THE ULTIMATE STRENGTH OF DOUBLE SHORT COMPOSITE COLUMNS UNDER CONCENTRIC LOADS

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Abstract

No-Fine concrete filled double steel tube columns (CFDST) are being increasingly used for structural applications. It has been used for submerged tube tunnels, nuclear containment, liquid and gas retaining structures, vessels under external pressure in very deep water and for compression members in offshore construction, this is due to the aesthetic appearance, ease of maintenance and simple of construction. The (CFDST) columns also have excellent resistance to seismic loads and fire. This paper comprises of an experimental study on the structural behavior of double steel tubular columns filled with No-Fine concrete under axial load. Eight samples of double steel circular tubes with different diameters for the inner and outer tubes are used, with different slenderness ratios (L/r), different ultimate strengths of No-Fine concrete (f_c'). Also two cases are study for (CFDST) samples first with hollow inner tube and second with completely filled inner and outer tubes with No-Fine concrete.

The experimental results show that the effect of height (the slenderness (L/r) ratio) on the ultimate strength of CFDST columns will have a reverse relation. While the effect of uniaxial compressive strength (f_c') and the effect of fully filling the core of internal tube on the ultimate strength of CFDST columns will have an increase relation.

Keywords: No- Fine Concrete, Compression Members, Concrete Filled Double Steel Tubes (CFDST).

المقاومة القصوى للأعمدة القصيرة المركبة المزدوجة تحت تأثير الأحمال المركزية

الخلاصة

إن الخرسانة المنتجة بدون استعمال الركام الناعم (الرمل) المالئة للأعمدة الحديدية الأنبوبية المزدوجة أصبحت تستعمل وبصورة متزايدة في التطبيقات الإنشائية مثل القنوات الأنبوبية الغاطسة والمنشات النووية وأحواض الخزن الخاصة بالسوائل والغازات المتعرضة الى ضغوط خارجية وبأعماق كبيرة أسفل البحر وكذلك تستعمل في أعضاء الانضغاط (الأعمدة) في المنشات الساحلية، ان السبب في ذلك يعود الى جمالية مظهرها وسهولة صيانتها وبساطة تصنيعها.
وبالإضافة الى ذلك فان الأعمدة الحديدية الأنبوبية المزدوجة تمتلك مقاومة إنشائية ممتازة للزلازل والحرائق. ان هذا البحث يتضمن دراسة عملية للتصرف الإنشائي للأعمدة الحديدية الأنبوبية المملوءة بالخرسانة المنتجة بدون استعمال الركام الناعم تحت تأثير الأحمال المحورية، ثمانية نماذج للأعمدة الحديدية المزدوجة الدائرية المختلفة الأقطار (داخليا وخارجيا) تمت دراستها تحت تأثير نسب نحافة متغيرة و مقاومة قصوى للخرسانة متغيرة، وكذلك تمت دراسة حالتين لهذه الأعمدة الأولى بكون العمود الداخلي خالي من الخرسانة و الحالة الثانية بكون العمود الداخلي والخارجي مملوء كليا بالخرسانة. لقد بينت النتائج ان تاثير تغير طول العمود (نسبة النحافة) يكون عكسيا على مقدار المقاومة القصوى لهذه الاعمدة بينما يكون تاثير تغير قيمة مقاومة الخرسانة القصوى وتغير ملئ اللب للعمود الداخلي طرديا.

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Introduction

Recently many different types of composite material systems have been widely applied to concrete column design to provide better performance in terms of high strength, stiffness, ductility and seismic resistance. Some of these composite columns are fully encased steel sections, partially encased steel sections and concrete filled steel tube. Among them, the concrete-filled double steel tube (CFDST) column system has turned out to be one of the most successful composite concrete column systems. The (CFDST) column is a composite material system which employs the various advantages of different materials and combines them together in a double steel tube column which is filled-in with concrete [1].

Steel members are characterized by high tensile strength which is equal to its compressive strength and ductility. On the other hand, concrete members have the advantages of high compressive strength and stiffness. Thus, steel-concrete composite members have the advantageous qualities of both materials, e.g. sufficient strength, ductility and stiffness. Modern structures tend to be composed of different materials in their individual elements, and in recent years innovative new construction systems have been developed and tested. Issues such as ductility, durability, fire, earth quake, ease of erection and maintenance have been major concerns. Nowadays, it is common practice to have associations of reinforcement and prestressed, concrete-encased steel profiles and concrete-filled tubes assembled together in the same structure. The behavior of these assemblages however is not always covered by design codes [2].

Concrete-Filled Double Steel Tube Columns (CFDST)

Concrete-filled double steel tube columns (CFDST) are being increasingly used for structural applications. It has been used for submerged tube tunnels, nuclear containment, liquid and gas retaining structures, vessels under external pressure in very deep water and for compression members in offshore construction, this is due to the aesthetic appearance, high corrosion resistance, ease of maintenance and ease of construction.

This type of composite columns Figure (1) consisting of two concentric circular thin steel tubes with filler (concrete) between them, the inner void may be filled with concrete if desired. the concrete is enclosed in such a way that axial loading of the column results in a triaxial stress state in the concrete. Axial loading of any of these column sections will cause a tendency of the concrete to expand laterally which is counteracted by the shell. This will bring the concrete in a state of confinement and thus change its stress-strain behavior and increase its compressive strength. In this way, the composite column will act as a synergetic system where the confining pressure of the shell brings the concrete in a triaxial stress state, allowing it to reach higher strength, while the concrete prevents the shell from buckling. This will create a more-than-optimum engineering solution where the strength of the composite column is higher than the sum of its components.

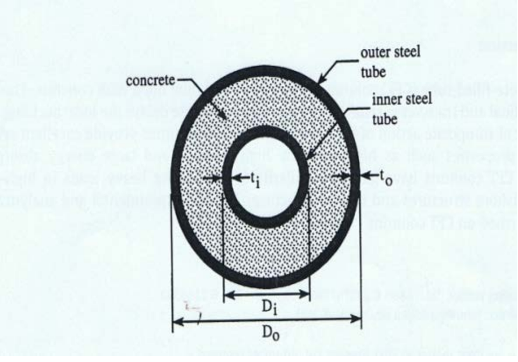

Fig. (1) :Cross-section of CFDST

Advantages of Concrete-Filled Double Steel Tube Columns

The CFDST columns system has many advantages compared with ordinary steel or reinforced concrete system. The main advantages are listed below [3]:

1- Interaction between steel tube and concrete

Local buckling of the steel tube is delayed and the strength deterioration after the local buckling is moderated, both due to the restraining effect of the concrete. On the other hand, the strength of the concrete is increased due to the confining effect provided by the steel tube, and the strength deterioration is not very severe, because concrete spalling is prevented by the tube.

2- Cross-sectional properties

The steel ratio in the CFDST columns cross-section is much larger than in reinforced concrete and concrete-encased steel cross sections. The steel of the CFDST columns section is well plasticized under bending because it is located most outside the section.

3- Construction efficiency

Labor for forms and reinforcing bars is omitted, and concrete casting is done by pump-up method. This efficiency leads to a cleaner construction site and a reduction in manpower, construction cost, and project length.

4- Cost performance

Because the above reasons, better cost performance is obtained by replacing a steel structure with a concrete-filled double tube structure.

5- Ecology

The environmental burden can be reduced by omitting the formwork and by reusing steel tubes and using high-quality concrete with recycled aggregates.

The location of the steel and the concrete in the cross-section optimizes the strength and stiffness of the section. The steel lies at the outer perimeter where it performs most effectively in tension and in resisting bending moment. Also, the stiffness of the concrete-filled column is greatly enhanced because the steel is situated farthest from the centroid, where it makes the greatest contribution to the moment of inertia.

No-Fines Concrete

No-fines concrete can be defined as a lightweight concrete composed of cement and coarse aggregate. Uniformly distributed voids are formed throughout its mass. The main characteristics of this type of lightweight concrete is it maintains its large voids and not forming laitance layers or cement film when placed on the wall. No-fines concrete usually used for both load bearing and non-load bearing for external walls and partitions. The strength of no-fines concrete increases as the cement content is increased. However, it is sensitive to the water composition. Insufficient water can cause lack of cohesion between the particles and therefore, subsequent loss in strength of the concrete. Likewise too much water can cause cement film to run off the aggregate to form laitance layers, leaving the bulk of the concrete deficient in cement and thus weakens the strength.

Experimental Work

The main purpose of the test program is to generate data and provide information about the structural behavior of compression members (No-Fine Concrete-filled double steel tube columns (CFDST)) under concentric loading conditions through a series of eight columns. The experimental work is carried-out in the Structural Laboratory of the College of Engineering, University of Kufa. The parameters considered are the No-Fine concrete compressive strength (f'_c), the length of columns (the slenderness ratios (L/r)). Also two cases are study for (CFDST) samples first with hollow inner tube and second with completely filled inner and outer tubes with No-Fine concrete. The column specimens are instrumented to evaluate the behavior in terms of the load-axial displacement response.

Materials Used to Fabricate the Specimens

The materials used in this investigation are commercially available materials, which include cement, natural gravel, water and Steel tubes.

Cement

Ordinary Portland cement manufactured by TASLUJA BAZIAN CEMENT COMPANY (Product of SULAYMANIYAH- IRAQ) is used throughout the investigation. The cement was kept in closed plastic containers throughout the experimental work to keep the cement in good condition to minimize the effect of humidity.

Coarse Aggregate (Gravel)

Natural gravel obtained from Al-Badra-wa-Jasan is used throughout the experimental work. Its grading satisfied the limits of Iraqi standard No.45/1984 for graded gravel with maximum size of 12.5 mm. The sieve analysis test was conducted according to ASTM C136.

Steel Tubes

The Steel tubes used are commercially available (Galvanized Iron tubes of Turkish type). The tubes are of two circular cross sections first with 3" (76.2mm) and second with 6" (152.4mm) of external diameters and tube thickness of 2 mm.

Mechanical Properties of the Steel Tubes

The mechanical properties of the steel tubes were obtained by testing specimens from them and verified with the data provided by the manufacturer (see Table 1). The material properties were determined by tensile test conducted on cut coupons from the tube. Although the nominal dimensions of the tubes are known, the outside diameter and wall thickness are measured at several locations. These measured values are used in determining the cross-sectional properties.

Table (1): Steel tubes properties

Steel tube thickness (mm)	Yield Stress f_y (MPa)	Ultimate Stress f_u (MPa)
2	300	380

Concrete Mix

Two concrete mixes are used to investigate the influence of the concrete strength on the behavior of No-Fine concrete composite columns. The mix proportions of the ingredients of the first mix, Mix 1, by dry weights are [1 cement : 2 gravel], and the water cement ratio (w/c) was 40%, to give a cylinder compressive strength of about 35 N/mm^2 at age of 28 days (three standard cylinders (200x100) mm were cast and test). For the second mix, Mix 2, the mix proportions of the ingredients by dry weights were [1 cement : 3 gravel], and the water cement ratio (w/c) was 40%, to give a cylinder compressive strength of about 25 N/mm^2 at age of 28 days.

No-Fine Concrete Composite Column Specimens

A total of eight columns are tested under axial compressive loads. The columns are divided into two groups (C) and (D) and each sample is consisting of two steel tubes (the first have 3"(76.2mm) diameter and the second have 6"(152.4mm) diameter . For each group, four specimens are prepared {two with different heights (300mm and 600mm) and two with different cases (the first is hollow inner tube) and (second with completely filling for inner and outer tubes) by No-Fine concrete.

The two groups are casted without steel reinforcement. Two concrete mixes are used, Mix 1 is used for group (C) and Mix 2 is used for group (D). The variables in this stage are the column height (the slenderness (L/r) ratio), the concrete cylinder compressive strength (35 and 25 N/mm^2), and the hollow inner tube and completely filling inner and outer tubes. All specimens are tested under compressive axial force up to failure. Table (2) gives the details of the columns including their designation, also (see Figure 2).

Table (2): Details of samples

Group No.	Column designation	Concrete mix	Inner Tube diameter *(Di)* (mm)	Outer Tube diameter *(Do)* (mm)	Outer and Inner Tube thickness (*t*) (mm)	Do/t ratio	Length *(L)* (mm)	Slenderness ratio (L/r) $(L/r = 4L/D)$
C	C1	1	76.2	152.4	2	76.2	300	7.87
	C2	1	76.2	152.4	2	76.2	600	15.75
	C3*	1	76.2	152.4	2	76.2	300	7.87
	C4*	1	76.2	152.4	2	76.2	600	15.75
D	D1	2	76.2	152.4	2	76.2	300	7.87
	D2	2	76.2	152.4	2	76.2	600	15.75
	D3*	2	76.2	152.4	2	76.2	300	7.87
	D4*	2	76.2	152.4	2	76.2	600	15.75

Note: the symbol (*) meaning that the sample is completely (inner and outer cores) filling by No-Fine concrete.

Fig. (2): Column specimens

Fabrication of the Specimens

The steel tubes are cut to the desired length of the columns and cleaned. For concreting, tubes were positioned vertically, fixed on the laboratory floor, and filled with concrete in approximately 75 mm layers, and each layer is compacted by a steel rod. To prevent the leakage of cement paste from the bottom of the steel tube, it is closed with nylon. After the tube is filled, the top surface was flattened carefully. The composite columns were left in the laboratory till the time of testing. The specimens were moistened with water every day after twenty four hours after of casting. During casting, three 150 x 300 mm cylinders are made for each group. The specimens are wrapped with the burlap sacks and moistened with water till the time of testing.

Samples Preparation

Before testing, the top and the bottom surfaces of column specimens are smoothened by a scraper machine to make the surfaces of concrete and steel lying on the same elevation, and therefore ensuring a transfer of load to both concrete and steel at all levels Fig(3).

Fig. (3) :Smoothing the columns surface

Instrumentation and Test Setup

All specimens are tested under axial compression loads using a universal testing machine with a capacity of 2000 kN at the laboratory of structures in Engineering college of Kufa University. The column specimen is centered in the testing machine to ensure that the compressive axial load is applied without any eccentricity. The top and bottom faces of specimen were grinded and made smooth and leveled to remove surface imperfections and maintain uniformity of loading on the surface. The vertical displacement of the lower movable head of the testing machine was measured in relation to the upper head of the testing machine by a dial gauge with magnetic base and the accuracy of the dial gauge is 0.01 mm. Readings of applied load and displacement are recorded at regular intervals during the tests. The application of the load was continued until the failure of column (see Figure 4).

Fig. (4): Test setup and instrument of samples tested

Behavior of (CFDST) Samples

In (CFDST) samples, the steel tubes cause the development of a triaxial stress field within the confined concrete, constraining it during dilation and thereby increasing the load carrying capacity[4]. The axial load plotted as a function of axial displacement for (CFDST) No-Fine concrete composite columns shown in Figures (5) to (12). It is shown that the tubes can improve the performance of concrete, both its strength and ductility, under axial load. The load-displacement relationships of all (CFDST) composite columns are generally bilinear in nature with a small transition zone. Therefore, the behavior of composite columns under axial loading can be divided into three regions. In the first region, the behavior of composite column is similar to that of plain concrete column: this is due to the fact that the confining effect of (CFDST) columns is still not activated by the lateral expansion of the concrete core. In the vicinity of the peak load of plain concrete columns, the confined concrete reaches a state of unstable volumetric growth caused by excessive cracking. At this point, the (CFDST) column is activated and starts to gradually restrain the rapid growth of the lateral strains. This region of response is characterized by a transition curve at approximately the ultimate load of the plain concrete column. Finally, a third region is recognized in which the (CFDST) No-Fine composite column fully activated and the load-displacement relationship continued as a straight line with a second slope up to the failure at ultimate load. The figures show that the slope of third part of relationship is less than the slope of the first part, and proportional to the stiffness of the (CFDST) column used. Observations, after peak loads, showed that the failure of the composite columns happens step by step and a complete collapse of the column by a suddenly explosive mode does not occur until large deformations are introduced (The failure patterns of the columns are shown in Figures 13 to 20). However, the presence of the (CFDST) column significantly increased the axial plastic strain before collapse.

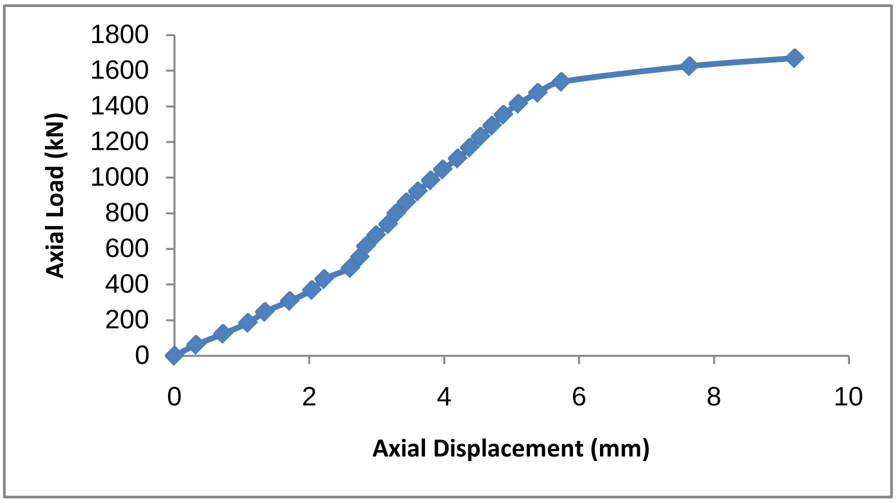

Fig. (5) Load- Axial Displacement for Column (C1)

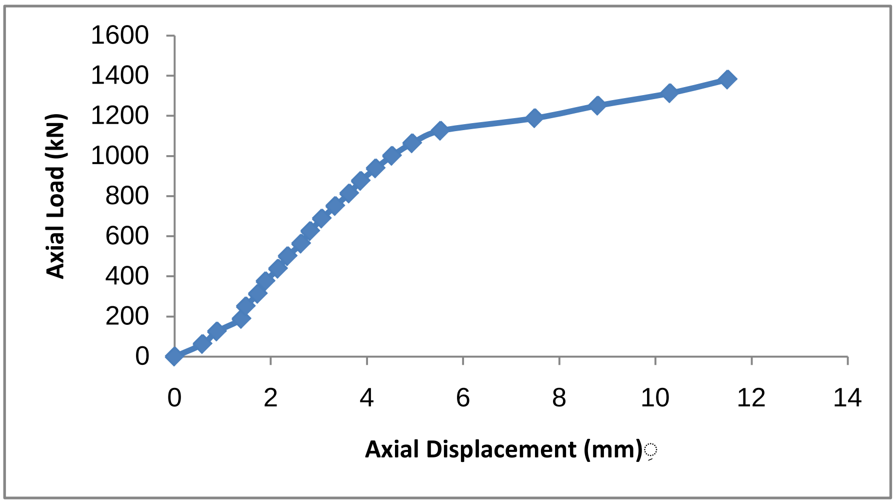

Fig. (6) Load- Axial Displacement for Column (C2)

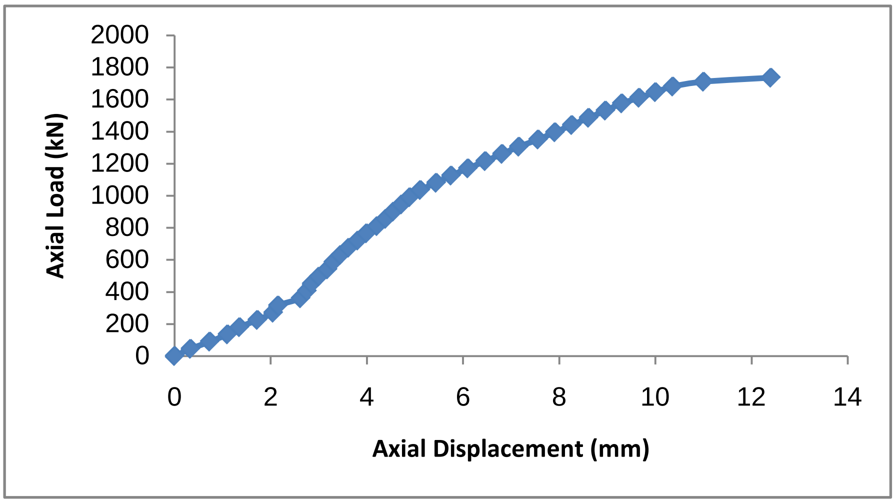

Fig. (7) Load- Axial Displacement for Column (C3)

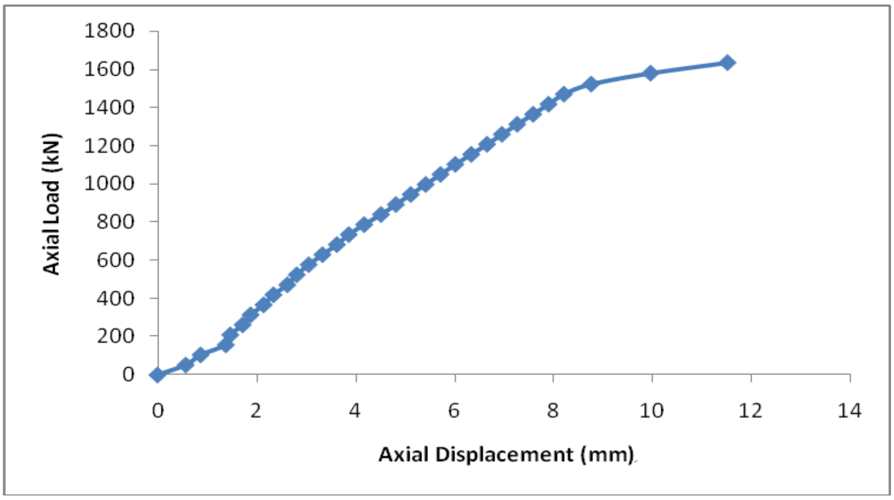

Fig. (8) Load- Axial Displacement for Column (C4)

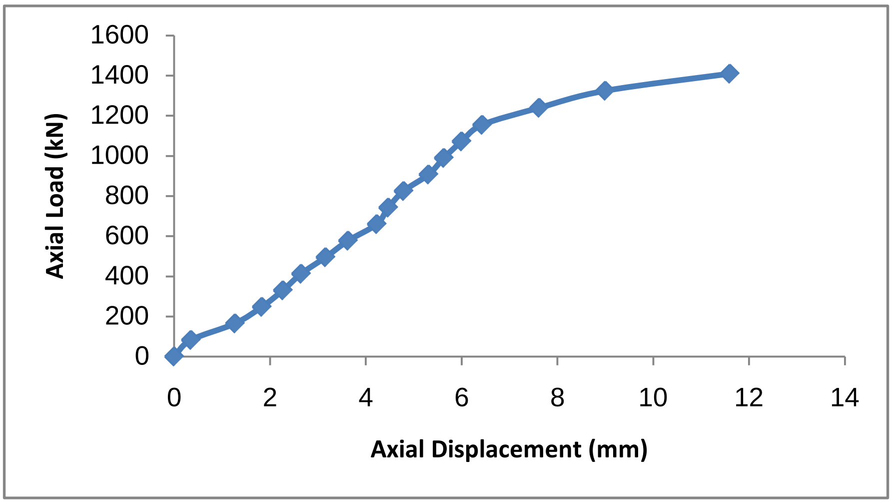

Fig. (9) Load- Axial Displacement for Column (D1)

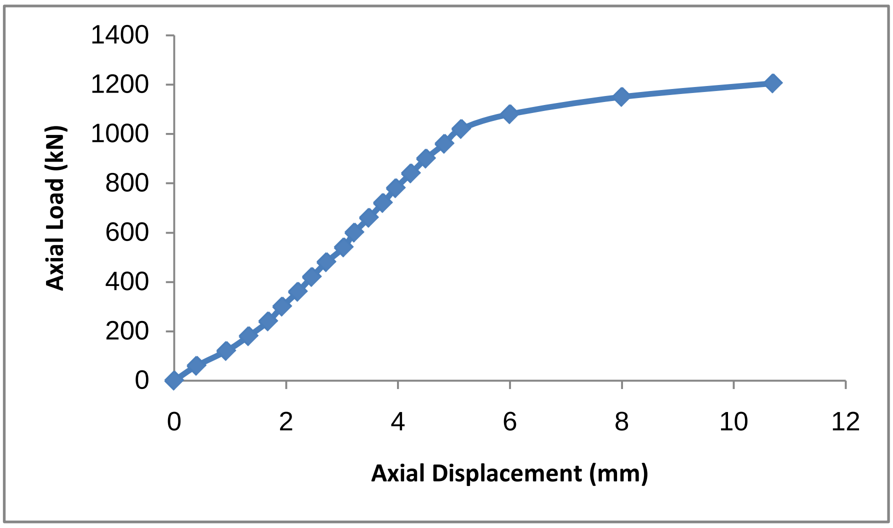

Fig. (10) Load- Axial Displacement for Column (D2)

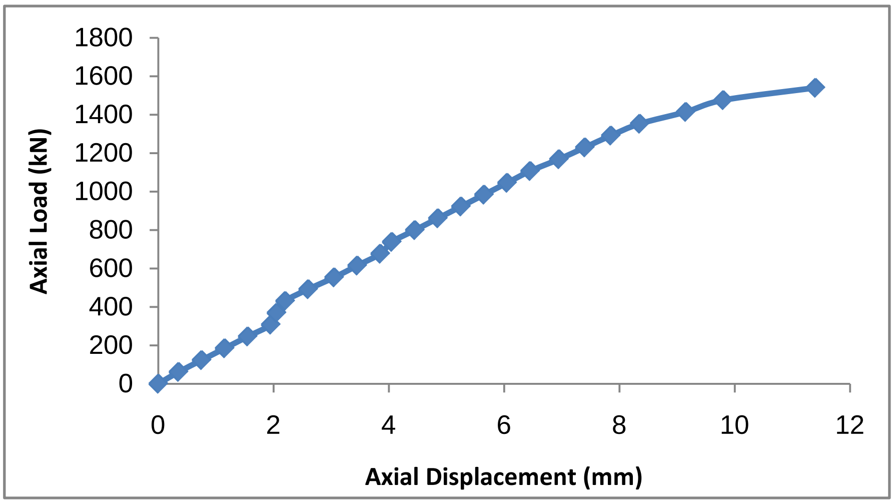

Fig. (11) Load- Axial Displacement for Column (D3)

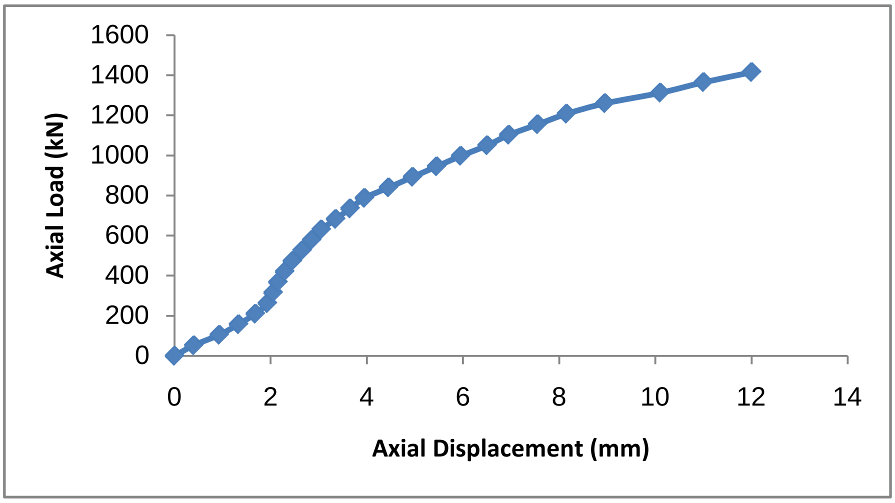

Fig. (12) Load- Axial Displacement for Column (D4)

Fig. (13): Failure Pattern of Sample C1

Fig. (14): Failure Pattern of Sample C2

Fig. (15): Failure Pattern of Sample C3

Fig. (16): Failure Pattern of Sample C4

Fig. (17): Failure Pattern of Sample D1

Fig. (18): Failure Pattern of Sample D2

Fig. (19): Failure Pattern of Sample D3

Fig. (20): Failure Pattern of Sample D4

Conclusions

The most important conclusions that can be drawn from the present study are:

1- The using of double steel tube provided sufficient lateral support to the concrete core and increased the ultimate strength of the composite columns, the steel shell will confine the concrete and improve its strength and ductility. At the same time the filling concrete will enhance the steel carrying capacity so that all the section will reach its limit state and avoid the possibility of buckling until cracking induced in concrete at high load levels.

2- It was found that the typical failure mode for all the tested concrete filled double steel columns was the local buckling mode, and this local buckling was in an outer direction (outward folding mechanism) because of the infill of concrete.

3- The effect of height (the slenderness (L/r) ratio) (varies from 7.87 to 15.75) on the ultimate strength of CFDST columns will have a reverse relation (about -5.76 to -17.36%).

4- The effect of fully filling the core of internal tube on the ultimate strength of CFDST columns will have an increase relation (about 3.89 to 18.48%).

5- The effect of uniaxial compressive strength (f'_c) (varies from 25 to 35MPa) on the ultimate strength of CFDST columns will have an increase relation (about 12.66 to 18.44%).

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