Journal of Engineering and Development
www.jead.org
Vol. 20, No.02, March 2016
ISSN 1813-7822

BEHAVIOR OF CONCRETE FILLED DOUBLE SKIN STEEL TUBULAR COLUMNS UNDER STATIC AXIAL COMPRESSION LOAD

Dr. Riyadh J. Aziz[1], Dr. Laith Kh. Al-Hadithy[2], *Shayma M. Resen[3]

1) Assist Prof., Civil Engineering Department, Al-Israa University College, Baghdad, Iraq.
2) Assist Prof., Civil Engineering Department, Al-Nahrain University, Baghdad, Iraq.
3) Ph.D. Student., Civil Engineering Department, Al-Nahrain University, Baghdad, Iraq

(Received: 08/10/2015; Accepted: 8/12/2015)

Abstract: Concrete Filled Double-Skinned Steel Tubular Columns CFDSST are composite columns consisting of two concentric circular steel tubes with concrete filler in between. This research studies the behavior of the CFDSST columns under axial compression load.An experimental program included the fabrication of scaled columns of (5) CFDSST specimens of an outer tube diameter of (114 mm), and length of (600 mm). Three of them have three different thicknesses of outer steel tube and two with different hollowness ratios subjected to axial compression load. Making use of its ability to flow under its self weight, Self Compacting Concrete (SCC) used as the filled concrete. The experimental test results were presented in terms of load displacement curves and the axial and hoop strains at mid height of the outer tubes. Effect of the outer steel tube thickness on the axial capacity was studied as well the effect of Hollowness ratio was taken into account in this study. It was found that the axial load carrying capacity increased as the thickness of the outer steel tube increased since the confinement pressure increased.

Keywords: *CFDSST, composite columns, Self compacting concrete, experimental,*

سلوك الاعمدة الحديدية الانبوبية ثنائية القشرة المملوؤة بالخرسانة تحت حمل عمودي ساكن

الخلاصة: الاعمده الفولاذيه ثنائيه القشره المملوؤة بالخرسانةCFDSST هي نوع جديد من الاعمدة المركبة، حيث انها تتكون من أنبوبين حديدين خارجي وداخلي وفراغ بينهم يملئ بالخرسانة. في هذا البحث تم دراسه سلوك الاعمده CFDSSTتحت تاثير حمل عمودي ، حيث يشتمل الجزء العملي على إعداد واختبار خمسة نماذج بقطر خارجي مقداره (114 مم) وطول (600 مم) وبثلاث اسماك مختلفة للانبوب الخارجيواثنينبنسبة مختلفة لحجم الفراغ . بسبب قابليتها على الجريان بسهوله تم استخدام الخراسانة ذاتية الرص لملئ الفراغ بين الانابيب الحديدية. عرضت النتائج العملية من خلال علاقات الحمل والازاحة العمودية ، بالاضافة الى قياس مقدار الانفعالي الطولي والطوقي في منتصف الارتفاع للنابيب الخارجيه. وجد من خلال هذا البحث ان زيادة سمك الانبوب الخارجي يؤدي الى زيادة ضغط الحصر على الخرسانة وبالتالي زيادة التحمل العمودي للعمود.

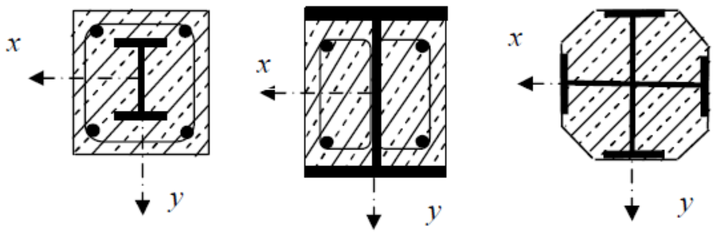
1. Introduction

A composite steel-concrete column can be defined as a compression member, which may be either a concrete encased steel section or a concrete filled steel tubular section. During the past decades composite columns have been used for high-rise

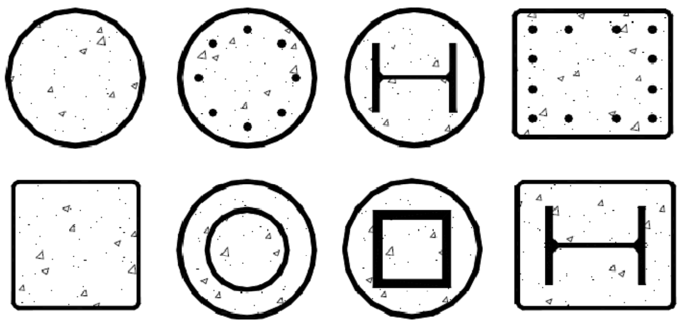
* shayma.mohammed2@gmail.com

buildings as an alternative to ordinary reinforced concrete. Recently, compositecolumns have been increasingly used throughout the world, which has been affected by the development of high strength concrete enabling these columns to be considerably economized.

Two types of steel concrete composite columns, those with steel section encased in concrete and those with steel section in-filled with concrete are commonly used in buildings. Basic forms of cross-sections representative of composite columns are indicated in Fig. (1) Concrete-encased steel composite columns have become the preferred form for many seismic-resistant structures. CFST (Concrete Filled Steel Tubular) columns were used for earthquake-resistant structures, bridge piers subject to impact loading from traffic, columns considered for supporting storage tanks, decks of railways, columns in high-rise buildings and as piles. Concrete-filled steel tubes require additional fire-resistant insulation if fire protection of the structure is necessary [1].



(a) Encased composite steel concrete columns



(b) In filled composite steel concrete columns

Figure (1), Types of concrete steel composite column, [1].

In the recent years, possibility of using self-compacting concrete (SCC) has been received very favorably by structural engineers. SCC may be considered as a revolution in the field of concrete technology. The self-compactability of concrete refers to the capability of the concrete mix to flow under gravity and fill in the formwork in casting process. Due to its rheological properties, many advantages can be mentioned and new structural applications can be realized. Among them concrete filled tubes CFT or concrete filled double skin tubular CFDSST columns.

Elchalakani, et. al [2] reported that CFDSST columns have almost all the same advantages as traditional CFST members. Moreover, they have lighter weight, higher bending stiffness, and have better cyclic performance. It is also expected that CFDSST columns will have higher fire resistance capacities than their CFST counterparts, because the inner tubes of the former being protected effectively by the sandwiched concrete under fire condition.

2. CFDSST Columns under Axial Compression

Axial force is the major force applied to columns in tall buildings. The benefit of using concrete filled columns is to enhance the load carrying capacity of columns. Many experiments were conducted on concrete filled columns subjected to axial loads. The ultimate loads of short columns with stocky tubular sections are considerably larger than the nominal axial load capacities. The reason for this increase in the ultimate load is attributed to the strain hardening effect of steel tubes and confinement effect of concrete [3].

Tomii [4], found that the measured axial load carrying capacities of concrete filled steel tubes was greater than the nominal capacity, which was defined as the sum of the compressive strength of the unconfined concrete and steel. This was related mainly to triaxial containment of the concrete and the strain hardening of the steel.

Han et. al., [5], showed that, when the CFDSST column member is axially compressed, the three components, inner tube, outer tube, and the concrete, are supposed to be subjected to the same axial strain. The axial load sustained at this strain is the sum of the forces acting on the three components.

$$N = A_c f_c + A_{it} f_{it} + A_{ot} f_{ot} \qquad (1)$$

where,

A_c =cross sectional area of concrete,

A_{it} =cross sectional area of inner steel tube,

A_{ot} = cross-sectional areas of outer tube,

f_{it} =axial stress of the inner steel tube,

f_{ot}= axial stresses of the outer tube.

The nominal strength CFDSST columns calculated from the sum of the strengths of three components according to equation (1) was verified with that got from experimental tested by Wei et al., [6]. It was found that due to the confinement effect of outer and inner tubes, the sum of the strengths of three components agrees with the test result, as shown in Fig. (2).

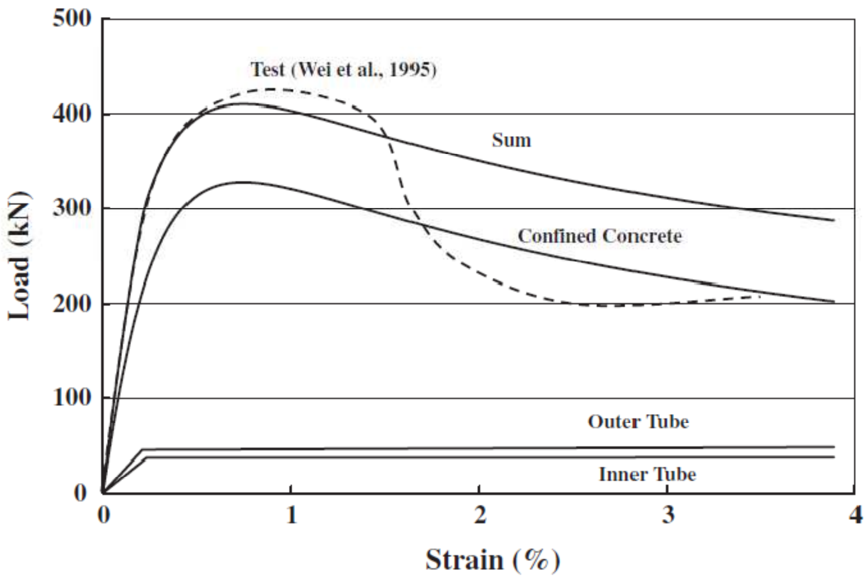


Figure (2), Comparison between analysis and test result for the strength of CFSSDT columnmember,**[5]**

3. Experimental Works.

3.1 CFDSST Column Details

A set of CFDSST columns with both inner and outer tubes made of steel and have circular shape have been prepared according to the experimental program to be tested, Fig**.** (3), shows a schematic view of the CFDSST specimens.

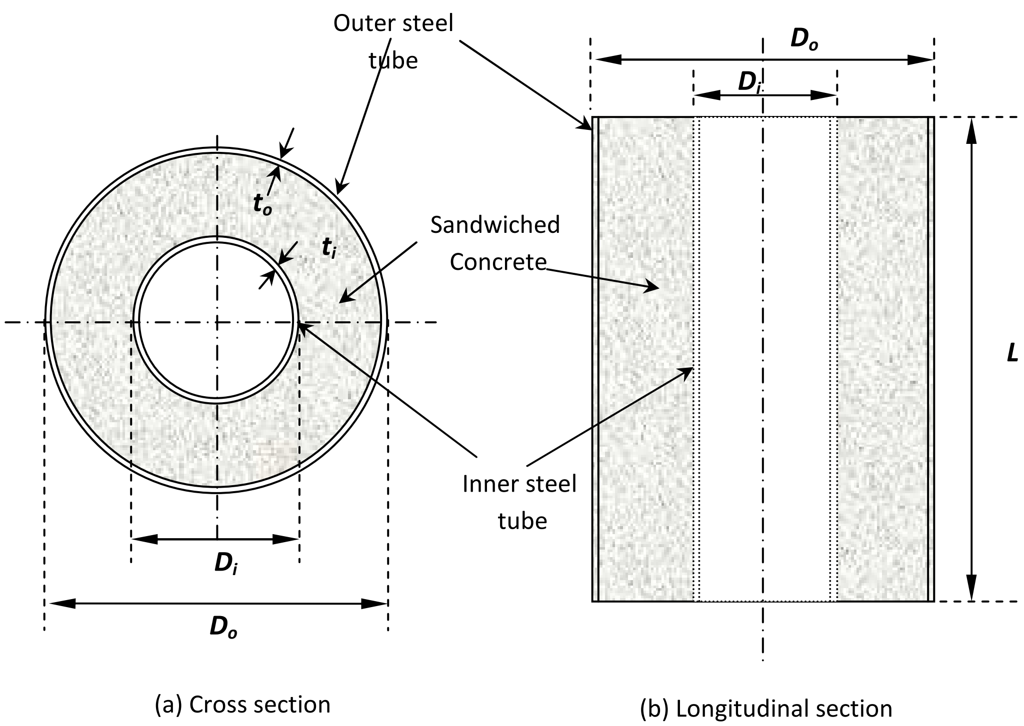


Fig. (3) CFDSST columns details, (a) Cross section, (b) Longitudinal section

3.2 Experimental Program.

The experimental program included preparation and testing of five CFDSST specimens, the hollowness ratios (χ), and the thickness of the outer steel tube are the parameters investigated throw out this study. Each column has been tested under axial compression loading which marked as (DSM-Ti-Hi), where, T and H are the thickness and hollowness ratio respectively. All specimens have the same length of (600 mm), Table (1) include details of the experimental program and CFDSST specimens' details.

Table (1) Experimental program and CFDSST specimens' details

Column designation	D_o (mm)	t_o (mm)	D_i (mm)	t_i (mm)	χ	L (mm)
DSM-T1-H1	114.0	4.5	40	3.0	0.381	600
DSM-T1-H2	114.0	4.5	60	3.8	0.571	600
DSM-T1-H3	114.0	4.5	75	3.0	0.714	600
DSM-T2-H1	114.0	2.0	40	3.3	0.363	600
DSM-T3-H1	114.0	3.0	40	3.3	0.37	600

D_o: Diameter of outer steel tube, t_o: Thickness of outer steel tube, D_i: Diameter of inner steel tube, t_i: Thickness of inner steel tube, L: length of steel tube, χ : Hollowness ratio = $\chi = \frac{D_i}{D_o - 2t_o}$ .Ti: Thickness No. i (i=1(4.5), 2, 3), Hi: Hollowness No. i (i =1(0.381),2(0.571),3(0.714))

4. Material properties

4.1. Steel Tubes

Regarding the properties of the steel tubes used as CFDSST specimens, samples were taken from the original tubes of different thickness. These samples were tested to examine the chemical and physical properties of the used steel tubes. DIN 50125 [**7**] Standard was considered in sampling, getting coupons, and testing steel for getting the tensile strength of steel. The yield stress and the modulus of elasticity are 375 MPa and 200000 MPa, respectively.

4.2 Properties of Filling Concrete

Self-compacting concrete is considered as the filler concrete to create the CFDSST column specimens. The properties of the materials needed to have this kind of concrete are:

4.2.1 Cement:

Ordinary Portland cement (Type-I) was used throughout the experimental program. The chemical composition and physical properties of the cement used comply with the requirements of the Iraqi Specification Standards [8] as shown in table (2) and table (3), respectively.

Table (2): Chemical composition and main compounds of the cement.

No.	Compound Composition	Chemical composition	%(weight)	Iraqi specification No. 5/1984
1	Lime	CaO	60.54	-
2	Silica	SiO2	19.68	-
3	Alumina	Al2O3	5.5	-
4	Iron Oxide	Fe2O3	3.28	-
5	Magnesia	MgO	2.19	max. 5
6	Sulfate	SO3	1.8	max.2.8
7	Loss on ignition	L.O.I	3.72	max.4.0
8	Insoluble residue	I.R	0.54	max.1.5
9	Lime saturation factor	L.S.F	0.93	0.66-1.02
10	Tricalcium silicate	C3S	70.52	-
11	Dicalcium silicate	C2S	2.27	-
12	Tricalcium aluminates	C3A	9.03	-
13	Tricalcium alumina ferrite	C4AF	10.15	-

Table (3) Physical properties of the cement.

Physical properties	Test result	Limit of Iraqi specification No.5/1984
Specific surface area (Blaine Method), m2/kg	352	230 (min)
Setting time (Vicat method)		
Initial setting, hrs: min	1:44	00:45 (min)
Final setting, hrs: min	4:30	10:00 (max)
Compressive strength, MPa3 days	16.8	15.00 (min)
7 days	24.61	23.00 (min)
Autoclave expansion %	0.24	0.8 (max)

4.2.2 Fine aggregate:

Natural sand was used in concrete mixes for, the fine aggregate had rounded partial shape and smooth texture with fineness modulus of (2.78).The obtained results indicate that, the fine aggregate grading is within specification the Iraqi Specification Standards[9] as shown in Table (4).

Table (4) – Physical properties of fine aggregate

Physical properties	Test result	Limit of Iraqi specification No.45/1984
Specific gravity	2.60	-
Sulfate content	0.11%	0.5% (max)
Absorption	0.75%	-

4.2.3 Coarse aggregate:

Crushed gravel brought from Al-Niba'ee region was used, which conforms to the Iraqi Specification [9] as shown in Table (5)

Table (5) Physical properties of coarse aggregate

Physical properties	Test result	Limit of Iraqi specification No.45/1984
Specific gravity	2.60	-
Sulfate content	0.0 6%	0.1% (max)
Absorption	0.75%	-

4.2.4 Water:

Ordinary tap water was used for both mixing and curing of all concrete specimens used in this investigation. It was free from injurious substances like oil and organic materials.

4.2.5 Limestone powder (LSP):

This material is locally named as "Al-Gubra". It is a white grinding material from lime-stones, and is usually used in the construction processes and as filler for concrete production for many years. In the experimental program, a fine limestone powder, grind by blowing technique has been used. Particle size of the limestone powder is less than 0.125 mm, it conforms to EFNARC [10]. The chemical composition of LSP is listed in Table (6).

4.2.6 Superplasticizer:

A superplasticizer type sulphonted melamine and naphthalene formaldehyde condensates, which are known commercially as Gleniume-51, was used in this work. Glenium-51 is free from chlorides and complies with ASTM C 494 [11] types A and F. This admixture provides flowable concrete with greatly reduced water demand.

Table (6) Chemical composition and physical properties of LSP

Oxides	Content %
SiO_2	1.38
Fe_2O_3	0.12
Al_2O_3	0.72
CaO	54.1
MgO	0.13
SO_3	0.21
L.O.I	42.56

4.3Testing Setup

Axial compression loads were applied to CFDSST specimens according to the experimental program. All specimens were tested in the vertical position; vertical level was used to ensure verticality and to avoid any eccentricity. The vertical load was applied at the top end of the CFDSST specimen using a self-supporting loading frame through, where thick steel plates were put over and under the specimens to ensure uniform loading distribution. Safety fence was added to the loading system to prevent any accidental movement of specimens.

The testing program was performed through universal loading system which applies the vertical load through a hydraulic jack of 2000 kN capacity. Loading was controlled through the control box, where load was applied incrementally by subjecting a constant displacement through each cycle of loading. Load in (kN) and displacement in (mm) were automatically recorded by the system.

5. Experimental Program Results and Discussion

According to the experimental program the five CFDSST specimens were tested under axial compression loading, these specimens named as DSM (Double Skin under Monotonic Loading. These Specimens have the same outer diameter but with three different thicknesses so as to investigate the effect of outer tube thickness on the behavior of CFDSST, the hollowness ratio also changed through using three different diameters of the inner tube. Table (7), presents a summary of the experimental program results as well as Details of CFDSST specimens' characteristics and material properties in addition to the ultimate strength of each specimen.

Table (7) Summary of experimental test results

Column designation	$D_o \times t_o$ (mm)	$D_i \times t_i$ (mm)	χ	f_{yo} (MPa)	f_{yi} (MPa)	N_u (kN) Test	N_o (kN)	N_z
DSM-T1-H1	114×4.5	40×3.3	0.381	375	250	1188	927	1.28
DSM-T2-H1	114×2.0	40×3.0	0.363	375	295	632	647	0.97
DSM-T3-H1	114×3.0	40×3.0	0.37	375	295	838	763	1.09
DSM-T1-H2	114×4.5	60×3.8	0.571	375	375	1210	1030	1.17
DSM-T1-H3	114×4.5	75 ×3.3	0.714	375	375	1070	979	1.09

6.1 CFDSST Modes of Failure.

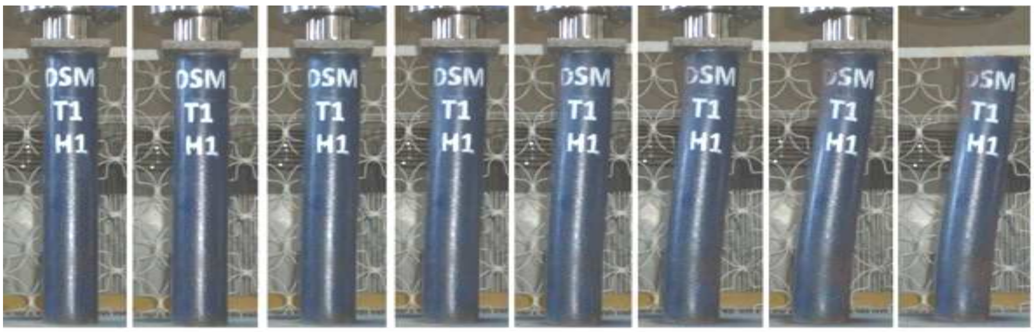
A single cycle of axial compressions was considered as the monotonic loading phase. In this types of loading, load was applied through 2000 kN hydraulic jack which is part of the loading system. Load was applied incrementally by subjecting a constant displacement through each cycle of loading. Load in (kN) and displacement in (mm) were automatically recorded by the system. Specimens were tested until failure, which was considered when displacement continued to increase while load was decreasing.

Testing progress of the five specimens were captured using a fixed camera, pictures were taken as the test ran at constant rate. Fig. (4) shows the testing progress pictures, by examining these pictures, it can be seen that DSM-T1-H1 failed with overall failure, whereas DSM-T2-H1 and DSM-T3-H1 failed with local buckling at the ends and overall buckling concentrated at the middle of the specimens, this was mainly affected by the thickness of the outer steel tube and its yield strength.

Even the hollowness ratio changed for specimens DSM-T1-H1, DSM-T1-H2 and DSM-T1-H3, these tubes failed mainly by the overall buckling mode in addition to slight bulging of the top and bottom ends which is more obvious in the last specimens , as for this specimen the quantity of filled concrete is less than that in the other specimens resulting in a stress concentration near the outer steel tube which made the outer steel tube failing locally.

6.2 Effect of Outer Steel Tube Thickness on the Behavior of CFDSST Specimens

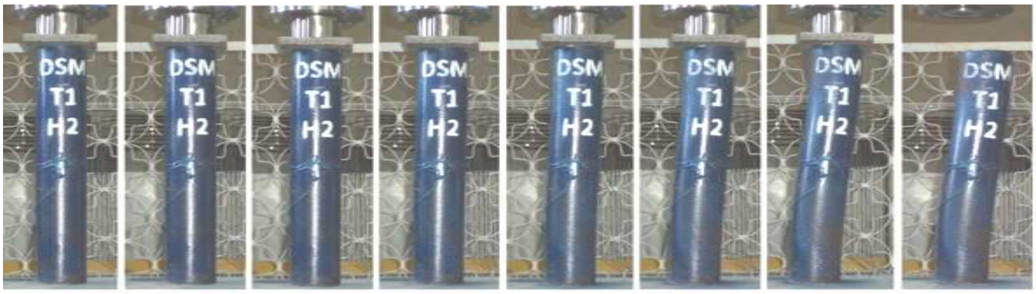
Axial load- axial displacement relationships of these specimens are shown in Fig. (5), in this figure the first specimen with outer tube thickness ($\boldsymbol{t}_o$ = 4.5 mm) provided the maximum axial strength of 1189 kN, the other two specimens showed lower axial strength with 838 kN and 630 kN for DSM-T3-H1 and DSM-T2-H1, respectively.



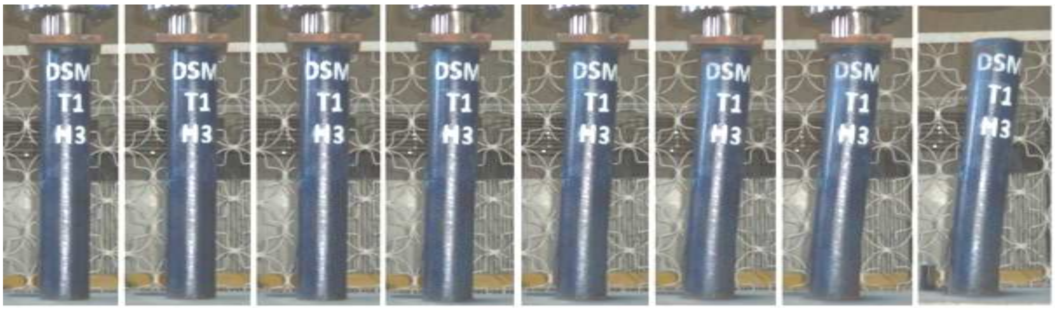
a) CFDSST Specimen no. (1), labeled as (DSM-T1-H1)

b) CFDSST Specimen no. (2), labeled as (DSM-T2-H1)

c) CFDSST Specimen no. (3), labeled as (DSM-T3-H1)



d) CFDSST Specimen no. (4), labeled as (DSM-T1-H2)



e) CFDSST Specimen no. (5), labeled as (DSM-T1-H3)

Figure (4) Testing progress of CFDSST specimens under axial compression load.

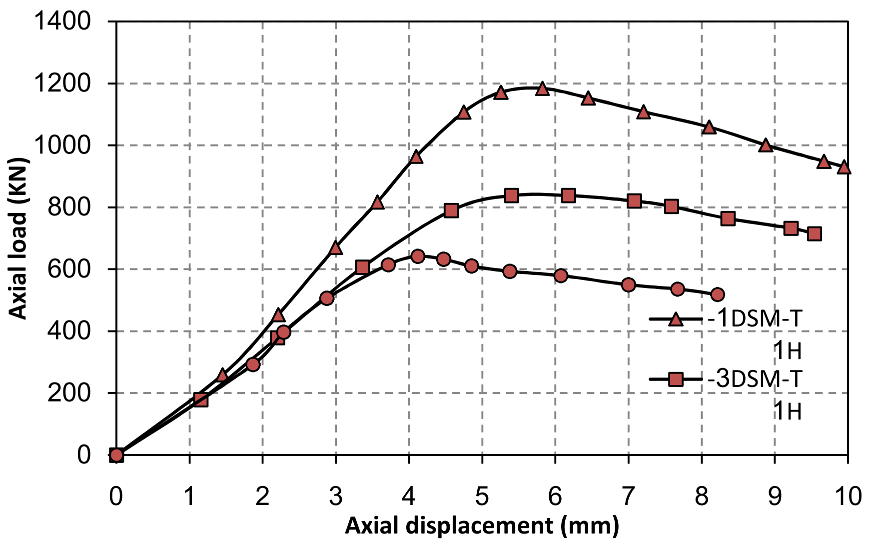


Figure (5) Axial load-axial displacement of CFDSST columns under axial loading with thicknesses of outer tube (T1= 4.5, T2=2.0, and T3=3.0) mm.

Considering the normalization of the ultimate axial strength is important in eliminating the effect of yield stress difference, where the selected steel tubes acting as inner or outer tubes were from different sources, at the other hand coupon tests of these tubes revealed different values of yield stress. Normalized axial ultimate strength (N_z)is considered in studying the effect of (t_o), this factor is explained in Equation (2). The variation of ultimate axial strength of the three specimens with the thickness of the outer steel tube is shown in Fig. (9), which is plotted between the normalized axial strength factor (N_z) and the outer steel thickness (t_o).

$$\mathbf{N_z = \frac{N_u}{N_o}} \qquad (2)$$

where,

N_z :Normalized axial strength Factor,

N_u : Ultimate load capacity, Experimental

N_o : Nominal axial strength, as in Equation (1)

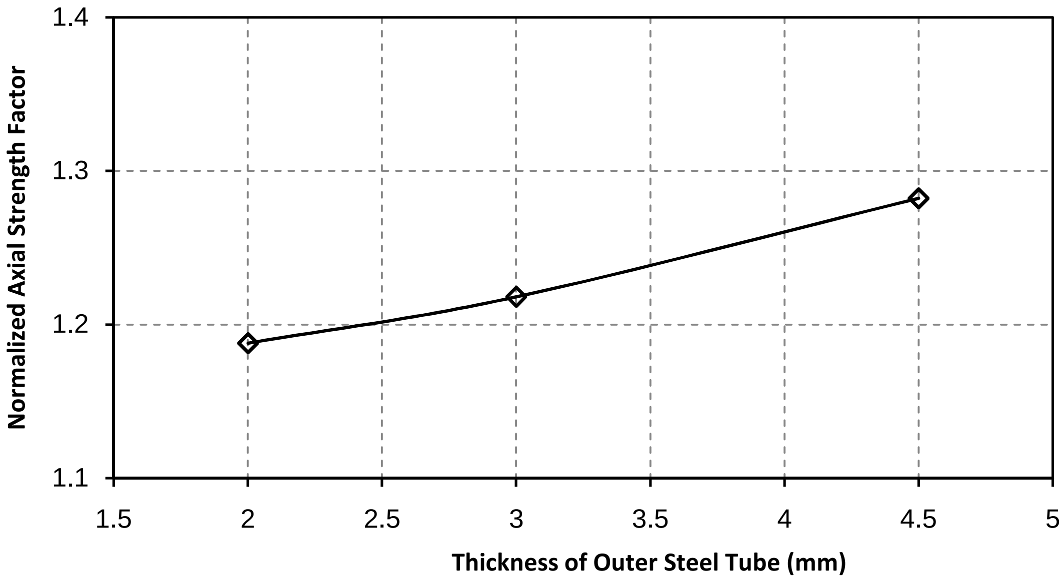


Figure (6) Variation of Normalized Axial strength factor (N_z) with the thickness of Outer Steel tube (t_o) for CFDSST specimens.

By checking Fig. (9), it can be seen that the variation of normalized axial strength with thickness of outer steel tube is nonlinearly ascended, whereas an improvement in CFDSST strength of about 6% when (t_o) is increased from 3.0 mm to 4.5 mm.

Increasing the thickness of the outer steel tube means an increase in the cross sectional areas, and then the axial strength of this tube increases in both cases of acting alone or in composite action, this is proved making use of the axial strain gauges attached to the mid span of the outer tube, as shown in Fig. (10).

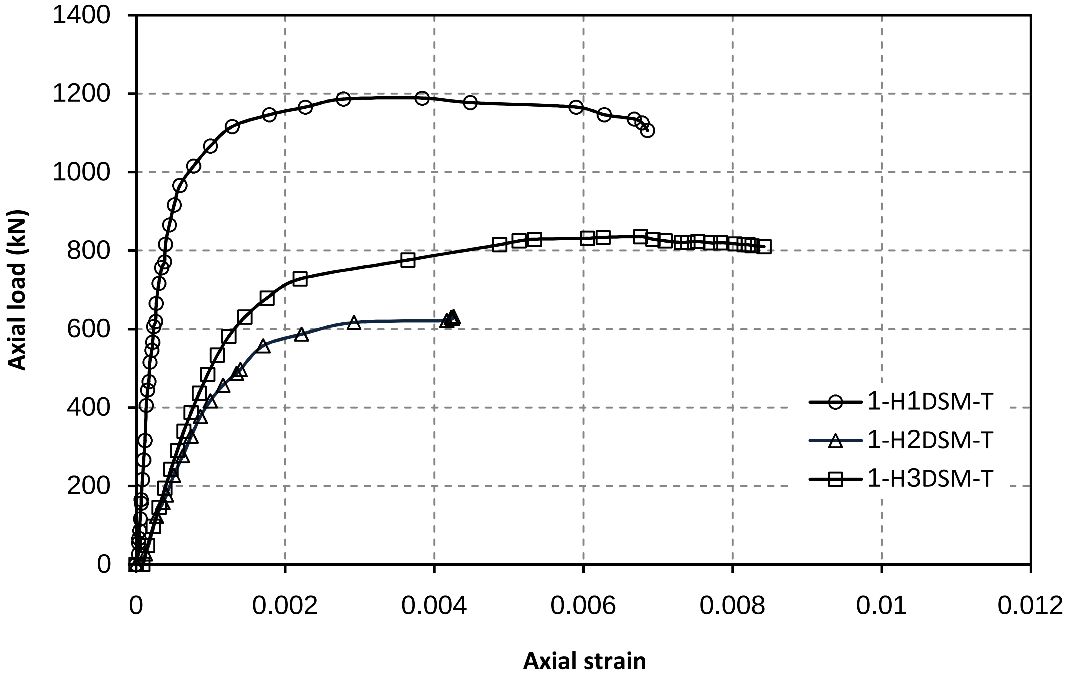


Figure (7)Axial Load-Axial mid span strain of CFDSST specimens, under axial compression with outer tube thickness of (T1= 4.5, T2=2.0, and T3=3.0).

This parameter also affects the amount of confinement subjected to concrete in between, Fig. (8) presents the relation between the hoop strain at mid span and the axial load for the three considered thicknesses, DSM-T1-H1, with $\mathbf{t_o}$=4.5, provided the highest confinement expressed in terms of low hoop strain development with loading.

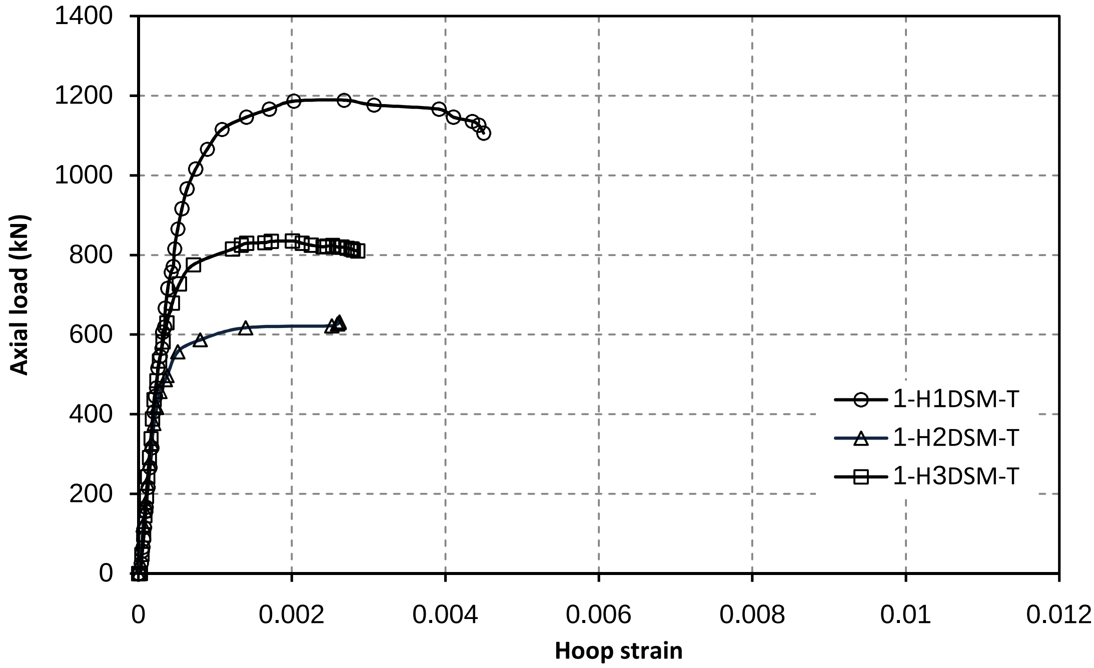


Figure (8)Axial load-hoop mid span strain of CFDSST specimens under axial compression with outer tube thickness of (T1= 4.5, T2=2.0, and T3=3.0).

6.4 Effect of Hollowness Ratio on the Behavior of CFDSST Specimens

According to Tao et al.[15], hollowness ratio (χ) is an important parameter that affects CFDSST columns behaviour. This ratio is defined as

$$\chi = \frac{D_i}{D_o - 2t_o} \tag{3}$$

where,

χ : hollowness ratio
D_i: diameter of inner steel tube,
D_o: diameter of outer steel tube
t_o: thickness of outer steel tube,

If hollowness ratio is equal to zero for a CFDSST column, the column is actually a conventional concrete-filled steel tube (CFST). This parameter is included in the experimental program to study its effect on the ultimate axial strength. threeCFDSST specimens names as (DSM-T1-H1, DSM-T1-H2, and DSM-T1-H3) with the same outer tube diameter and thickness, but with different hollowness ratios, the values of (χ) are (0.381, 0.571 and 0.714), respectively. Fig. (9) shows the load-displacement curves for the three hollowness ratios.

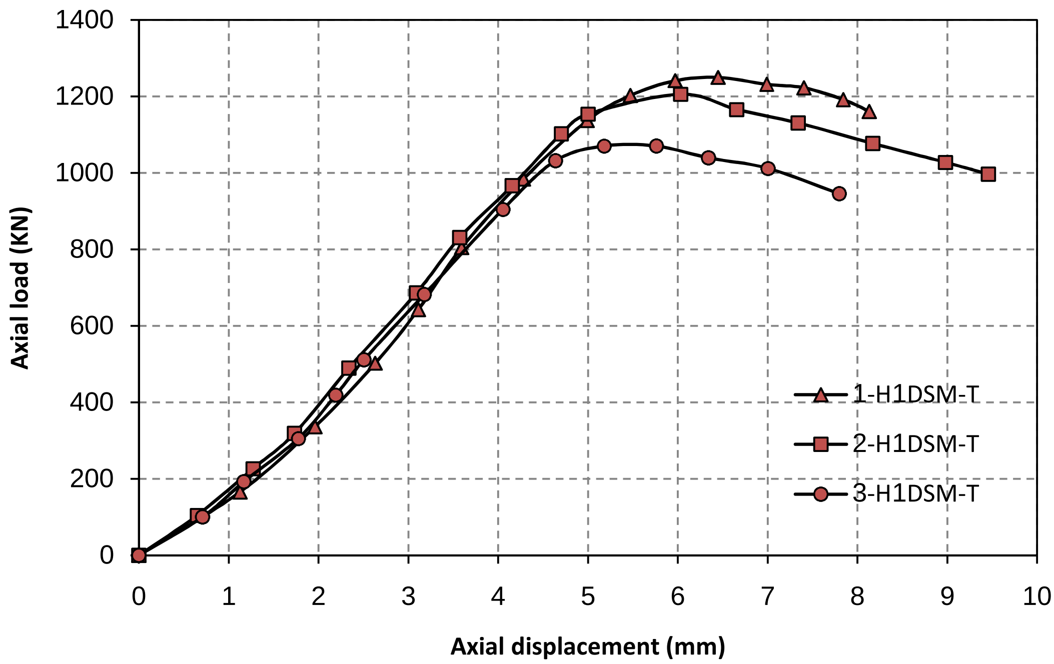


Figure (9) Axial Load-Axial Displacement of CFDSST Specimens under axial loading with different Hollowness ratios

Fig. (10), presents the normalized axial strength factor with the hollowness ratio. In general the axial strength decreased with the increase of hollowness ratio, this degradation in strength is almost linear when hollowness ratio changed from H1 to H3, where about 20% loss in strength occurred. Also it can be observed that the ultimate load decreases as the hollowness ratio increase.

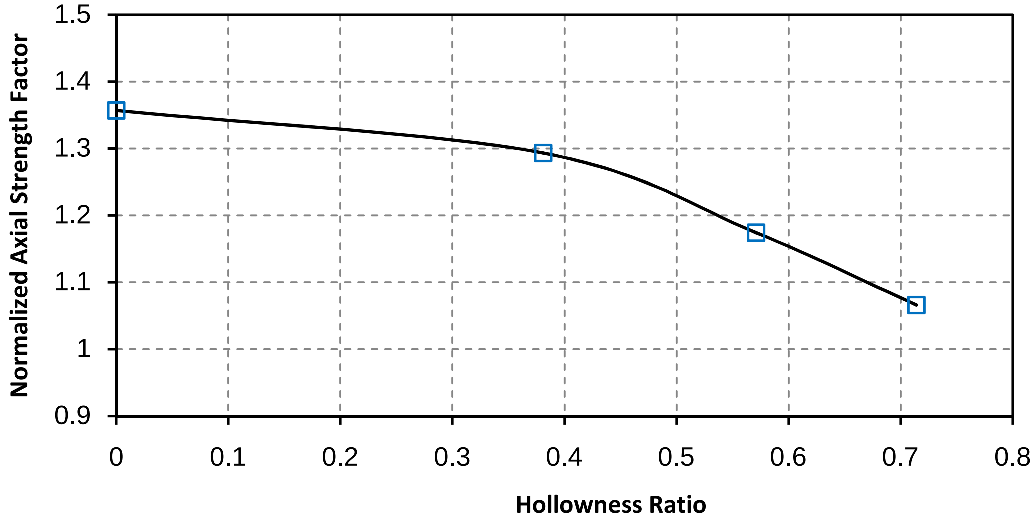


Figure (10) Variation of Normalized Axial strength factor (N_z) with Hollowness ratio (χ) for CFDSST specimens.

Hollowness ratio has an effect on the axial and hoop strains measured at mid span of the outer steel tube, as shown in Figs. (11) and (12), respectively. For the three specimens at the elastic range of loading, axial strain increased with the increase of hollowness ratio, this is also true for the yield strain correspondent to that load when the curve started to bend nonlinearly. Hoop strain-axial load relation for DSM-T1-H1 and DSM-T1-H2 are approximately close. The difference in behavior is clear with the specimen DSM-T1-H3, since the quantity of concrete in between tubes is less and therefore the Axial capacity have been lesser.

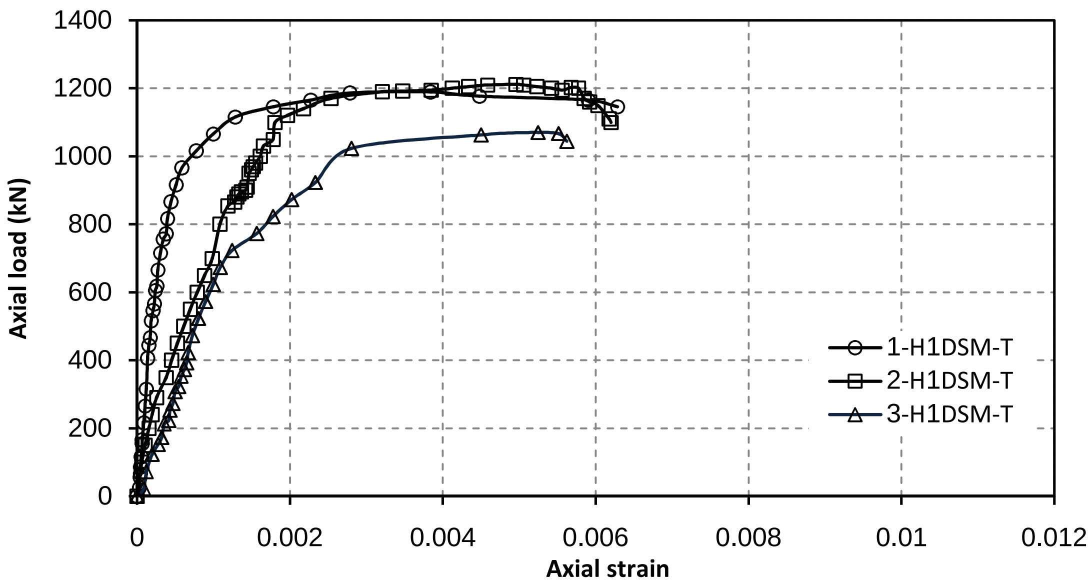


Figure (11)Axial load-axial mid span strain of CFDSST columns under axial loading with different Hollowness ratios,

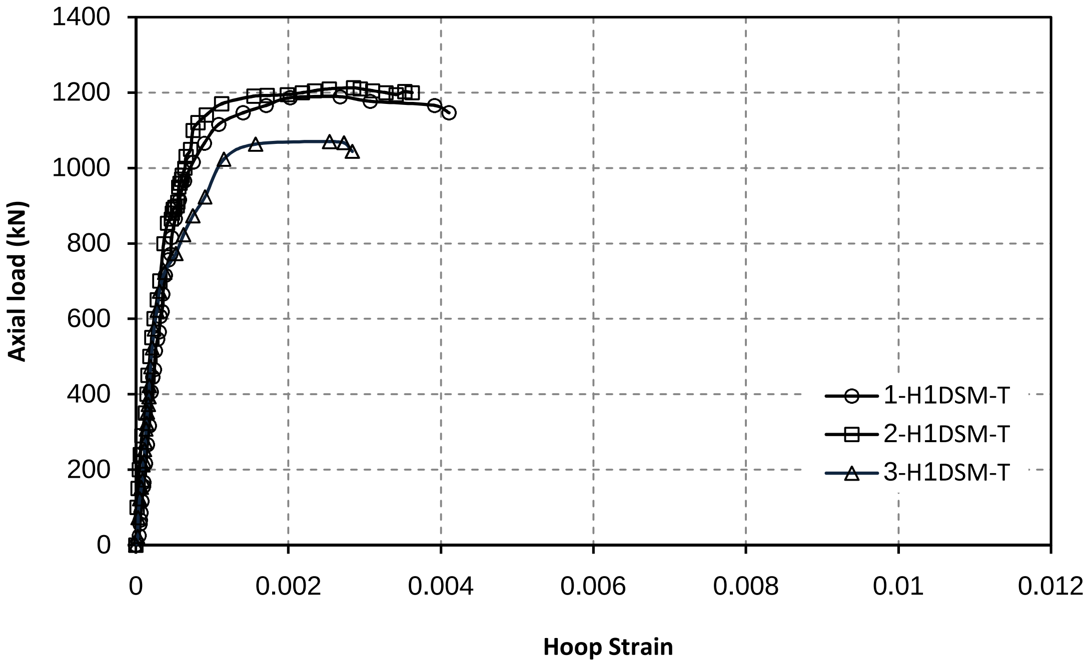


Figure (12) Axial load-hoop mid span strain of CFDSST columns under Monotonic Loading condition with different Hollowness ratios,

7. Conclusions

The experimental program yields the following conclusions:

1. The collapse of the CFDSST columns is mainly due to the failure of the outer steel tube, which is caused by the combined axial compression and concrete expansion. The failure modes of outer steel tubes included the outward local buckling, while no failure was found in the inner steel tube.
2. Cross-sectional area of the confined concrete by the outer and inner steel tubes has the most significant effect on the ultimate axial load capacity and corresponding axial shortening of CFDSST Columns.
3. There is a linear relationship between the outer steel tube thickness and the ultimate axial capacity of CFDSST, where an improved of about 8% was obtained when the thickness changed from 2 mm to 4.5 mm.
4. The axial strength decreased with the increase of hollowness ratio, this degradation in strength is almost linear when hollowness ratio changed from 0.381 to 0.714, where about 20% loss in strength occurred

8. References

1. Shanmugam, N.E., and Lakshmi, B., (2001), "*State of the art report on steel concrete composite columns*", Journal of Constructional Steel Research 57, 1041–1080, Elsevier Science Ltd
2. Elchalakani M; Zhao XL, and Grzebieta RH, (2002). "*Tests on concrete filled double-skin (CHS outer and SHS inner) composite short columns under axial compression*", Thin-Wall Struct.;40(5):415–41.

3. Mursai, Mohanad, , (2007),"*The Behavior and design of thin walled concrete filled steel box columns*", Ph. D. thesis, Sydney, Australia.
4. Tomii, M. (1991). "*Ductile and strong columns composed of steel tube, infilled concrete and longitudinal steel bars*", Proceedings of the Third International Conference on Steel-Concrete Composite Structures, 26-29 September, Fukuoka, Japan, 39-67
5. Han T. H.; Stallings J. M., and Kang Y. J., (2010), "Nonlinear Concrete Model for Double-Skinned Composite Tubular Columns". Construction and Building Materials 24(12): 2542–2553
6. Wei, S., Mau, S.T., Vipulanadan, C. and Mantrala, and S.K. (1995), "*Performance* of New Sandwich Tube under Axial Loading: Experiment", J. Struct. Eng., ASCE, Vol. 121(12), 1806-1814.
7. DIN 50125-2009, "Testing of metallic materials - Tensile test pieces", German Institute for Standardization (DIN)
8. Iraqi Specifications /5, " Iraqi Cement ", The Central Device for Standardization and Quality Control, Baghdad 1984.
9. Iraqi Specifications /45, " Natural Sources Aggregate used in Concrete and Constructions, The Central Device for Standardization and Quality Control, Baghdad 1984.
10. EFNARC, (2005): European Federation Dedicated To Specialist Construction Chemicals and Concrete Systems, "Specification and Guidelines for Self-Compacting Concrete",
11. ASTM –C494-05, (2005), "Standard Specification for Chemical Admixtures for Concrete", American Society for Testing and Materials,
12. TML Strain Gauges Catalog Manual, Tokyo Sokki KenkyujoCo.,Ltd, http://www.tml.jp.
13. Emborg, M., (2000) "Mixing and Transport", Final Report of Task 8.1, Betongindustri AB, Brite EuRam, Sweden.
14. Al- Jabri, L.A., (2005), "The Influences of Mineral Admixtures and Steel Fibers on the Fresh and Hardened Properties of SCC", M.Sc. Thesis, Al-Mustansirya University, Baghdad, Iraq.
15. Tao, Zhong; Han, Lin-Hai; and Xiao-Ling Zhao, (2004),"Behavior of concrete-filled double skin (CHS inner and CHS outer) steel tubular stub columns and beam-columns", Journal of Constructional Steel Research 60 (2004) 1129–1158, Elsevier Ltd.