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Computation for Flexural Strength of Circular Concrete Filled Tube

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ABSTRACT

This study examines flexural strength of concrete filled tube (CFT) according to several codes such as ACI, AISC, and Eurocode. Especially in AISC and Eurocode, two methods are available; strain compatibility method (SCM) and plastic stress distribution method (PSDM). The ACI method is basically the same as the SCM of AISC, while the PSDM of Eurocode approach is also similar to PSDM of AISC with different material strength definitions. The PSDM of AISC is quite easy to use because AISC provides relatively simple equations for calculating the flexural strength. However, it is much difficult to calculate the flexural strength of CFT using other codes, especially for circular CFT. Therefore, this study attempts to suggest a convenient algorithm computing flexural strength of circular CFT corresponding to each code. Finally, this suggested computer algorithm is programmed using MATLAB and expected to be useful to make a design aid chart for various steel grades and strengths.

1. INTRODUCTION

Recently a lot of long span structures are built, and usage of concrete filled tube (CFT) is becoming greater because of its several structural advantages such as larger stiffness and strength compared to bare steel tubes. By following this trend, the use of CFT beams is promoted. The flexural strength of CFT can be estimated according to available codes but the differences between the codes exist (ACI 2014, AISC 2011, Eurocode 2004, Leon and Hajjar 2008, Kang, Lee, and Rha 2011). In fact, it is more difficult to estimate the flexural strength of circular concrete filled tubes (CCFT) than rectangular CFT due to the complicated computation associated with circular section. Thus, this study aims to provide guides for calculating the flexural strength of circular CCFT which is subjected to pure bending. For the beginning, the differences between the ACI, AISC, and Eurocode 4 methods are identified. After that, the study proposes a computer program calculating the flexural strength of CCFT. In the end, it compares the

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calculated flexural strengths by the suggested program and the measured flexural strengths from existing experiments to verify the suggested program.

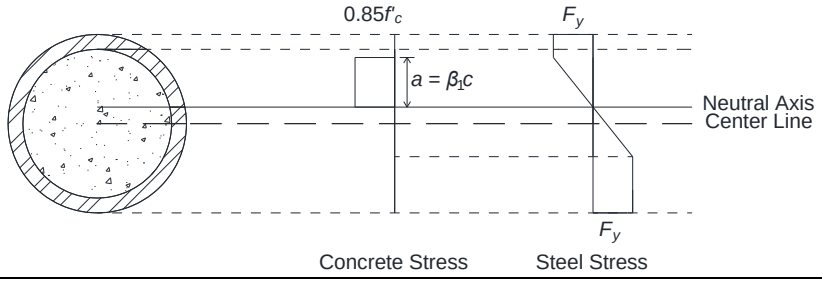
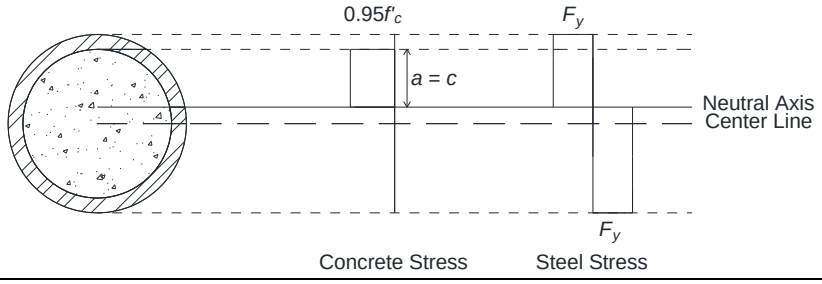
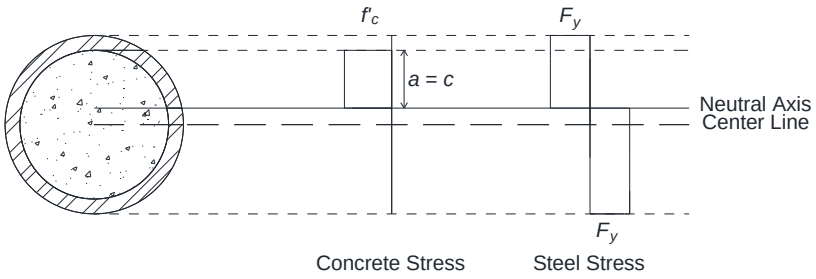
2. ALGORITHM OF COMPUTING FLEXURAL STRENGTH OF CIRCULAR CONCRETE FILLED TUBE ACCORDING TO EACH CODE

From ACI, AISC, and Eurocode 4, the flexural capacity of circular concrete filled tube (CCFT) can be calculated, but each code has different assumptions, so somewhat different values of flexural capacities are calculated according to each code. The differences are mentioned in the following subsections and all those differences are directly implemented to the programmed algorithm.

2.1 Flexural Strength of Circular Concrete Filled Tube according to ACI, AISC, and Eurocode 4

ACI, AISC, and Eurocode 4 provide the methods of computing flexural strength of circular concrete filled tube as mentioned earlier. Moreover, there are some differences between them and those differences mainly lie on the assumed stress distributions of concrete and steel at the ultimate state as shown in Table 1.

Table 1. Flexural Strength of CCFT according to Each Code

	Stress Distribution of Concrete and Steel
ACI	
PSDM of AISC	
PSDM of Eurocode 4	

First of all, the method of ACI regards CFT as regular reinforced concrete by replacing steel with the same amount of reinforcing bars, considering that steel and concrete follow the strain compatibility. The compressive strength of concrete is estimated when the strain of concrete reaches 0.003 and tensile strength of concrete is ignored as in reinforced concrete. Furthermore, the compressive strength of concrete can be assumed to have an equivalent rectangular stress distribution and the value of it is $0.85f'_c$. The depth of concrete equivalent stress block, a, is set equal to $\beta_1 c$. On the other hand, steel is assumed to be an elastic-perfectly plastic material.

In fact, the strain compatibility method (SCM) of AISC, which is one of two methods that AISC specifies, is almost the same as the ACI method. The Eurocode also provides two methods as AISC but the SCM of Eurocode is different from the ACI or AISC approach. The differences arise because the Eurocode assumes that the compressive strength of concrete is estimated when the strain of concrete reaches 0.0035. Moreover, the compressive strength of concrete is assumed to have trapezoidal or curved shape stress distribution in the SCM of Eurocode.

Another method that AISC and Eurocode specify is the plastic stress distribution method (PSDM), but PSDM of AISC and PSDM of Eurocode are not the same. The PSDM of AISC is assumed such that the flexural strength is estimated when steel has a plastic stress distribution and concrete has an equivalent rectangular stress distribution. The compressive of concrete at that time is $0.95f'_c$ for CCFT and the depth of concrete equivalent stress block is equal to the distance from the extreme top fiber of concrete to neutral axis.

Eurocode 4 also suggests the method of computing flexural strength of CCFT in PSDM. It is also assumed that the flexural strength is estimated when steel has a plastic stress distribution and concrete has an equivalent rectangular stress distribution. The only difference is that the compressive of concrete f'_c while the depth of a concrete equivalent stress block is the distance from the extreme top fiber to neutral axis as PSDM of AISC.

2.2 Process for Computing Flexural Strength of Circular Concrete Filled Tube

Even though several methods are available for calculating the flexural strength of CFT, it is still difficult to hand-calculate circular shaped concrete filled tubes exactly. For this reason, there is a need to use a computer program to calculate the flexural strength of CCFT for accuracy and convenience, and mostly for generation of a design aid chart. This study attempts to propose the calculating program.

For calculating the flexural strength, the way of separating section is important and should be carefully considered for section analysis. That's because the errors such as Figures 1 and 2 can be caused by having missing and additional parts of section. Thus, this study is assumed that CCFT consists of three components in the developed computer program; imaginary outer steel, imaginary inner steel and inner concrete, and analyze each component separately to avoid errors. Figure 3 is a conceptual diagram which is applied to the calculating program. In the suggested program, three components are analyzed independently first and then the sectional analysis of inner small steel is subtracted from that of outer large steel but the sectional analysis of inner concrete is added afterwards.

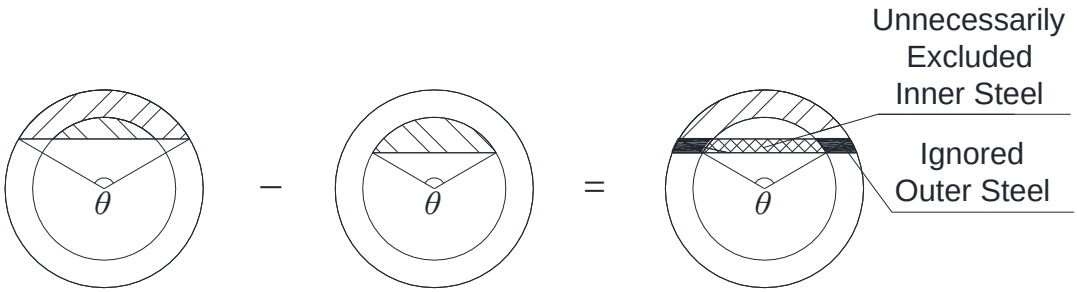


Fig 1. Errors Caused by Circular Segment Analysis for Steel Tube

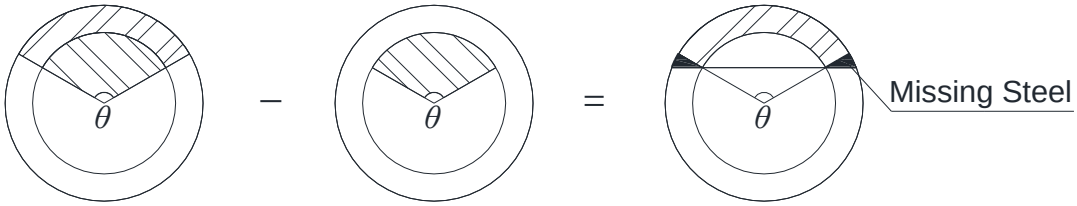


Fig 2. Errors Caused by Circular Sector Analysis for Steel Tube

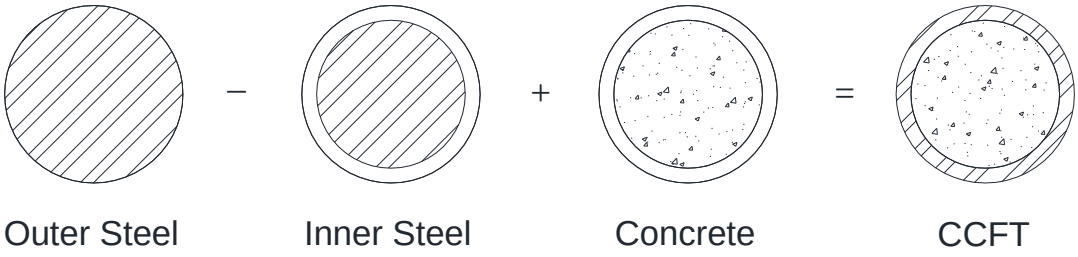


Fig 3. Conceptual Diagram for calculating program

The following Figure 4 represents the algorithm of calculating the flexural strength of CCFT. At the beginning of the program, the following parameters are entered by a user as input data: b_o, t, F_y, E_s, and f'_c which are the outer diameter of steel, thickness of steel, yielding stress of steel, Young's modulus of steel, and concrete strength, respectively. After that, the user also can choose the method to calculate the flexural strength of CCFT. The program is set to find the neutral axis of CCFT section. The neutral axis is located when the sum of forces from all materials becomes zero and from this equilibrium the neutral axis can be found mathematically. If temporary values of variables do not produce the condition of sectional equilibrium, the program is operated to iterate the process until finding the equilibrium condition and corresponding neutral axis. During this process, other parameters of d_1, d_2, d_3, and d_4 in the flow chart represent the vertical distances relating to specific locations from the neutral axis and yield parts in compression and tension regions as shown in Figure 5.

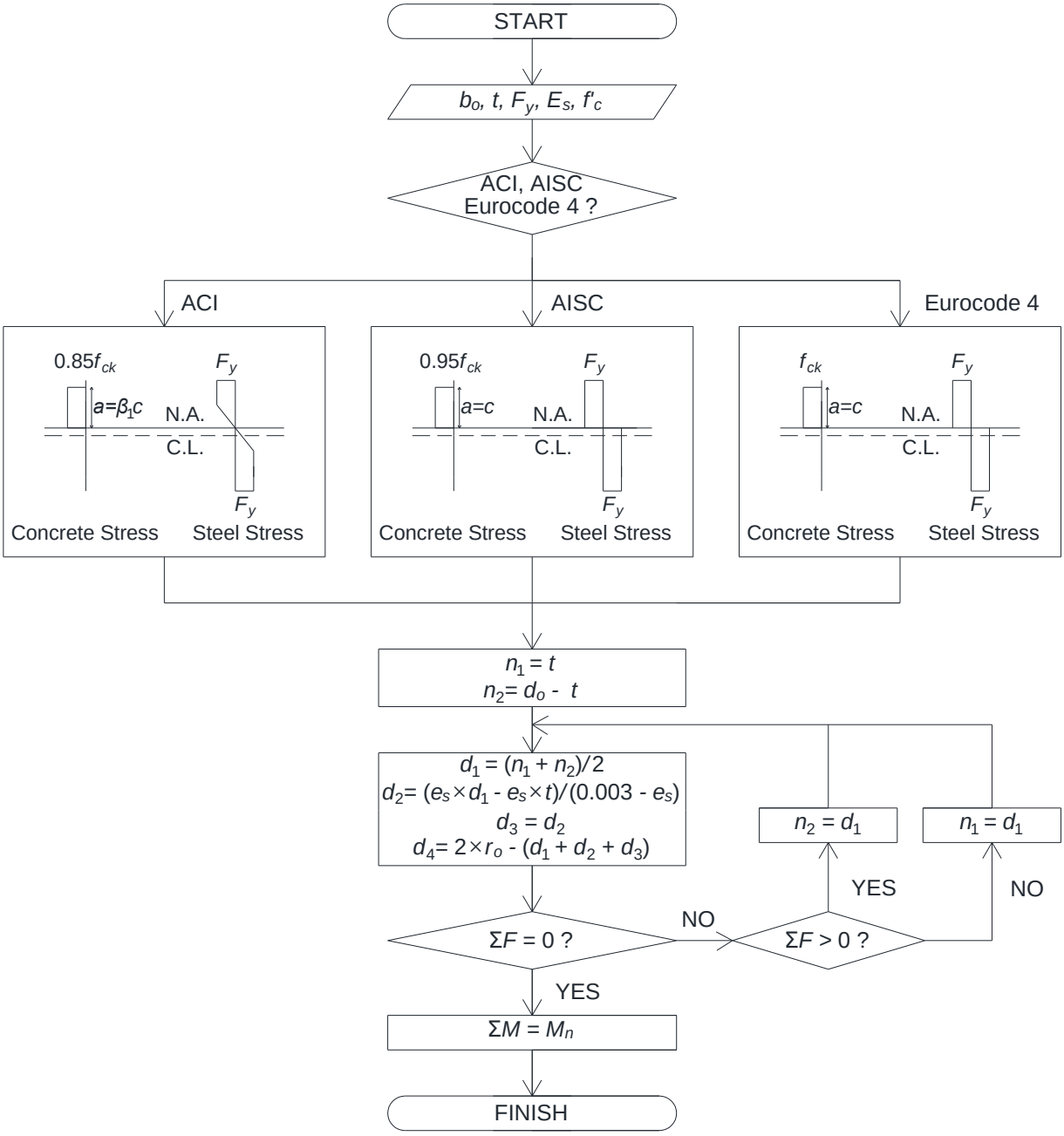


Fig 4. Flow Chart of Computing Flexural Strength of CCFT

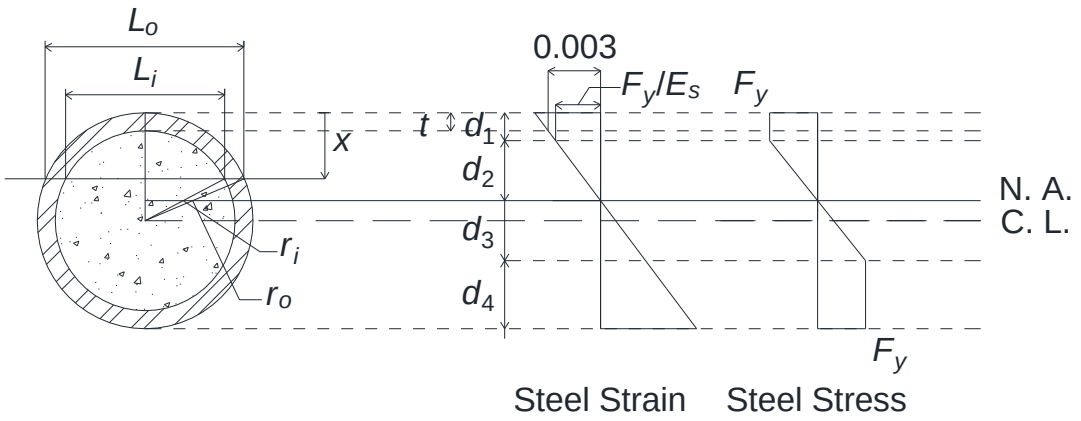


Fig 5. Section Analysis according to ACI Method Applied to the Computing Program

After finding the neutral axis, it is possible to determine the flexural strength of CCFT which is the main purpose of the suggested program. The flexural strength of CCFT is obtained by Eq. (1) which is in line with the concept of Figure 3.

$$M_n = M_{outersteel} - M_{innersteel} + M_{innerconcrete} \tag{1}$$

3. FLEXURAL STRENGTH OF CIRCULAR CONCRETE FILLED TUBE

To examine the suggested program and to check how different between each method, this study compares the measured flexural strength of CCFT form real experiment and the calculated flexural strength of CCFT by the suggested program.

3.1 Experimental and Modeling Specimens

This study focuses only on the circular concrete filled tubes under pure bending. A total of 13 specimens are used for investigation of the flexural strength of CCFT, which were subjected to pure bending with no axial force, and are used to compare the measured and calculated flexural strengths. All specimens were from other researchers as listed in the reference list. The suggested program is started to operate after the user enters input data, and those input data for each specimen are shown in Table 2.

Table 2. Input Data for Each Specimen

Shape	b_o [mm]	t [mm]	F_y [MPa]	E_s [MPa]	f'_c [MPa]
Circular 152x1.65	152	1.65	362	200,000	73.00
Circular 152x1.65	152	1.65	328	200,000	92.00
Circular 200x3.2	200	3.20	400	200,000	50.00
Circular 200x3.2	200	3.20	400	200,000	19.20
Circular 200x4.5	200	4.50	400	200,000	50.00
Circular 200x4.5	200	4.50	400	200,000	19.20
Circular 200x6.0	200	6.00	400	200,000	50.00
Circular 200x6.0	200	6.00	400	200,000	19.20
Circular 406x6.4	406	6.40	350	200,000	40.00
Circular 406x6.4	406	6.40	350	200,000	55.00
Circular 456x6.4	456	6.40	350	200,000	48.00
Circular 456x6.4	456	6.40	350	200,000	56.00
Circular 457x12.7	457	12.70	407	200,000	22.44

3.2 Comparison between Measured and Calculated Flexural Strengths according to Each Code

The program is designed to select the code among ACI, AISC, and Eurocode 4 and calculate the flexural strength of CCFT for each code. The result of the suggested program is summarized in Table 3 which represents the nominal flexural strength calculated for each CCFT.

Table 3. Results of Calculated and Measured Flexural Strengths of CCFT

Shape	Calculated [kN-m]			Measured [kN-m]
	ACI	AISC	EC4	
Circular 152x1.65	12.2 (0.627)	12.3 (0.634)	12.3 (0.636)	19.4
Circular 152x1.65	15.2 (0.725)	15.4 (0.734)	15.5 (0.736)	21.0
Circular 200x3.2	60.8 (0.697)	62.7 (0.719)	63.0 (0.722)	87.3
Circular 200x3.2	55.2 (0.684)	58.0 (0.718)	58.2 (0.721)	80.7
Circular 200x4.5	80.2 (0.666)	83.1 (0.690)	83.5 (0.693)	120.5
Circular 200x4.5	73.2 (0.662)	77.2 (0.698)	77.4 (0.700)	110.6
Circular 200x6.0	102.1 (0.669)	106.1 (0.708)	106.6 (0.698)	152.6
Circular 200x6.0	93.8 (0.670)	99.2 (0.889)	99.5 (0.710)	140.1
Circular 406x6.4	423.7 (0.867)	434.9 (0.897)	436.8 (0.893)	489.0
Circular 406x6.4	436.9 (0.877)	446.7 (0.897)	448.5 (0.901)	498.0
Circular 456x6.4	552.6 (0.877)	565.2 (0.885)	567.6 (0.901)	630.0
Circular 456x6.4	560.6 (0.866)	572.4 (1.262)	574.7 (0.888)	647.0
Circular 457x12.7	1062.6 (1.195)	1122.0 (1.174)	1125.8 (1.266)	889.0

As shown in Table 3, not only between calculated and measured flexural strengths of CCFT but also between calculated flexural strengths according to the codes, there are differences in strength. The values in parentheses are the calculated to measured flexural strength ratios, which show conservative flexural strength estimations except for the last two specimens in Table 3. As shown in the values of the ratios, the flexural strength based on the ACI method is more conservative than the AISC and Eurocode 4 methods for all cases.

4. CONCLUSIONS

This study investigates the flexural strength of circular concrete filled tubes (CCFT) calculated according to ACI, AISC, and Eurocode 4. The differences between the codes come from each code's basic concept and/or assumption. Mostly, the stress

distributions of concrete and steel at the ultimate stage are different. By accurately accounting for these differences, the suggested estimating program is set to run for calculating the flexural strength of CCFT. The suggested program is configured to accept the material properties of diverse CCFTs, so that it can be used for estimating any kind of CCFT's flexural strength. Therefore, the suggested program is expected to be useful to generate a design aid chart for various steel grades and various strengths of steel and concrete in the future.

Moreover, to verify the performance of the suggested calculating program, this study compares the calculated flexural strength by the program and measured flexural strength from real experiments. Based on the comparison, there are differences between calculated and measured flexural strengths, and only by using the ACI method the flexural strength of CCFT can be more conservatively estimated. However, this study only deals with a few specimens, and there is a need to have a further research to obtain more experimental values and evaluate the cod-specified values with sufficient experimental data.

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