Numerical Study on Behaviour of Spiral Concrete Columns and Slender Concrete Filled Steel Tube (CFST) Columns against Concentric Axial Loads

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Abstract. Concrete columns with a circular cross-section have been used since a long time ago due to its better performance and advantages in many ways. The value of axial force in circular column is greater than in square column under the equivalent condition. To date, there has been no study that compares CFST behaviour with spiral concrete columns. This study can fill the gaps in comparative studies in between performance of the two types of columns with axial loading on slenderess variations using finite element modelling. Based on the results of the finite element modelling, with the same material capacity the CFST column has a greater resistance to geometric or bending failure with 8.63% than the spiral concrete column. The CFST column has a larger Critical Buckling Load than the spiral. And in general, with the greater the value of L/D or the slenderer the column is designed, the value of the Critical Buckling Load will tend to decrease and this occurs in both types of columns.

1. Introduction
Concrete columns with a circular cross-section have been used for a long time because it has better performance and advantages in several ways. The axial force value of the circular column is greater than the square column under equal material capacity condition [1]. Circular column is better to resist the deflection than rectangular cross-section with the same cross-sectional area, due to inertia of the column cross-sectional dimensions [2]. In terms of slenderess, the critical load required to bend in a large circular column will tend to have the same value because of its symmetrical nature between the center axes of the cross-section. Unlike the rectangular cross-section which tends to be different, bending tends to occur first in between the two weakest axes [3].

However, in the past 20 years CFST columns or Concrete Filled Steel Tube has been mainly used as an alternative to the spiral-circular columns. CFST column is formed by filling a steel tube with concrete [4]. CFST columns are commonly found in high-rise structures, bridge supports, power transmission towers and coastal structures [5]. These structures are utilized because filling a steel tube with concrete can increase both strength and ductility without increasing the size of its cross-section. Many researchers have found that CFST columns have a number of advantages compared to the ordinary steel or reinforced concrete systems in terms of strength, stiffness, ductility and performance during earthquakes. It is also known that the circular shape / tube provides a large bending and bending capacity
by placing steel around the outside of the column section. This will result in a large moment of inertia and radius of gyration.

Research on spiral column remains limited to experimental research. As for the CFST column, although there has been research using finite elements, only little works have been done that compare it with the spiral column model.

Recently, no research has compared CFST with spiral concrete columns. Research in spiral concrete columns is still limited to experimental research. For this study, it is limited to the parametric slenderness problem. Thus, this research can fill the gaps in the finite element modeling method by comparing the performance between the two types of columns on various axial load and slenderness. The purpose of this study is to determine the ultimate capacity of spiral concrete column models and CFST columns against axial loads and slenderness variations.

2. Literature Review

2.1 Constitutive Model for Concrete

Figure 1. Simplified Compressive Uniaxial Stress-Strain Curve For Concrete [6]

Stress-Strain Curve used for material modeling on unconfined reinforced unconfined concrete follows the following equations [6]:

\[ f = \frac{E_c \varepsilon}{1 + \left(\frac{\varepsilon}{\varepsilon_0}\right)^2} \]  \hspace{1cm} (1)

\[ \varepsilon_0 = \frac{2 f' c}{E_c} \]  \hspace{1cm} (2)

Where:
- \( f \) = stress on a particular strain (MPa)
- \( \varepsilon \) = strain on \( \sigma \) stress (mm/mm)
- \( \varepsilon_0 \) = strain on \( f_c \) stress (mm/mm)
- \( f' c \) = maximum stress of concrete (MPa)
- \( E_c \) = modulus young (MPa) = 4700√\( f_c \)
Stress-Strain Curve used for material modeling on confined concrete follows the following equations [7]:

\[
f_{cc} = f_c \left( -1.254 + 2.245 \left( \left( 1 + 7.94 \frac{f_{rp}}{f_c} \right)^{0.5} - 2 \frac{f_{rp}}{f_c} \right) \right) \quad (3)
\]

\[
\varepsilon_c = \begin{cases} 
0.7 f_{cm}^{0.31} \rightarrow 0.7 f_{cm}^{0.31} < 0.0028 \\
0.0028 \rightarrow 0.7 f_{cm}^{0.31} \geq 0.0028 
\end{cases} \quad (4)
\]

\[
f_{rp} = 0.3111 \left( \frac{D}{t} - 2 \right)^{-1.027} f_y \quad (5)
\]

\[
f_{cu} = \begin{cases} 
\frac{f_{cc}}{f_c} \left( \frac{0.1 f_y}{f_c} \right)^{0.1} \rightarrow \frac{D}{t} \leq 40 \\
\frac{f_{cc}}{f_c} \left( \frac{0.1 f_y}{f_c} \right)^{0.1} \left( \theta + (1 - \theta) e^{\left(\frac{-D}{40 t} - 1\right)} \right) \rightarrow \frac{D}{t} > 40 
\end{cases} \quad (6)
\]

\[
\varepsilon_{cu} = 11 \varepsilon_{cc} \quad (7)
\]

\[
f_t = 0.56 f_c^{0.5} \quad (8)
\]

\[
f_{ccb} = 1.16 f_{cc} \quad (9)
\]

\[
\sigma = \begin{cases} 
\frac{E_0 \varepsilon}{1 + \left( \frac{E_0}{E} - 2 \right) \left( \frac{\varepsilon}{\varepsilon_{cc}} \right) + \left( \frac{\varepsilon}{\varepsilon_{cc}} \right)^2} \rightarrow \varepsilon \leq \varepsilon_{cc} \\
f_{cu} + \left( f_{cc} - f_{cu} \right) \left( -\frac{\varepsilon}{\varepsilon_{cc}} \right) \rightarrow \varepsilon_{cc} < \varepsilon \leq \varepsilon_{cu} 
\end{cases} \quad (10)
\]

\[
\sigma \varepsilon_{cc} = \frac{f_{cc}}{f_c} \varepsilon_0 \quad (11)
\]
With definitions:

- \( f'_c \) = Maximum stress of unconfined concrete (MPa)
- \( f'_{cc} \) = Maximum stress of confined concrete (MPa)
- \( f_{cu} \) = Maximum residual stress of confined concrete (MPa)
- \( f_t \) = Tensile stress of concrete (MPa)
- \( \sigma \) = Stress on a particular strain, \( \varepsilon \) (MPa)
- \( f_{rp} \) = Surface pressure between concrete and steel pipes (MPa)
- \( \varepsilon_c \) = Concrete strain on \( f'_c \) stress (mm/mm)
- \( \varepsilon_{cc} \) = Concrete strain on \( f'_{cc} \) stress (mm/mm)
- \( \varepsilon_{cu} \) = Concrete strain on \( f_{cu} \) stress (mm/mm)
- \( k \) = Constanta
- \( f_{cxb} \) = Concrete biaxial stress (MPa)
- \( D \) = Exterior diameter CFST (MPa)
- \( t \) = Thickness of the steel pipes (mm)
- \( f_y \) = Yield stress of the steel pipes (MPa)
- \( \theta \) = Empirical parameter taken with its value of 0.6

### 2.2 Limiting conditions

There are some limiting conditions in design including:

a. Analysis of column strength is performed for concentric axial load.
b. The design process is carried out according to ACI-318-14 regulations for spiral Concrete columns.
c. The design of parametric CFST columns follows the design of spiral concrete columns.
d. In CFST column modelling, surface interactions between steel pipes (Pipe Tube) and concrete (Concrete) are made of the frictional type with a surface coefficient of 0.2 according to the research model of Hsuan et al in 2003 [2].
e. The concrete is a normal concrete with a unit weight of 2400 kg/m\(^3\).
f. The cross section of the steel pipe in the reviewed CFST model is circular and without the use of longitudinal or lateral reinforcement in the concrete.
g. The concrete is a medium quality concrete, i.e., concrete with compressive strength between 21 - 40 MPa.
h. The column analysed is the slender column which means that the failure of the column occurs due to the buckling effect.
i. Nonlinear analysis is carried out until the ultimate stress point occurs and does not review the part once the ultimate stress point has been reached.
j. Analysis using the finite element method was performed with ANSYS Workbench v.18.1 software.
k. Setting of Meshing size uses automatic meshing built-in ANSYS Workbench v.18.1 software.

Meanwhile the limiting conditions of columns at the equalization stage involve the followings:

a. The planned factored-load is 2 MN. Strength of concrete compression is 30 MPa
b. The type of steel used is A36 Steel according to the ASTM International standards.
c. Yield strength of the steel is 250 MPa for longitudinal steel, lateral reinforcing steel, and steel pipes.
d. The ratio of the longitudinal reinforcement to the cross-sectional area is 0.08 which applies to both the lateral spiral reinforced column and the CFST column.
e. Side skins of spiral concrete are 40 mm.
f. Upper and lower surface skins of longitudinal reinforcement of spiral concrete columns are 40 mm.

4. Research Method

![Flowchart of Research](image)

**Figure 3. Flowchart of Research**

4. Analysis and Discussion

4.1 Validation of the Spiral Concrete Column Model (VAL/SC)
At this stage the validation calculations of the spiral concrete column model have been carried out based on the experimental results of Shamim et al in 2002 [5]. The results of numerical calculations and comparison of responses with experimental models can be seen in Figure 4. The figure 4 shows the comparison of the compressive testing result for the spiral concrete column model (VAL / SC) of ANSYS v18.1.

![Figure 4. Comparison of Maximum Axial Load Capacity VS Experimental and Finite Element Numerical Calculation](image)

From model validation between the experimental results and the finite element model, the results are not so different with the comparison of P.EXP and P.FEM values of 0.895 - 0.958. Thus, the constitutive model that is defined to create the spiral column model can be reasonably accurate to describe experimental behavior of the column. This constitutive model can be further defined for parametric testing.

4.2 Validation of the CFT Column Model CFST (VAL/CFST)

At this stage validation calculations have been made for the CFST column model based on the experimental results of Schneider et al in 2004 [8] and Huang et al in 2002 [9]. The results of numerical calculations and comparison of responses with experimental models can be seen in Figure 5. It Shown that the comparison of compressive test results of the CFST column (VAL/CFST) from ANSYS v18.1.
The validation model between the experimental results and the finite element model show only slightly different results of comparison of P.EXP and P.FEM values of 1.000 – 1.061. Thus, the constitutive model that is defined to create the CFST column model can quite accurately describe the experimental behavior of the column. This constitutive model can be further defined for parametric testing.

4.3 The Results of Parametric Model Testing of Spiral Column (VAR / SC) and CFST Column (VAR / CFST)

Figure 6 shows the comparison of parametric results of the two types of columns. As noted earlier, the both types of columns have the same value of column material capacity (Factored Force Load), which is approximately 2.0 MN. Looking at the Factored Force Load line as the column material capacity, the two border values can be obtained from the intersection of this line with two VAR/SC and VAR/CFST buckling load curves. The first L/D value of 15.65 is intersection between the Factored Force Load line and the Critical Buckling Load VAR/SC curve line, whereas the second of 17.00 is intersection between the Factored Force Load line and the Critical Buckling Load VAR/CFST curve line. The L/D boundary value of 15.65 indicates that failure of elastic buckling will occur in a spiral concrete column when it has a height of 15.65 from the diameter its cross-section. If the height of spiral concrete column is less than 15.65 of its cross-section diameters, then the failure that occurs is caused by material capacity (the column will reach maximum capacity and break down holding the load).

The threshold L/D limit value of 17.00 indicates that failure of elastic buckling will occur in the CFST column when it has a height of 17.00 of its cross-section diameters. If CFST columns have a height of less than 17.00 of its cross-section diameters, then the failure that occurs is caused by material capacity (the column will reach maximum capacity and break down holding the load).

The threshold L/D limit value of 17.00 indicates that failure of elastic buckling will occur in the CFST column when it has a height of 17.00 of its cross-section diameters. If CFST columns have a height of less than 17.00 of its cross-section diameters, then the failure that occurs is caused by material capacity (the column will reach maximum capacity and break down holding the load).

With the L/D value of CFST columns greater than the L/D value of spiral concrete columns, it can be concluded that with the same maternal capacity CFST columns have greater resistance to geometric failure or buckling than the spiral concrete column. In application, CFST columns can be designed with a L/D value greater than spiral concrete columns which results in a far more efficient design.

From the VAR/CFST Critical Buckling Load curve and the VAR/SC Critical Buckling Load, it can be seen that the VAR/CFST Critical Buckling Load curve is above the VAR/SC Critical Buckling Load
curve. This means that CFST columns has larger a critical buckling load than the spiral one. In general, with the greater the value of L/D or the slenderer column designed, the Critical Buckling Load value will tend to decrease and this happens in both types of columns.

Comparison of the critical buckling Load value reached 8.63%. This means that the use of CFST-type columns can increase the resistance to buckling failure relative to 8.63% compared to the SC model column with cross-section and quality as well as the limitations as explained in this research report.

![Comparison of the Parametric results of both types of columns](image)

**Figure 6. Comparison of the Parametric results of both types of columns**

5. **Conclusion and Suggestion**

5.1 **Conclusion**

Based on the results of this study, the conclusions are:
The constitutive model behavior used to create a validation model in ANSYS v.18.1 software is sufficient to describe the actual performance consistent with comparison of existing experimental data. The same material capacity between the average L/D ratio of 8 to 18 shows that CFST columns have greater resistance to geometric failure or bending of 8.63% than spiral concrete columns. CFST columns have greater Critical Buckling Load than spiral concrete columns. In general, the greater the value of L/D or the slimmer column designed, the Critical Buckling Load value will tend to decrease and this occurs in both types of columns.

5.2 **Suggestion**

Suggestions for the future studies are:
Specimens can be extended to various D / t ratios or another longitudinal reinforcement ratio and can be expanded into various types of loads, such as eccentric loads, cyclic, or transverse loads. This study can also be extended to include higher values concrete compressive strength. The study can consider the cost efficiency and time of work.
Acknowledgement

The authors thank to all colleagues and parties that provide supports for this study.

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