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BEHAVIOR OF DOUBLE SKIN (CFRP/STEEL) TUBULAR CIRCULAR HIGH STRENGTH MORTAR COLUMNS UNDER AXIAL COMPRESSION LOAD

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DEDICATION

To my parents for their limitless support .... With love and respect

Hanaa Abdul-Baset Ali

March 2019

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Behavior of Double-Skin(CFRP/Steel) Tubular Circular High Strength Mortar Columns under Axial Compression Load

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ABSTRACT

A hybrid double skin tubular members (DSTM) consist of three composite materials in one section, include fiber reinforced polymer (FRP) tube out ward, steel tube in ward and concrete in between. These three materials give the member unique properties like protect column from harsh environment, reduce amount of concrete by presence of inner steel tube that allowed to the passage of services. Therefore, consider sustainable structure element, as well as rising strengthening of members and excellent corrosion resistance.

This study presents experimental program include 24 columns with two types of circular columns, concrete filled FRP tube (CFFT) and double skin tubular column (DSTC), with dimensions 100 mm*310 mm that divided into five groups which constructed and testing under axial compressive load till failure. With variables, numbers of layers of outer FRP tube, compressive strength of mortar, ts/d ratio and ds/d ratio of inner steel tube.

The experimental results showed that the mortar was effected confinement in the hybrid DSTC led to very ductile behavior of stress–strain relationship, the number of outer FRP layers was the most effective parameters on DSTCs behavior. The nominal confinement ratio was affected by thickness of outer FRP tube and compressive strength of concrete inside DSTCs. By increase number of layers of outer FRP tube from 1 to (2 and 3) layers, the strength enhancement ratio increasing by

(48%, 72% and 155%), the enhancement of axial strain increasing by (114%,123% and 274%) and the ductility rising by (149%,183% and 266%). When increasing mortar compressive strength from 45 to (50, 55 and 60) MPa, the strength enhancement ratio was about (50%, 40%, 41% and 48%), enhancement of axial strain decreasing by (215%, 164%, 157% and 114%) and the ductility decreasing by (174%, 160%, 167 and 149%). By using ts/d ratio of inner steel tube from 0.015 to (0.02 and 0.03), the strength enhancement ratio decreases by (48%, 38% and 41%), the enhancement axial strain increase by (114%, 126% and 134%) and the ductility was about (149%, 137% and 150%). By increase ds/d ratio of inner steel tube from 0.25 to (0.32, 0.38 and 0.48), the strength enhancement ratio decreased by (61%, 53%, 50% and 48%), the enhancement of axial strain was about (191%, 167%, 130% and 114%) and the ductility decreasing by (223%, 176%, 146% and 137%). When the ds/d ratio decrease the behavior of specimens similar to the behavior of CFFT. By compared between CFFT and DSTC the enhancement ratio is approximately more in CFFT than DSTC, and presence of inner steel tube in DSTC is supported to concrete in order to less press concrete on outer FRP tube.

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LIST OF SYMBOLS

Symbols	Description
$\frac{kl}{r}$	Slenderness ratio.
r	Radius of gyration.
l	Unsupported length.
A	Area of cross section .
C	Refer to concrete compressive strength.
Ds	Refer to diameter of inner steel tube .
Ts	Refer to thickness of inner steel tube.
I	Refer to number of carbon fiber reinforced polymer layers .
D	Diameter of DSTC and CFFT.
H	Height of DSTC and CFFT.
A	Diameter of flow test cone.
Fcu	Compressive strength of cubic.

$f'c$	Compressive strength of cylinder.
Ft	Splitting tensile strength of mortar (MPa).
Pu	Ultimate load capacity (kN)
Δu	Axial shortening (mm).
Fcon	Ultimate stress of confined concrete.
Eca	Axial strain of unconfined concrete.
εa	Axial strain of confined column .
Eh	Hoop strain of confined column .
Pc	Ultimate load of concrete.
Ps	Ultimate load of steel.
K1	Enhancement of axial strain .

LIST OF TERMINOLOGY

Terminology	Meaning
ACI	American Concrete Institute.
ASTM	American Society for Testing and Materials.
CFRP	Carbon fiber reinforced polymer.
FRP	Fiber reinforced polymer.
DSTM	Double skin tubular member.
DSTC	Double skin tubular column
CFFT	Concrete filled fiber tube.
CFST	Concrete filled steel tube.
HST	Hollow steel tube.
HSC	High strength concrete.
LWC	Light weight concrete.
RC	Reinforced concrete.
FCSC	Fiber confined solid cylinder.
FCHC	Fiber confined hollow cylinder.
L.V.D.T.	Leaner variable displacement transduce.

CHAPTER ONE

INTRODUCTION

1.1 Back ground

A compression member is a construction element subjected to an axial load or a combined axial load and bending moment such as columns, walls and another concrete members like trusses or frame. Column's cross-sectional dimensions are commonly less significant than its height. The columns are carry vertical load from roofs, floors and decks and transmit these loads to the foundations and then into ground. Generally, compression member can be design in any orientation like vertical, diagonal and horizontal, but columns are design in vertical because they are special case of a compression member design with a considerable safety factor than other construction element (**Mac Gregor et. al, 2012**). Failure of column is a major significance influence in both sides economic and human loss, so that design of columns needs for great attention, with higher provide strength than the concept of horizontal construction element and beam. Generally, column failures had slightly visual warning compared with other structural members, the requirement of compression members design at the **ACI code** provide the slighter considerable reduction factor of strength than flexural, torsion and shear members (**Ibrahim et. al, 2011**).

Buckling failure considered the most common failure of columns, buckling defined as sudden failure accompanied with considerable defection of structure due to comparatively loads lesser these needed to destroy the columns, this means that increasing load causes increase buckling, buckling is resulted from instability of structure element due to compressive action on construction member, involving; overloaded metal building columns, compressive member in bridge, roof trusses and hull of submarine (**Mac Gregor et. al, 2012**).

1.2 Classification of Columns

Columns can be classified to vary types according to their shapes of cross-section, arrangements of steel reinforcement, types of load and according to **ACI CODE**, these are explain below:

1.2.1 According to the Shape

There're several types of reinforced column based on its cross section shape, square section, rectangular section, circular section, L-section and T-section (**Gregor et. al, 2012**). Figure (1-1) illustrates cross section shape of columns.

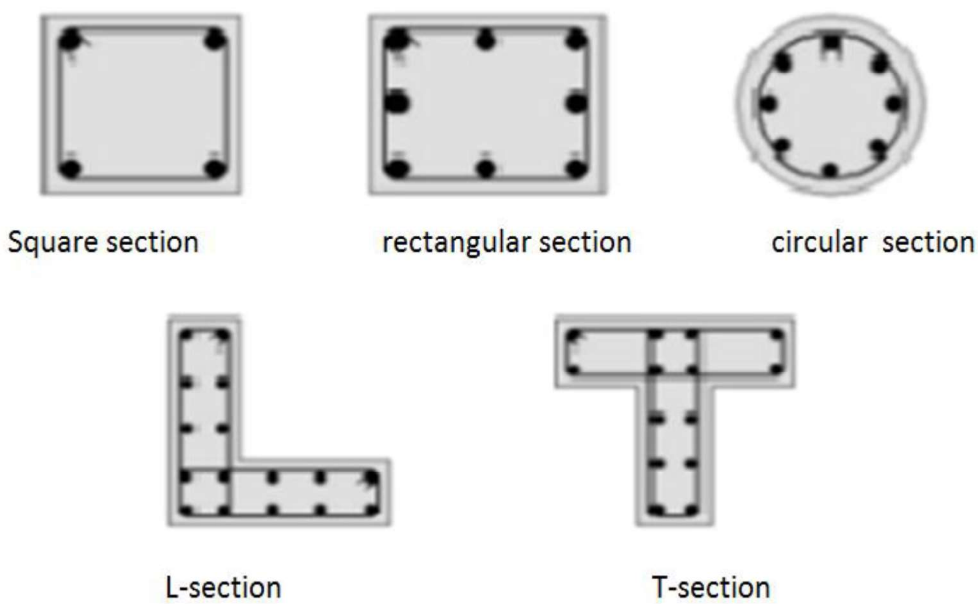


Figure (1-1) Types of column according to cross section shapes (**Mac Gregor et. al, 2012).**

1.2.2 According to the Reinforcement

Columns can be classified according the reinforcement into **(Ibrahim et. al, 2011) :**

1- Tied columns: the one of the most traditionally columns used in construction because its lower cost, as well as simpler installation.

2- Spiral columns: This type of columns has concrete core surrounded by bars and spaced helix, spiral column provides a large ductility and ability to sustain the ultimate load at maximum deflection and hence preventing the complete collapse of the construction element before re distribution of stresses.

3- Composite columns: This type of columns with a steel reinforcement, concrete and structural steel element, (longitudinal and transverse reinforced), Figure (1-2) shows type of columns according to arrangement of steel reinforcement.

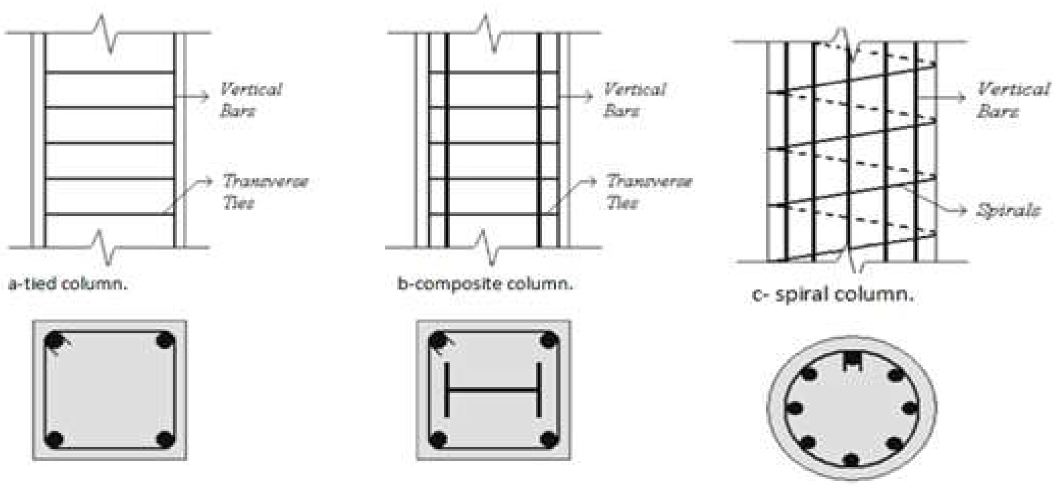


Figure (1-2) Types of column according to its reinforcement (**Ibrahim et. al., 2011).**

1.2.3 According to the Type of Load

Columns can be classified according the types of load into **(Ibrahim et. al, 2011):**

1- Concentric load: when column is subject to an axial load its centroid cross section. (called concentrically loaded column).

2-Eccentric load :when column is subjected to load a distance from centroid of its cross section. This type is also divided into uni-axial and bi-axial eccentrically loaded column. Figure (1-3) shows concentrically and eccentrically loaded column.

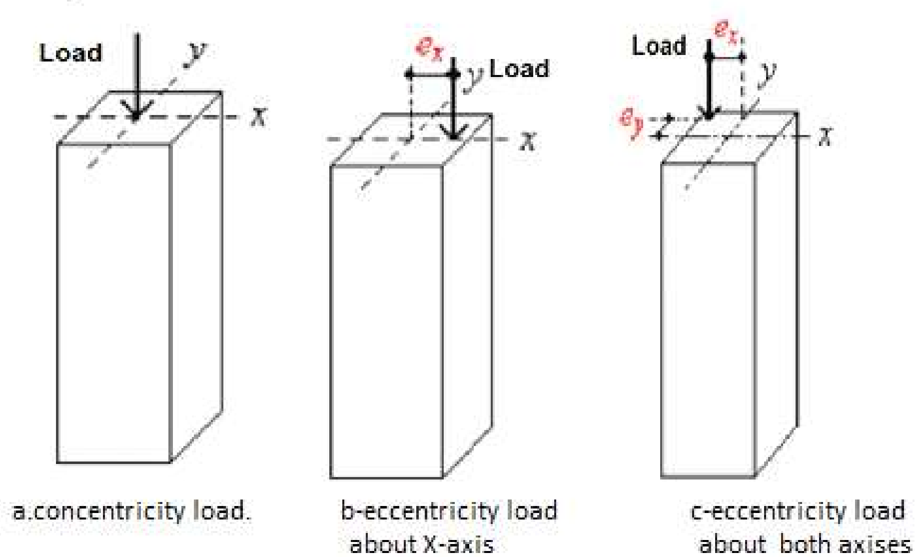


Figure (1-3) The types of columns according to the loading aspect (**Ibrahim et. al., 2011)**

Eccentricity is not only decided by location of columns, but also internal columns can be subjected to biaxial bending moment under same conditions, Figure (1-4) illustrates the eccentric of load on column.

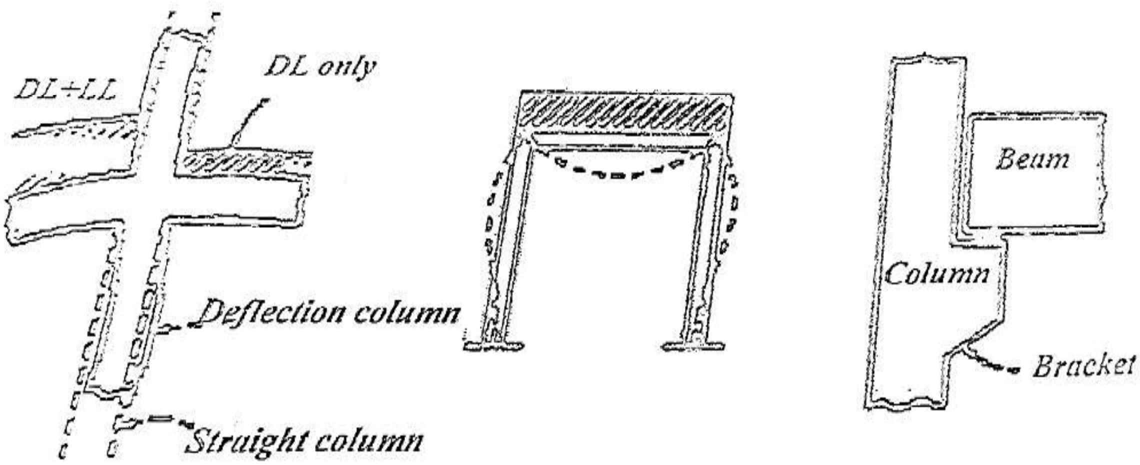


Figure (1-4) Eccentric loaded conditions on column (**Ibrahim et. al., 2011**).

1.3.4 According to the ACI CODE

The column can be classified by the slenderness ratio $\frac{kl}{r}$ it is the ratio between the effective length and (kl) and radius of gyration (r=$\sqrt{\frac{I}{A}}$) When slenderness ratio is equal or less than 22 the column is consider a short column, otherwise the column is said to be long column or slenderness column. With three different slenderness ratios, the failure modes is that: Mode one, column has not subjected to any lateral deformation and fall due to its material this is recognized as a compression failure. Mode two the failure is due to the companied influence of axial load and bending moment the short column may be have failure by its material of mode two. On the other side, a long column submit to axial load only sustain deformation due to influence of beam-column and may be failed by its material under companied impact of axial load and bending moment that's a mode three. These two last modes called combined compression and bending failure, this type of failure is called as elastic buckling, its occur by elastic instability of very long column even under small load much before the materials reach to the yield stresses Columns can be classified according to the reinforcement into **(Ibrahim et. al, 2011).** These three modes illustrate in Figure (1-5).

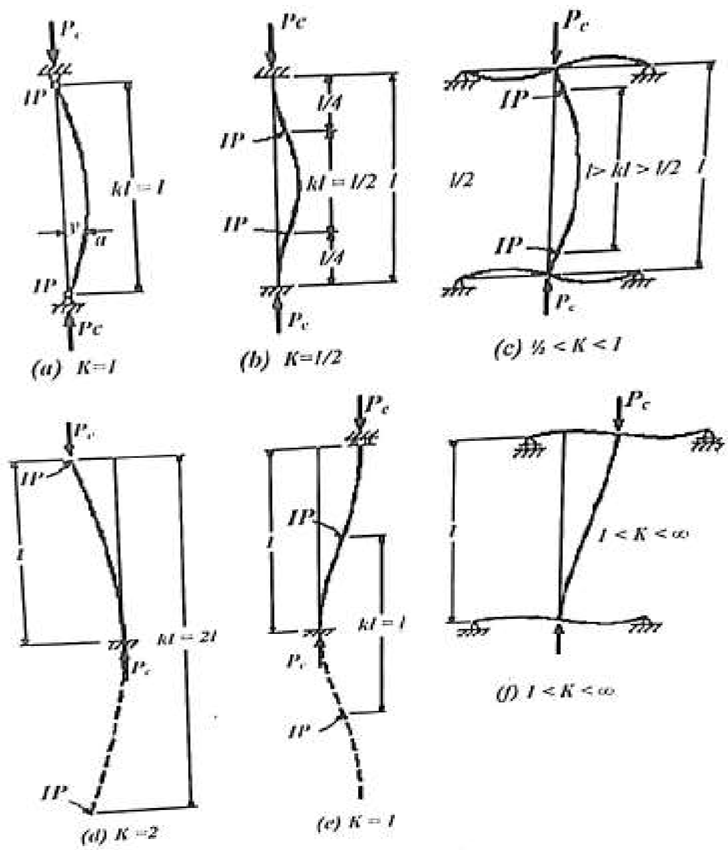


Figure (1-5) Modes failure of columns (**Ibrahim et. al., 2011**).

1.3 Hybrid Double Skin Tubular Member (DSTM)

Hybrid double skin tubular members (DSTM) are composite members proposed by Pro. Teng (at The Hong Kong University) consist of three components FRP tube outside, steel tube inside and concrete in between or inside tube also (dual grade concrete), these two tubes are placed eccentrically for flexural members and concentrically for compression member. These three materials supported each other (FRP protect and confined concrete, concrete prevent buckling and corrosion of steel tube, steel tube prevent crushing of concrete) component to gather on one section had usefulness over common construction members, DSTM protected concrete from environment condition especially when column is exposed to wreathing condition because of good confinement column by FRP outward, so hybrid DSTC consider sustainable member. DSTCs can be formed in vary cross section shape of two tubes (circular, square, rectangular etc.) Figure (1-6) illustrates cross section of DSTMs(a) Circular DSTM. (b) square DSTM with circular steel tube .(c)square DSTM. (d) circular DSTM with eccentricity of inner steel tube.

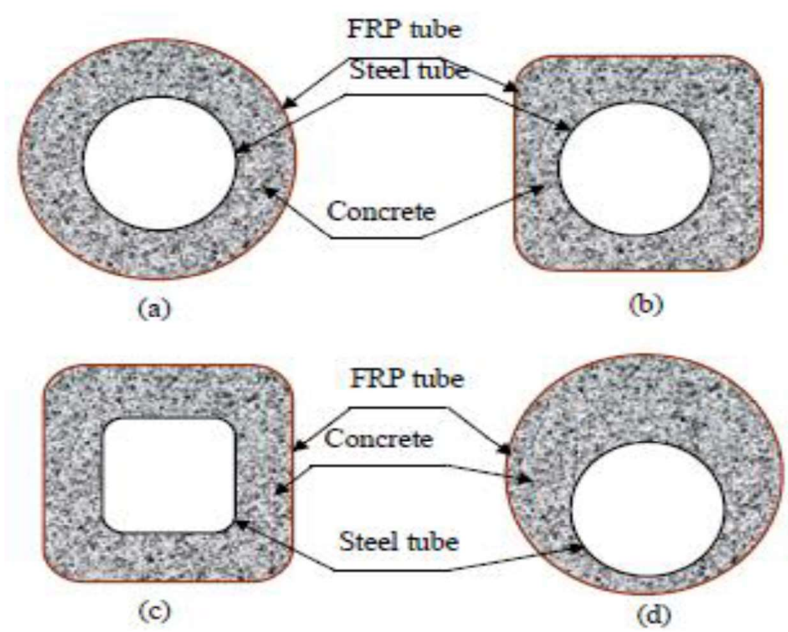


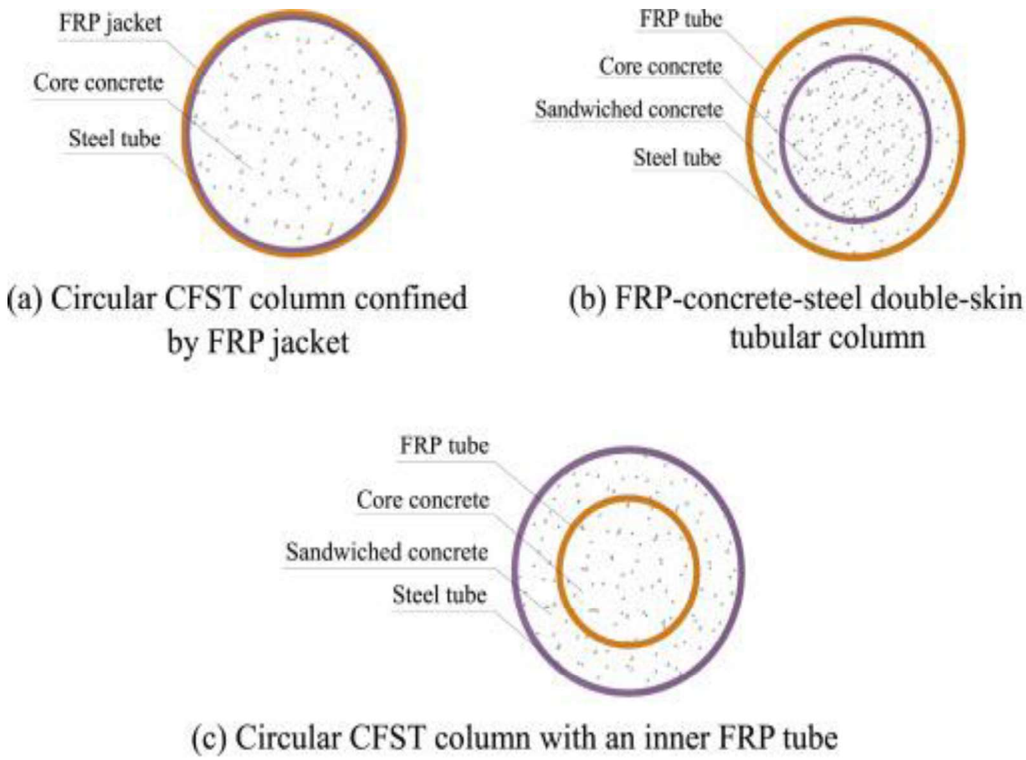
Figure (1-6) Cross section of DSTMs (**Yu et. al, 2007**).

also DSTCs can be established in vary forms like:

1- FRP tube confined steel tube filling with concrete. As shown in Figure (1-7) a.
2- FRP tube outside, steel tube inside and concrete in between .as shown in Figure (1-6). When filled inner steel tube the member become a dual grade concrete as shown in Figure (1-7) b.

3- Concrete filled steel tube with inner FRP tube. As shown in Figure (1-7) c.

4- Concrete filled between two tubes of steel. As shown in Figure (1-8).



(a) Circular CFST column confined by FRP jacket

(b) FRP-concrete-steel double-skin tubular column

(c) Circular CFST column with an inner FRP tube

Figure (1-7) different cross section of DSTMs.(**Long et. al, 2018**).

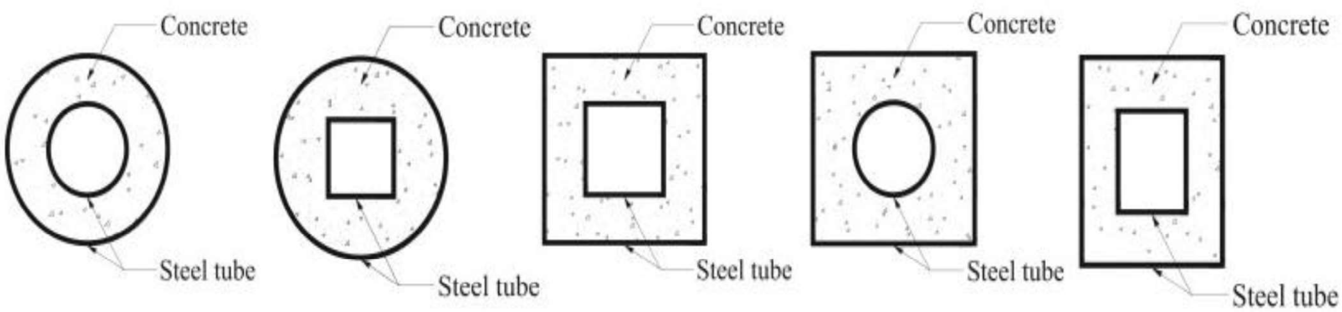


Figure (1-8) concrete between two steel tubes outward and inward.(**Chen et.al., 2016).**

1.4 Advantage of Hybrid FRP-Concrete-Steel DSTC

At recent years DSTC gain great attention and excessive research to show advantage of composite section with three materials component :

1- To increase strength of columns as concrete confinement by two tubes, inner steel tube and outer FRP tube (**Yu et. al, 2007**).
2- To get better ductile behavior of column (**Yu et. al, 2007**).
3- Hybrid DSTCs prevent corrosion and buckling of inner steel tube because of concrete restrained steel tube, absolutely leading to improve the rigidity of steel tube (**Yu et. al, 2007**).
4- Prevent concrete from being crushed (steel tube benefit) (**Yu et. al, 2007**).
5- Resistance to seismic load (DSTCs resistance to lateral load) (**Ozbakkaloglu et. al, 2013**) .
6- Highly capacity to support loading (steel tube benefit) (**Yu et. al, 2007**).
7- Easy to connection with other construction member (beams) because existence of steel tube (**Ozbakkaloglu et. al, 2013)**.
8- Three materials of DSTCs support and protect each other, concrete confined by two tubes, steel prevent concrete crushed, FRP protect concrete from weathering condition that made DSTCs sustainable section (**Yu et. al, 2013**).

1.5 Materials of Double Skin Tubular Columns

1.5.1 Fiber Reinforced Polymer

Fiber reinforced polymer (FRP) include that fibers embedded in polymeric resin and have feature over steel that high strength to weight ratio and good corrosion resistance, FRP composites are found wide application in civil engineering construction such as warp jacket of columns by FRP to increase its strength, FRP have very different types, glass fiber, basalt fiber, aramid fiber and carbon fiber etc. These types formed into sheet fiber with unidirectional or bidirectional embedded in polymeric resin (epoxy resin).

1.5.2 Concrete

Concrete is filling material, which consists of cement, aggregate (coarse and fine) and water with different percentage also have many kinds like (high strength concrete(HSC), fiber reinforced concrete (FRC), light weight concrete (LWC), by add admixture and change its properties and strength, it was very important material in compression members specially for columns because of its considerable compressive behavior, it is unique material when being with steel reinforcement and reinforcement concrete (RC) was content (very important material in engineering construction). Concrete pour between two tubes of fiber and steel to enhancement concrete strength by confinement method .

1.5.3 Steel Tube

Hollow steel tubes (HST) are widely used in engineering structural applications like bridge service sections etc., because of its high strength to weight ratio and excellent behavior under compression, bending and torsion resistance. Hollow steel tube with different diameter and thickness was used, with deferent void ratio (ratio between thickness of steel tube to the its diameter), with very cross section shape (circular, square, rectangular or congregated shape) hollow steel tubes filled with concrete pipe column, also HST had used in DSTCs to reinforcing concrete, they are play an important role in DSTCs behavior by preventing crushing of concrete inside DSTC.

1.6 Aim of The Study

The aim of present study is to investigate experimentally compressive behavior of confinement columns when using the sustainable benefit of hybrid double skin tubular member. To verify the behavior of (DSTC) in terms of ultimate load capacity, stress enhancement ratio, strain enhancement ratio and nominal confinement ratio. The following , variables of the experimental work are experimentally investigated:

1. Number of FRP layers.
2. Concrete compressive strength .
3. Diameter of inner steel tube.
4. Thickness of inner steel tube.

1.7 Methodology

Experimental program of this work included preparing and testing 24 specimens two concrete filled fiber tube column and 22 fiber reinforced polymer mortar –steel tube double skin tubular column, specimens are divided into five groups, all specimens subjected to an axial compression load.

1.8 Thesis Layout

Excessive research in this field is done to made new member construction, aim of this study is that, the present study consists of five chapters :

- ❖ **Chapter 1** the current chapter show that background about column their types, double skin tubular columns their advantages and materials, aim of study, methodology and layout of these study.
- ❖ **Chapter 2** present previous experimental and theoretical studies about confinement of column and DSTCs.

- ❖ **Chapter 3** this chapter describes in details experimental program of the columns divided into groups, illustrate materials used, tested it, poured specimens and instrumentation was used in this study.
- ❖ **Chapter 4** explain compression test result of columns that have gain from experimental work and their discussion.
- ❖ **Chapter 5** this chapter provides conclusions of this work based on experimental study and recommendation.