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Concrete filled double skin circular tubes: a review

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Abstract. A review of the research conducted on the compressive strength of concrete filled double skin circular tubes (CFDSCT) columns is conducted. Variables of the CFDSCT considered in this review include the concrete strength, steel strength, inner and outer tube diameter, steel thickness and length of the stub columns. Test results show that the composite columns had compressive strengths of up to 41% higher than the sum of the individual strengths of the section. All the outer tubes of these composite columns by failed local buckling. A review of the design equations proposed are presented and discussed. The paper also identifies gaps for further research for these types of columns.

Keywords. Concrete-filled tube, stub columns, local buckling, double skin, axial compression, CFDSCT, confinement effect.

Introduction

In multi-storey buildings architects may detail downpipes or other services like electrical wiring in the centre of columns. This is done for aesthetic reasons. One way of achieving this is to use concrete filled double skin tubes (CFDSTs). Concrete filled double skin tubes (CFDSTs) are structural members that have a double steel skin with concrete sandwiched between the two steel tubes. These structural elements range from concrete filled double skin rectangular tubes (CFDSRTs), concrete filled double skin circular tubes (CFDSCTs) to concrete filled double skin square-circular tubes (CFDSSCTs), as shown in Figure 1.

These members are economical and quicker to construct when compared to conventional concrete reinforced columns because the steel tube serves as form-work. The concrete fill prevents the outer steel tube from buckling inwards whilst the steel prevents the concrete from deforming laterally, under compressive loads. CFDST columns have structural benefits similar to concrete filled tube (CFT) columns, however, CFDST are lighter, stronger and possesses better energy absorption when compared to CFT columns [1, 2].

Zhao and Han [2] have listed research work done in this field and Elchalakani et al. [1] have conducted research on stub CFSDT columns with a square hollow inner tubes and circular hollow outer tubes. The slenderness ratios of the stub columns tested by Elchalakani et al. [1] ranged from 35 to 90. It was found from this investigation that a simple arithmetic addition of the strengths of the steel tubes and concrete predicted the

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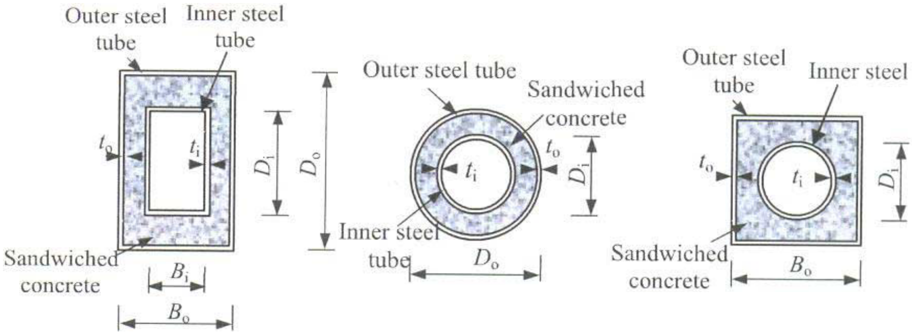

(a) CFDSRT (b) CFDSCT (c)CFDSSCT

Figure 1. Cross section of CFDSTs

test results well. Yang et al. [4] conducted research on CFDST with an octagonal outer tube and a circular inner tube. From the results of this experiment, it was found that the axial capacity of the proposed CFDST columns was larger than CFDSTs with a square outer tube and a circular inner tube and smaller than CFDSTs with a circular outer tube and a circular inner tube. The CFDST's were modelled numerically and the results obtained agreed well with the proposed simple formula. This aim of this paper is to review CFDSCT only.

1. Literature review

1.1. Tested specimen

Tao et al. [4] conducted 12 tests on CFDSCT stub columns. The lengths of the stub columns varied from 342 and 900 mm. Two concrete filled circular tube (CFCT) columns were also tested in order to compare the results against the CFDST results. The concrete cube strength was 47 MPa at the time of the test and the yield strength of the steel inner tube (f_{yi}) varied from 295 to 396 MPa, while that of the outer tube (f_{yo}) was either 276 or 295 MPa. As given in Table 1 the outside tube diameters (D_o) were 114, 180, 240 and 300 mm and the inside tube diameters (D_i) were 48, 58, 88, 114, 140 and 165 mm.

Uenaka et al. [5] tested 12 stub columns in total. Nine out of the twelve samples were CFDSCT stub columns and the remainder were CFT columns. The concrete strength was 23 MPa. Outer tubes had an average dimension of 158 mm while the average dimensions of the inner tubes were 39, 77 and 114 mm. The inner and outer steel tubes' strengths ranged from 221 to 308 MPa and each stub column was 450 mm in length.

Wei et al. [6] conducted tests on CFDSCT with outer tube diameters ranging from 74.7 to 114.3 mm and inner tube diameters ranging from 61.2 to 88.9mm. The diameter-to-thickness ratio of the outer tubes varied from 43 to 169. Aggregates made up 86% of the polymer concrete in terms of its weight and the remaining 14% was polymer resin. The polymer concrete strength achieved was 75 MPa. As shown in Table 3, the yield strengths of the inner tubes and outer tubes ranged from 216 to 512 MPa and 255 to 524 MPa, respectively. All the stub columns were machined to have a length of 230 mm.

1.2. Failure modes

Uenaka et al. [5], Tao et al. [4] and Wei et al. [6], all found that the mode of failure of the outer tube was outward local buckling. The diameter-to-thickness ratios of these tubes ranged from 38 to 176. Uenaka et al. [5] and Wei et al. [6] also noted that the inner tubes failed by inward local buckling. After exposing the concrete infill, both authors found that the concrete infill had failed by shear. The diameter-to-thickness ratios for the inner tubes ranged from 19 to 146. Tao et al. [4], however, found that the inner tubes with larger diameter-to-thickness ratios failed by inward local buckling of the tube, whilst those with smaller diameter-to-thickness ratios showed no sign of local buckling.

1.3. Test strength results

The yield strengths of the steel used by all authors ranges from low to medium strength steel. Such steel is expected to achieve the required ductility. None of the researchers tested slender columns since the main aim of these testing programmes were to determine the behaviour and strength of stub columns. Simply supported end conditions were simulated in all the tests performed. The tests results for the stub columns conducted by Tao et al. [4], Uenaka et al. [5] and Wei et al. [6] are given in Tables 1, 2 and 3, respectively. In these tables N_T represent the test compressive strength and N_P represent the sum of the strengths of the individual components (two tubes plus the concrete infill).

Based on the test results in Table 1, Tao et al. [4] suggested that concrete confinement exist in CFDSCT, and proposed a basic formula, given in Equation 1, to define the strengths of these stub columns.

$$N_u = \left(C_1\chi^2 f_{syo} + C_2(1.14 + 1.02\xi)f_{ck}\right)A_{sco} + A_{si}f_{syi} \qquad (1)$$

where χ is the hollowness ratio of the inner tube over the outer tube, ξ is the confinement factor that is equal to the product of the area of steel and yield stress of steel divided by the product of the area of concrete and the yield stress of the concrete, f_{syo} is the yield strength for the outer tube, f_{ck} is the cylindrical strength for the concrete, A_{sco} is the area of the outer tube and sandwiched concrete, A_{si} is the area of the inner steel tube and f_{syi} is the yield strength of the inner tube, $C_1 = \alpha/(1+\alpha)$ and $C_2 = (1+\alpha)/(1+\alpha_n)$. In C_1 and C_2, α is equal to the area of steel over the area of concrete and αn is the same with only the nominal area of concrete. Equation 1 is a modification of the sum of the individual strengths of the steel tubes and concrete and assumes that the inner steel tube only acts compositely when the hollowness ratio is less than 0.8. It is clear from the results in Table 1 that although Equation 1 suggests that the outer tube causes enhancement, there is little or no enhancement.

Table 1. Tao et al. test results

Test	D_o (mm)	D_i (mm)	D_o/t_o	D_i/t_i	f_{yi} (MPa)	f_{yo} (MPa)	N_T (kN)	N_P (kN)	N_T/N_P
1	180	-	60	-	-	276	1680	1547	1.09
2	180	-	60	-	-	276	1618	1547	1.05
3	180	48	60	16	396	276	1790	1633	1.10
4	180	48	60	16	396	276	1791	1633	1.10
5	180	88	60	29	370	276	1648	1566	1.05
6	180	88	60	29	370	276	1650	1566	1.05
7	180	140	60	47	342	276	1435	1285	1.12
8	180	140	60	47	342	276	1358	1285	1.06
9	114	58	38	19	375	295	904	830	1.09
10	114	58	38	19	375	295	898	830	1.08
11	240	114	80	38	295	276	2421	2376	1.02
12	240	114	80	38	295	276	2460	2376	1.04
13	300	165	100	55	321	276	3331	3283	1.01
14	300	165	100	55	321	276	3266	3283	0.99

Uenaka et al's [5] test-to-predicted strengths in Table 2, imply that there is significant concrete confinement in the CFDSCT and that the concrete confinement exists only because of the outer tube. According to Uenaka et al. [5] the effect of confinement became smaller as the internal diameter increased. In Uenaka et al. [5] results, strength enhancement ranges from almost 0 to 41%, and based on these experimental results, Equation 2 was developed.

$$N_u = \left[2.86 - 2.59\left(d_i / d_o\right)\right] A_{so} f_{yo} + A_{si} f_{yi} + A_c f_c^{'} \qquad 0.2 \leq di/do \leq 0.7 \quad (2)$$

where, N_u is the axial capacity, D_i is the inner tube diameter, D_o is the outer tube diameter, A_{so} is the area of the outer tube, f_{yo} is the yield strength of the outer tube, A_{si} is the area of the inner tubes, f_{yi} is the yield strength of the inner tube, A_c is the area of concrete and f'_c is the cube strength of the concrete. Similarly to Equation 1, Equation 2 is a modification of the sum of the individual strengths of each material. As indicated above, the results obtained by Uenaka et al. [5] vary by a large margin. Such a large variation casts doubt on the accuracy of Equation 2.

Table 2. Uenaka et al. test results

Test	D_o (mm)	D_i (mm)	D_o/t_o	D_i/t_i	f_{yi} (MPa)	f_{yo} (MPa)	N_T (kN)	N_P (kN)	N_T/N_P
1	159	-	176	-	221	221	700	497	1.41
2	158	38	176	43	221	221	635	450	1.41
3	159	76	176	84	221	221	540	440	1.23
4	159	114	176	126	221	221	378	395	0.96
5	158	-	105	-	308	308	815	581	1.40
6	158	39	105	26	308	308	852	648	1.31
7	158	77	106	51	308	308	728	640	1.14
8	158	114	106	76	308	308	589	542	1.09
9	158	-	74	-	286	286	908	680	1.33
10	158	40	74	19	286	286	968	705	1.37
11	158	77	74	36	286	286	879	752	1.17
12	157	115	73	54	286	286	704	697	1.01

Wei et al. [6] found that the average test strength of the CFDSCT is 15% larger than the sum of the strengths of the individual components (Table 3). Most of the results in this table are closer to Tao et al. [4] test results. Based on the variation of the strength results in Tables 1–3 and the discussion above, it inconclusive as to whether there is useful confinement in CFDSCT or not. The test-to-predicted strength in Tables 1 suggests that the test values can clearly be represented by the sum of the individual strengths of the materials.

Table 3. Wei et al. test results

Test	D_o (mm)	D_i (mm)	D_o/t	D_i/t	f_{yi} (MPa)	f_{yo} (MPa)	N_T (kN)	N_P (kN)	N_T/N_P
1	74.8	62.0	73	62	470	486	283	264	1.07
2	74.7	62.0	77	66	470	486	285	254	1.12
3	75.4	62.7	58	51	470	486	348	325	1.07
4	75.2	62.4	63	52	470	486	348	314	1.11
5	76.3	62.0	43	62	470	486	395	350	1.13
6	76.3	62.0	44	66	470	512	395	353	1.12
7	81.0	62.0	90	62	470	524	330	303	1.09
8	81.0	62.0	93	66	470	524	335	294	1.14
9	81.5	62.7	73	55	470	524	386	348	1.11
10	81.5	62.2	71	55	470	524	395	350	1.13
11	87.4	61.8	88	71	452	428	378	338	1.12
12	87.3	61.6	93	70	452	428	385	332	1.16
13	87.9	61.4	70	69	452	428	432	363	1.19
14	87.9	61.2	75	72	452	444	408	371	1.1
15	99.7	80.3	169	146	474	409	283	238	1.19
16	99.9	86.8	145	142	444	409	299	228	1.31
17	99.9	80.5	141	120	474	409	357	275	1.3
18	99.9	74.0	143	119	512	409	380	302	1.26
19	99.8	61.4	151	112	432	409	443	389	1.14
20	101.7	61.5	63	110	432	409	644	541	1.19
21	88.8	63.5	57	55	216	286	357	319	1.12
22	101.4	63.4	65	55	216	255	477	426	1.12
23	101.5	76.1	62	64	235	255	417	363	1.15
24	114.3	63.5	70	57	216	262	598	549	1.09
25	114.3	76.1	70	67	235	262	551	492	1.12
26	114.3	88.9	70	57	286	262	524	460	1.14

2. Conclusions

This paper provides a review of the literature available on CFDSCT short columns. The stub columns are intended to give guidance for the design of long columns. Important aspects of each paper are covered, which include the specimen dimensions and properties, failure modes, effects of confinement, test results and the proposed design formulations. As expected, the mode of failure of the outer tubes was outward local buckling. All authors reviewed also found that the inner tubes of some CSDSCT failed by inward local buckling and shear of the concrete infill. This was common in inner tubes with larger diameter-to-thickness ratio. The availability of concrete confinement varied from author to author. Tao et al. [4] results suggest that there is no enhancement; Uenaka et al. [5] results suggest that confinement ranges from 0 to 41%, and Wei et al. [6] results suggest that test specimen have an average of 15% confinement. Based on the discussions above it is inconclusive to judge whether there is useful confinement in CFDSCT or not.

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