, creep and plasticity. These modified stresses are listed for columns of medium and high slenderness and medium and large load eccentricities. In case of EC4 these modification factors are given only for columns of medium slenderness and small values of load eccentricity. Therefore, the ultimate loads predicted by EC4 are lower than the values given by ECCS.

COLUMNS ANALYSED

This paper presents the ultimate loads of 36 square columns and 36 circular columns. Concrete core of M25 grade and steel tube of Fe250 grade (which are the minimum permitted by ECCS) are assumed. The core size 'd', the tube thickness 't', length of the column 'L', eccentricity of load 'e', are as listed in Table 1.
### Table 1: Ultimate Loads of Filled Tubular Columns

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<th>e, cm</th>
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**Note:**  
- \( P_s \) (All load short term)  
- \( P_l \) (All load permanent)  
- \( P_m \) (All load permanent)  

Calculations by ECCS  
Calculations by EC4.

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The ultimate loads 'P' are calculated for the following cases. Ultimate loads of square columns by ECCS method assuming (1) all the load is short term (2) all the load permanent. Ultimate loads of circular columns by the same assumptions. Calculations are repeated by EC4 method for circular columns. (The effect of concrete confinement, creep and plasticity being predominant only in circular columns). Results are presented in Table 1.

DISCUSSION OF RESULTS

Concrete filled tubular sections of large load carrying capacity can be designed with compact cross sections. A circular section of 20 cm core diameter and 6 mm tube has concrete area 314 cm² and steel area 38.8 cm². Steel areas of such magnitude are not possible with RCC columns. The ultimate axial load of this column 1358 kN for 3m height and 854 kN for 6m height by ECCS method. The load predicted by EC4 method for the 3m column is 15 percent less at 1157 kN.

The reduction in the load carrying capacity due to long term loading is negligible (as can be seen directly from the table) for both square and circular columns.

In case of circular columns there is enhancement of compressive strength of core concrete while in square columns this phenomenon is not present. Hence it is interesting to compare the ultimate axial loads of square and circular columns (of equal value of d and t). Square columns have larger values of concrete and steel areas while circular columns exhibit larger core strength. It is seen that square columns have larger load capacity especially as the value of L/d increases. This conclusion can be expected to be valid for square and circular columns of equal core areas as the former has larger values of steel area and larger I_s and I_c (moment of inertia of steel and concrete).

In case of eccentrically loaded columns it is seen that the load carrying capacity greatly diminishes with increase in eccentricity. Hence it is necessary to properly estimate and control the eccentricity of loading. In most cases of concrete filled tubular columns (such as bridge piers), the girders directly rest on capping
plates and eccentricity can be realistically estimated and kept low. EC4 recognises the need for keeping the eccentricity low and specifies an upper limit of eccentricity = 0.1d. For larger eccentricities the ultimate load is calculated without using the strength enhancement parameters used in ECCS. The difference in the estimated ultimate loads by both the methods (P₁ and Pₘ) can be seen directly from the table.

The ultimate loads decreases with increase in the column length, the extent of reduction being directly seen from the table. Since the columns are generally pin-ended with girders resting on cap plates, there is no difficulty in estimating the effective length and the corresponding load.

![Diagram](image)

**Fig. 2 Zone requiring strengthening**

**FATIGUE LOADING**

100 million cycles in 20 years
Wave frequency = 0.17 Hz
Horizontal wave forces = 10 times wind force
Life expectancy in sea = 40% of land structure
There are 150 platforms in India more than 25 year old.
Stud fatigue formula log \( N = 22.32 - 8 \log f_r \)

\( N \) fatigue life cycles
\( f_r \) stress range \( (f_{\text{max}} / f_{\text{min}}) \)

As already mentioned, square columns have a larger axial capacity than circular columns of same core width. In case of eccentrically loaded columns the situation is different. It is seen that as many as 18 out of 24 cases, the ECCS method predicts a higher load
carrying capacity for circular columns. (Columns 2, 3, 6, 9, 12, 15, 18, 20, 21, 23, 24, 27, 29, 30, 32, 33, 36). The comparison is made between square and circular columns of same height, core width, tube thickness and eccentricity. When the more conservative EC4 method is used the circular columns show a larger load carrying capacity than the corresponding square columns in 12 cases. (Column 3, 6, 9, 12, 18, 21, 24, 27, 29, 30, 33, 36). It is thus seen that in case of columns with large eccentricity the enhanced strength of core concrete of circular columns outweighs the advantage of higher areas and moments of inertia of square sections. However, it is not likely that in normal range of columns eccentricities of the order $0.25d$ used in this paper occur. Hence square columns may be more widely used compared to circular columns.

CONCLUSIONS

1. Concrete filled steel tubular columns offer both constructional and structural advantages.
2. The sections of tubular columns are more compact compared to RCC columns for the same length and load carrying capacity.
3. Design methods and codes are available for routine adoption of tubular columns as bridge piers.
4. Square cross-sections are stronger compared to circular sections under axial loading.
5. Circular cross sections are stronger than square cross-sections when the eccentricity of the load is large. However, the eccentricities of load for bridge piers are not likely to be of a large magnitude to warrant the use of circular cross-sections.

REFERENCES