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Civil Engineering Department

EXPERIMENTAL INVESTIGATION OF SLENDER PLASTIC CONCRETE COMPOSITE COLUMNS

A THESIS
SUBMITTED TO THE COLLEGE OF ENGINEERING OF MISAN UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER IN CIVIL ENGINEERING
(STRUCTURES)

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May 2019 **Ramadan 1440**

بِسْمِ اللهِ الرحْمنِ الرَحِيمِ

((... يَرْفَعِ اللهُ الَّذِينَ آمَنُوا مِنْكُمُ
وَالَّذِينَ أُوتُوا العِلْمَ دَرَجَاتٍ وَاللهُ بِمَا
تَعْمَلُونَ خَبِير))

صَدَقَ اللهُ العَلِيُ العَظِيم

(سورة المجادلة، الآية 11)

TO

MY FATHER

AND

MOTHER

WITH LOVE

AND APPRECIATION

CERTIFICATION

I certify that the thesis entitled (***Experimental Investigation of Slender Plastic - Concrete Composite Columns***) which is being submitted by **Murtaza Allawi Raheemah** is prepared under my supervision at the University of Misan in partial fulfillment of the requirements for the Degree of Master in Civil Engineering (Structures).

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Date: / / 2019

In view of the available recommendations, I forward this thesis for debate by examining committee.

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EXAMINING COMMITTEE'S REPORT

We certify that we, the examining committee, have read the thesis titled (***Experimental Investigation Of Slender Plastic - Concrete Composite Columns***) which is being submitted by (***Murtaza Allawi Raheemah***), and examined the student in its content and in what is connected with it, and that in our opinion, it meets the standard of a thesis for the degree of Master in Civil Engineering (Structures).

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Abstract

In this study, the performance of PVC-concrete columns are investigated using various variables such as filling concrete compressive strength, columns slenderness ratio and PVC section slenderness ratio. The specimens are subjected to uniform axial compression in two loading modes. In the first mode; PVC tube is utilized to enhance concrete core as composite element, and in the second, PVC tube is utilized to confine concrete core only. The upgrading rate in sustained loading resistance of composite mode columns varied from 1.56 to 2.25, while it is 1.55 to 2.07 for confining mode columns. The same comparison is entirely reversed in case of ductility, where confining mode columns exhibited more axial and lateral deformations than the corresponding composite mode columns. The column slenderness ratios are varied so that overall column buckling investigated. The results showed that the composite mode columns exhibit more strength and ductility improving than those of confining mode. Experimental predicated effective flexural stiffness according to ACI 318 is normalized in term of filling concrete stiffness and PVC tube stiffness. The normalization results indicated that effective flexural stiffness depends on considered mode (confining or composite), PVC and filling concrete strength as well as column slenderness ratio. The results also are normalized in term of radial stress (f_r) and concrete compressive strength (f'_c), for determining enhancement of confined concrete strength (f'_{ce}) to predicate plastic capacity of columns for different mechanisms.

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Murtaza Allawi Raheemah

May 2019

CONTENTS

Symbol	List of Abbreviations
CFT	Concrete - Filled tube
CFFT	Concrete-filled FRP tube
CFST	Concrete-filled steel tube
FRP	Fiber reinforced plastic
BFRP	Basalt Fiber Reinforced polymer
UPVC	UnPlasticized polyvinyl chloride
PVC	Polyvinyl chloride.

Symbol	List of notations
f_{yp}	PVC yield tensile stress, MPa.
f'_c	Concrete compressive strength, MPa
f_r	Radial stress, MPa
L	Specimens length, mm
t_p	PVC tube thickness, mm
D	Outer section diameter, mm
A_c	Concrete core cross section area, mm
A_p	PVC tube section area, mm
λ	Slenderness ratio, Length / least width (diameter)
λ'	Section element compactness ratio, D/tp
P_p	Ultimate strength of PVC-concrete columns, kN
P_e	Euler buckling strength, kN
P_c	Ultimate strength of concrete columns, kN
P_{cm}	Experimental plastic capacity of composite mode columns, kN
P_{cn}	Experimental plastic capacity of confining mode columns, kN

EI_e	Effective stiffness N / mm^2
E_c	Concrete modulus of elasticity, Gpa
E_p	PVC modulus of elasticity, GPa
I_c	Concrete core second moment inertia, mm^4
I_p	PVC tube second moment inertia, mm^4
γ_{2}, γ_{1}	Coefficient depending on loading mode, materials strength and slender ratio.

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CHAPTER ONE

INTRODUCTION

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Introduction

1.1General

In civil engineering construction, the merits of a material are based on factors such as availability, structural strength, durability and workability. The properties of construction materials differ from each other; thus there is no material that can provide all structural requirements.[1] The engineer's problem therefore consists of an optimization involving different materials and methods of construction, with objective of building a structure at minimum cost to meet its requirements[2]. This is the reason of using two or more materials and connecting them together in order to make full advantage of their properties in getting one structural element that uses the desirable properties of the materials. The advantageous characteristics of different materials are combined to produce a member with high strength, enhanced stiffness, and to increase load carrying capacity. The structural member of two or more materials is known as a composite construction.[2] Resulted in the application of composite structures. Composite columns, particularly composite concrete filled steel tube (CFST) columns, are increasingly used for high-rise building structures, owing to the advantage of combined characteristics of the steel and concrete materials [1].

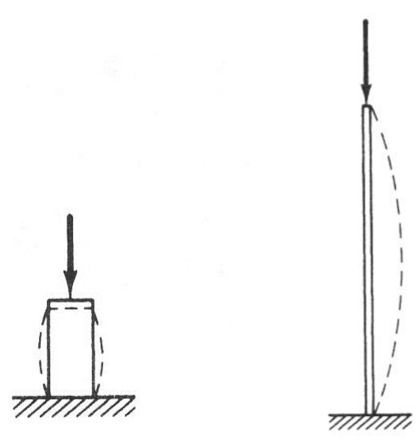
In the past, the composite columns have been employing steel or fiber-reinforced polymer tubes as the confinement material. However the use of these materials is becoming prohibiting due to a number of factors such as the corrosion problem of steel when used in aggressive environment such as undersea piling, and also the prohibitive costs of manufacturing fiber reinforced polymer (FRP) material. Although plastics have been used in construction and aesthetics for a wide application.[3]

1.2 Composite columns

Composite structures combined of two or more materials in a unit structure to provide tangible benefits and a versatile solution to suite different applications. Acomposite system reduces the unnecessary and unwanted material properties, such as weight and cost, without sacrificing required capacity[4]. The term 'composite column' implies a column constructed from two or more different materials in such a way that they work together in resisting stresses and strains induced by forces or external conditions of the column. Ordinary reinforced concrete columns fall within the scope of this definition. However, the term is normally used to indicate applications like either concrete-encased sections or concrete-filled tubes of square, rectangular or circular cross-section[2]. In the case of concrete filled tubes sections, 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. In the past, the composite columns have been employing steel or fiber-reinforced polymer tubes as the confinement material. However the use of these materials is becoming prohibiting due to a number of factors such as the corrosion problem of steel when used in aggressive environment such as undersea piling, and also the prohibitive costs of manufacturing fiber reinforced polymer (FRP) material. Although plastics have been used in construction and aesthetics for a wide applications[3].

1.3 Buckling of Columns

Buckling is the sudden uncontrolled lateral displacement of a column, at which point no additional load can be supported. Elastic instability is the condition of failure in which the shape of the column is insufficiently rigid to hold it straight under load[5]. At the point of buckling, a deflection of the axis of the column occurs suddenly then if the load is not reduced, the column will collapse. Columns are divided into two or rather three categories, (i.e. short columns, long columns, and columns of intermediate length). The load capacity of a slender column is directly dependent on the dimension and shape of the column as well as the stiffness of the material(EI), but is independent of the strength of the material (yield stress). The ratio of the length of a column to the least radius of gyration of its cross section is called the slenderness ratio which is a primary indicator of the mode of failure one might expect for a column under load. High slenderness ratios mean lower critical stresses[5]. It is convenient to classify columns into tow broad categories according to their modes of failure. Figure(1.1) shows column types and failure modes.



a. short column b. long column

Figure (1.1) Column types and failure modes.

For long (slender) column, buckling occurs at compressive stresses within the elastic range. While for short column will obviously not fail by elastic buckling, it will crush owing to general yielding and compressive stresses will be in the inelastic range. There is an estimation of slenderness for the slenderness ratio which eliminates the column types such as (long and short). The critical load for elastic buckling is valid only for relatively long columns. If the column is of intermediate length, the stress in the column will reach the proportional limit before buckling begins. To calculation critical loads in the intermediate range we need a theory of inelastic buckling [6]. The buckling load, or the point at which the deviation from the original geometry first occurs, is also called the critical load or bifurcation load. If the proportional limit has not been reached at any point in the member before the critical load is reached, the buckling is termed elastic buckling. And if the proportional limit of the material is exceeded somewhere within the cross section before buckling occurs. For usual material properties, this would often be the case for a column that has a length less than 20 to 25 times its diameter. Columns meeting this criterion will generally buckle inelastically, meaning permanent deformations will occur upon reaching the critical buckling load[6].

1.4 Polyvinylchloride

Plastics have exceptional properties, which make these materials attractive for different constructional applications. Some of these properties include high resistance to severe environmental attacks, electromagnetic transparency, and high strength to weight ratios. Due to these properties, there is great demand for structures such as piling, poles, highway overhead signs and bridge substructures to be made of plastics.[2] Polyvinylchloride (PVC), commonly referred to as vinyl, is a plastic material (polymer made on basis of salt and oil). Since a significant proportion of its mass is chlorine, creating a given mass of PVC requires less petroleum than many other polymers. PVC is thermoplastic material. Thermoplastic materials are those that can be melted again and again and after being heated up to a certain temperature they will harden again as they cool. It is used to make long-lasting products, often with a life expectancy exceeding 60 years. This provides some main attributes that make it useful in the construction of certain structures exposed to corrosive environments. Fundamentally, PVC pipe is hard to damage and lasts for long periods of time without the need for replacement and having lightweight, which permits easy handling, and impermeable to liquids and durable. Hence these pipes are used extensively in the construction industry[2].

1.5 Benefits of PVC Tubes in construction

The efficient of constructional using of PVC tubes with concrete could be related to :

Economic benefits represented by availability of plastic pipe.

1. The tube confines the concrete. This results in an increased strength and ductility of the concrete.
2. High performance of PVC to resist environmental deterioration and so protect concrete.
3. The tube provides a formwork for the casting of the concrete, which stays in place and does not need to be removed.

Plate (1.1) shows the use of plastic tubes as a formwork in construction of columns.

Plate (1.1) Using the plastic tubes as a formwork and for aesthetic.

1.6 Aims of Study

The main purpose of the present study is to provide information and generate data about the structural behavior of slender plastic-concrete composite columns consisting of PVC tubes filled with concrete under axial compression loading conditions.

Two modes of loading, composite and confining mode are considered. Different PVC tube thickness, slenderness ratios, diameter of PVC tubes and concrete compressive strengths are used to assess the effect of these variables on the strength and ductility of investigated columns.

1.7 Layout of Study

This study is arranged in five chapters. The current chapter is the first one, which give a general introduction about composite columns, their types, buckling of columns and aim of this study. **Chapter 2** contains review of historical works and studies related to composite columns. **Chapter 3** deals with the experimental work, including the properties and testing of the materials used, details of test columns, fabrication, instrumentation and test procedure. **Chapter4** presents the results of the experimental program, discussion of the obtained results is also given. **Chapter 5** summarizes the conclusions of the present study and recommendations for further researches.

CHAPTER TWO

LITERATURE REVIEW

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter presents a historical background concerning the studies dealt with the composite columns, relatively relate to considered investigation with a special importance on the concrete filled tube columns.

Composite columns have been widely used in the construction Industry for a number of years. The increase in the use of composite columns throughout the world in recent years is mainly due to the significant advantages that this type of columns could offer in comparison to more traditional construction methods.

2.2 Composite Columns

2.2.1 Concrete filled metallic tubes

Ali et al. [7] in 2013, presented an experimental behavior of circular steel tubular columns filled with self-compacting concrete under concentric load. Total six column specimens with different lengths (400 mm – 1500 mm) of constant diameter of 160 mm and wall thickness of 2.8 mm were tested to investigate the ultimate capacity and the deformation behavior of different slenderness ratio of columns. Experimental results indicate that the compression force capacity was affected by slenderness ratio of the column. For slender column the overall buckling was observed while for the short columns the crushing and the local buckling is the dominant failure shape.

Nasser[8] in 2014, deals with an experimental and computational study which was carried out on the structural behavior of circular concrete filled aluminum tubular columns subjected to increasing axial load. Twenty four specimens were tested to investigate the effect section slenderness ratio (d/t) and slenderness ratio of an aluminum tube on the load carrying capacity of the concrete filled tubular columns. Diameter to wall thickness ratio ranged (23.3 - 47.8), and the length to tube diameter ratio was (3 - 10) for this investigation. The average values of ratios of experimental to predicted ultimate loads were 1.001 for the Sugeno fuzzy inference system model. strength was increased due to the confinement of the concrete by the aluminum tube. The typical failure mode of short and intermediate length composite columns (L/D = 3 – 4) was classical shear mode failure. For the slender composite columns (L/D = 6-10), the failure mode of specimens was a long column buckling mode failure.

Resan [9] in 2014, presented an experimental and theoretical study of light weight concrete filled aluminum circular tubes. The structural performance of columns was investigated using different light weight concrete ingredient proportions and compressive strengths. The column specimens were subjected to uniform axial compression with two different loading styles. In the first, (composite action), aluminum tube was utilized to be axially loaded as well as its confining function, and in the second loading style (confinement action), aluminum tube is utilized to confine concrete core only. A grade of light weight expansion clay aggregate was used to fabricate light weight concrete. The strength, axial load-shortening displacement relationship, axial and lateral strain, and failure modes of column were presented. It was concluded that the aluminum lightweight concrete columns exhibited high capacity increments as compared with aluminum columns. Although the used aluminum tube adds (0.5 kg/m) for the aluminum lightweight concrete composite column, the overall stiffness and strength increase with high ratio. The ratios of increase in strength (P_{co} /P_{al})

ranged between (1.5) to (2.14) for composite action and between (1.3) to (1.86) for confinement action, this prove that the aluminum tube provided sufficient lateral support to the light weight core and increased the ultimate strength of the column. From theoretical analysis, It was observed that the general design guidelines specified in the American specifications were capable of predicting the values of ultimate strengths of aluminum lightweight concrete columns with a good agreement with the experimental values.

Resan [4] in 2014 presented an experimental study of composite columns of hollow circular aluminum tubes enhanced with a fibers reinforced polymer (FRP) sheet and filled by lightweight concrete. The test results discussed the influence of internal and external confinement effectiveness introduced by aluminum tube and carbon fiber reinforced polymer retrofitting sheet, respectively. The column specimens were subjected to uniform axial compression load. Structural aluminum alloy circular hollow section has been used. The test results indicated that confinement and composite action between the constituent materials resulted in enhanced compressive strength, ductility and energy dissipation capacity of the proposed composite column. The load capacity of the composite column significantly were more than concrete core or aluminum tube, where (P_{co}/P_c) and (P_{co}/P_{al}) ratios are (2.54) and (1.83). For all specimens, the ratio (P / P_{al}) is larger than (1), the average was (1.16).

Ajel and Abbas [10] in 2015, presented an experimental and finite element investigation on concrete filled steel tube compression members. The effect of concrete compressive strength, thickness of steel tube, stiffeners and longitudinal reinforcement were considered to investigate the structural behavior of concrete filled steel tube columns using experimental and analytical studies. Specimens that have been studied consist of sixteen square samples with dimensions of (150

× 150 × 300 mm) , and fifteen circular samples of 150 mm diameter and height of 300 mm. The tested samples were studied analytically using three dimensional finite element representation by ANSYS computer program. The results obtained from finite element solution shows that, the convergence between analytical and experimental failure load varied from 2 to 15 %. While the effect of compressive strength of concrete on columns having width/thickness (b/t) or diameter/thickness (d/t) equal to 37.5 was greater than columns which have (b/t) or (d/t) equal to 50. Plate (2.1) shows hollow steel specimens while plate (2.2) shows mode of failure of tested specimen. Deformations of columns filled with normal concrete (25 MPa) are larger than those of columns filled with high strength concrete (60MPa). When (b/t) or (d/t) decreases, the ultimate load capacity increased. Ultimate load capacity varied from 4.47 to13.37 % for square samples varied from 8.00 to 12.14% for circular samples depending on the type of stiffened, compressive strength of concrete and ratio of (b/t) and (d/t).

Plate (2.1) mode of failure

Alshimmeri [11] in 2016, introduced an experimental study on the behavior of confined concrete filled aluminum tubular column to improve strength, ductility and durability of concrete composite structures under concentrically loaded in compression to failure. Seven column specimens with same concrete diameter 100 mm and without steel reinforcement have been examined through experimental testing, which were used to study the effects of the thickness of the aluminum tube encased concrete on the structural behavior of concrete filled tube columns. It was concluded that the compression force capacity was affected by thicknesses of the aluminum tube with respect to reference specimen. For slender column the overall buckling was observed while the local buckling for the short column was the dominant failure shape.

Al-Mazini and Chkhewier [12] in 2017, presented an experimental results square and rectangular aluminum tube columns filled with concrete and analyze these results by finite element method. The studied parameters included the depth to wall thickness ratio (d/t), slenderness ratio of the aluminum tube and concrete core compressive strength. The experimental work included testing of twenty five composite concrete-filled aluminum columns subject to axial load. The depth to thickness ratio of the square and rectangle hollow columns ranged from 25 to 62.5. The column length to depth ratio ranged from 3 to 10. Different filled concrete strengths of (25, 40 and 60 MPa) were used. The column strengths, load-axial shortening relationship, load-lateral deformation relationship and failure modes of columns were presented and discussed. The experimental results showed that the ultimate load of hollow and filled columns increases with the decrease of the depth/ thickness ratio. The compressive strength exhibited very clear effect on the strength of columns filled with concrete. the stiffness of the columns increases as the compressive strength of concrete filled it increases. This is because the modulus of elasticity of concrete increases as a compressive strength increases. It has been observed that, the ductility of the composite columns improves as compared to the hollow columns.

Farooq[13] et al in 2018 study the effect of steel confinement on axially loaded short concrete columns. Total of six specimens were prepared in the laboratory, out of which, two columns were unconfined columns, two columns were strengthened with steel strips and remaining two columns were strengthened with a steel jacket. Columns has square cross section width (152.4 mm) and height (355.6 mm) All specimens were subjected to axial compression loading in increment until the failure of specimens. It was concluded after the experimental work that the steel strips enhanced axial load carrying capacity by a factor up to 1.54 times and steel jacketing enhanced the capacity by a factor of 2.38. It has also been observed that the steel confinement increased the cracking load by a factor up to 1.5 to 2.66 for strips and jacketing respectively. The failure occurred due to the crushing of concrete and buckling of steel strips and jacket between the fasteners. The steel strips and jackets are economical and feasible options for confining the concrete to increase its axial load carrying capacity.

2.2.2 Concrete Filled Nonmetallic Tubes

Saadoon [2] in 2010, presented an experimental and theoretical investigation of PVC-concrete composite columns. Series of thirty columns under axial compressive load were tested. The parameters considered were the concrete compressive strength, PVC tube thickness, and column slenderness ratio, and six PVC-concrete composite columns with transverse steel reinforcement at the ends of the columns in an attempt to improve their behavior. The tubes were of circular cross section with 110 mm external diameter and wall thicknesses of 3.2 mm and 5.3 mm. columns with heights with heights of 220, 400, 600, 800, and 1000 mm. The main purpose of the experimental program was to investigate the structural behavior of PVC-concrete composite columns under axial compression loading conditions. It was found that the plastic pipe (PVC tube) provided sufficient lateral support of the concrete core and increased the ultimate strength of the column. The ratio of strength of PVC-concrete composite column to strength of plain concrete column ranged between 1.419 and 1.896 for columns with 30 MPa concrete compressive strength, whereas it was between 1.118 and 1.405 for columns made with 50 MPa. Although the increase in the strength of reinforced composite columns was unnoticeable, the steel reinforcement at the ends is adequate to prevent failure to occur at these ends. Plate (2.12) shows failure modes of tested specimens.

a- Concrete columns

b- Composite columns

Plate (2.3) (a , b) Failure modes of tested columns

Shenglan et al. [14] in 2012, presented an experimental study on slexural behavior of circular concrete-filled FRP-PVC tubular members. Six specimens were prepared and tested under flexural loading. The main parameters varied in the tests were the layer of FRP and the strengthening approach of basalt fiber reinforced polymer (BFRP) and concrete and carbon fiber reinforced polymer. The results show that the external conferment of concrete specimens by FRP-PVC tubes results in enhancing the ultimate bending strength and ultimate deformation, and the ultimate bending capacity increased with the FRP layers. Simultaneously, the reinforcement effect in concrete and carbon fiber reinforced polymer was better than that in BFRP.

Soliman [15] in 2013, studied the failure mechanism for confined plain concrete columns. Eight polyvinylchloride tubes (PVC) confined concrete columns were tested to study the behavior of confined columns. In addition, experimental results of eight plain concrete columns carried out for comparing between confined and unconfined column behavior the theoretical prediction of confined compressive strength by using ultimate limit state method based on computability deformations was presented. Crack propagation and modes of failure were described. Analyses of the experimental results with the effect of column heights and diameters were discussed. The cracking behavior of confined concrete during loading is analyzed. The fracture compressive strain related to vertical stresses and corresponding axial strains, and fracture tensile strain related to horizontal acting stresses and corresponding radial strains were calculated. The experimental results showed that, the radial strains distribution may be not uniform through the hoop direction of confined columns. The results has been proven that used FRP confined concrete columns provides superior ductility and improves the load carrying capacity characteristics when comparing to conventional columns. The mode of failure changes by altering slenderness ratio of the confinement concrete column. FRP tube/sheet confinement concrete makes a restrain for crack and delays the crack development but not prevents internal cracks.

Gupta [16] in 2013, presented an experimental study presented to investigate the effectiveness of unplasticized poly vinyl chloride (UPVC) tube for confinement of concrete columns. Tubes having 140 mm, 160 mm and 200 mm external diameters were used to confine the concrete having compressive strength 20 MPa, 25 MPa and 40 MPa. The testing of the specimens was carried out on a displacement controlled INSTRON make Universal Testing Machine of 2500 kN capacity. During the experiments mode of deformation and corresponding load-compression curves were recorded and obtained results were compared with the existing models for confined concrete available in the literature. It was found that the predicted capacities of columns using different models are within ±6% of the experimental capacities. It was found that UPVC tubes can be effectively used for confinement of the concrete columns and to enhance their load capacity, ductility as well as energy absorbing capacity.

Gathimba et al. [3] in 2014, presented an experimental program which investigated the effect, on compressive strength, of using plasticized polyvinyl (UPVC) tubes in confining short concrete columns. Plastic tubes having varying diameters (55, 83and 110 mm) and thickness (2.5 and 3 mm) and slenderness ratio (2, 3 and 4) were used to confine concrete of different strengths (20, 25 and 30 MPA). The resulting composite columns were subjected to concentric axial compressive loads until failure. The principal failure mode was a typical shear failure. The results indicated that compressive strength of the column specimens increase with increased concrete strength while the same decreased with increase slenderness ratio. A comparison of the ultimate load carrying capacity and column compressive strength was then made between unconfined and the resulting composite column. Strength increased between 1.18 to 3.65 times the unconfined strength.

Usha and Eramma [17] in 2014, tested eighteen specimens of UPVC tubes of diameter 150 mm, thickness 7.11 mm with effective lengths of (500 , 600 and 700 mm), constant concrete strength of 20 MPa. Concrete of two different mixes having two different sizes of coarse aggregate 6.3 mm and 10 mm was filled inside the tubes for casting of UPVC concrete filled tube (CFT) column specimen, the specimens was axially loaded until failure of the specimen to investigate their load carrying capacity. The load-displacement curves and stress-strain curves were recorded. All the columns fail by local buckling. As the length increases the strength was increased and it was higher for the mix which have 6.3 mm size of coarse aggregate compared to 10 mm size of coarse aggregate. It was found that about 1.6 % increases in compressive strength of UPVC CFT columns experimentally when compared with theoretical value.

Gathimba [18] in 2015, proposed a novel-type concrete-filled composite column where unplasticized polyvinylchloride (UPVC) plastic tube was used to confine concrete. Concrete of varying class strengths (30 , 25, and 20 MPa) were used to fill UPVC tubes. The tubes had outer diameters of (55 mm, 83 mm and 110 mm) and thicknesses of 2.5 mm, 3.0 mm and 2.5 mm respectively. The composite columns had ratios (L / d) of (2, 3 and 4). The columns were tested to determine their behavior under compressive load. Results showed that UPVC pipes effective in confining concrete, since in all cases the compressive strength of confined concrete to unconfined concrete was larger than 1, ($f'_{cc}/f'_{co} > 1$). Plate (2.4) shows column specimens while plate (2.5) shows modes of failure.

Plate (2.4) Column specimens

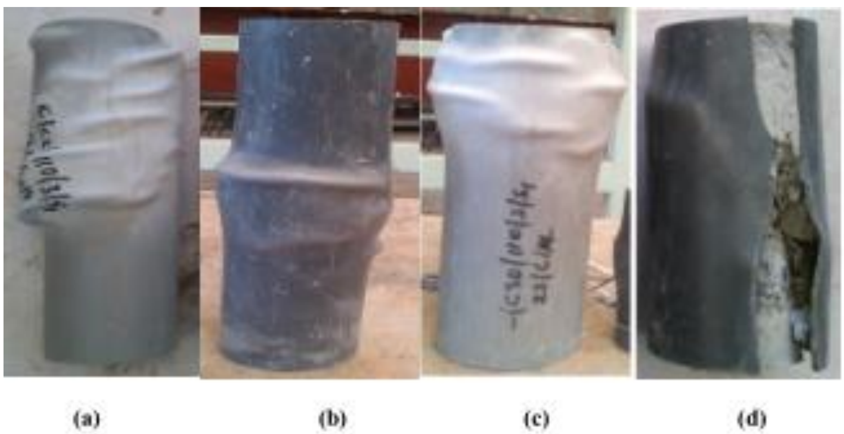


Plate (2.5) Modes of failure

Confined strength values increased between 1.18 to 3.65 times the unconfined strength values. Columns filled with low strength concrete tended to be more ductile as since they underwent large deformations under load before failure. This great ductility implied more energy absorption capacity suggesting a potentially earthquake resistant composite column system.

Abhale et al. [19] in 2016, studied the effect of polyvinylchloride (PVC) on axially loaded column. Twenty four specimens were tested. Twelve of them were made of PVC pipe and remaining specimens were of steel tube. PVC tubes of diameter. 152.4 mm, thickness 5mm with effective length of 500 mm and 600 mm, the specimens were tested to investigate their load carrying capacity. They concluded that the confinement of concrete columns with PVC tubes improves their compressive strength. The improvement in strength is dependent on the concrete strength and geometrical properties of the tubes. As the Length increases, the ultimate axial strength of the column decreases considerable.

Kumutha and Vijai [20] in 2016, carried out an experimental investigation to evaluate the effectiveness of PVC confinements in concrete columns. The strength characteristics of the plain and reinforced concrete columns under axial compression with and without external confinement using PVC pipes were studied. The parameters investigated were diameter of the specimens (152 mm and 178 mm) and thickness of PVC pipes (3 mm and 4 mm). Test results showed that the external confinement of concrete columns by PVC pipes results in enhancing compressive strength, ultimate load and energy absorption capacity. Test results also indicated that as the thickness of PVC pipes increases, the confining pressure also increases which in turn increases the compressive strength of concrete. This increased compressive strength leads to an enhancement in ultimate load carrying capacity of reinforced concrete columns.

Jamaluddin et al [1] in 2017, presented an experimental investigation of concrete filled PVC tube columns confined by plain PVC socket. Total of five concrete filled columns using PVC tubes (CFT PVC) was tested to investigate the columns' behavior. The column was 700 mm height, 100 mm external diameter and 3.5 mm tube thickness with different thickness of plain socket (socket with 5.8 and 6.8 mm thicknesses, 102 mm diameter and 100 mm depth). Plate (2.6) shows details of plain socket while figure (2.1) exhibits schematic diagram of PVC CFT column. The results presented include maximum axial load, plain socket confinement effect, the mode of failure, and lateral PVC strain. The axial load enhancement of PVC-concrete columns confined using plain socket shows an increment of 21.3% up to 55.2% and axial strain from 21% to 40% compared with displacement for control composite columns at 192 kN ultimate load.

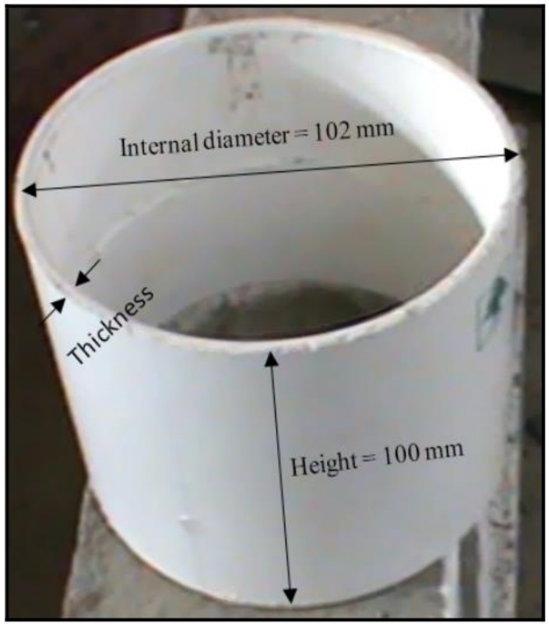


Plate (2.6) details of plain socket

2.3 Slender Composite Column

Tsuda.[21] in 2000, studied the strength and behavior of slender concrete filled steel tubular columns. Concrete filled steel square and circular tubular columns were tested. Test was composed of two series. In Series I, columns were subjected to concentric and eccentric axial force at both ends. In series II, columns were cantilever columns, and subjected to alternating horizontal load under constant vertical load. As a main experimental parameters, buckling length section depth ratio of a column was selected. Strength and behavior were examined, and design methods for slender composite columns were investigated.

It was observed that as the eccentricity becomes large the maximum load decreases, while the deflection at the load increases. Effect of the magnitude of eccentricity on the strength and behavior becomes small as the slenderness ratio (L /D) ratio becomes large.

Jiang [22] in 2014, studied the performance of slender concrete-filled carbon fiber-reinforced polymer polyvinyl chloride tubular columns under axial compression. Four specimens with different slenderness ratios were firstly carried out to explore their performance and failure modes under axial compressive loads in laboratory. Secondly, a nonlinear finite element model was developed to analyze the relation between loads and deformation, and the analytical values were compared with the experimental results. The parameters considered was varying the number of carbon fiber reinforced polymer layer, concrete compressive strength and the slenderness ratio were conducted by the nonlinear finite element model, and the ultimate bearing capacity formula. ultimate bearing capacity was compared among the experimental results. nonlinear finite element model analytical values and the prediction by the proposed formula. The results indicated that not only the developed nonlinear finite element model can effectively depict the varying process of the loads and deformation in details, but also the proposed ultimate bearing capacity formula was reasonable and reliable in the fast prediction of the bearing capacity for slender concrete-filled carbon fiber reinforced polymer polyvinyl chloride tubular columns.

Schnabl et al. [23] 2015, presented an analytical buckling of slender circular concrete-filled steel tubular columns with compliant interfaces. Efficient mathematical model for studying the global buckling behavior of concrete-filled steel tubular (CFST) columns with compliant interfaces. The mathematical model was used to evaluate exact critical buckling loads and modes of CFST columns for the first time. The results proved that the presence of finite interface compliance may significantly reduce the critical buckling load of CFST columns. A good agreement between analytical and experimental buckling loads of circular CFST columns was obtained if at least one among longitudinal and radial interfacial stiffness was high. The design methods compared in the study gave conservative results in comparison with the experimental results and analytical results for almost perfectly bonded layers. The parametric study reveals that critical buckling loads of CFST columns were very much affected by the section slenderness ratio ratio and concrete elastic modulus. Moreover, a material nonlinearity has a pronounced effect for short CFST columns, and a negligible effect for slender ones. The critical buckling loads increase as the (d/t) decreases along with the increase of interface compliance. comparing a high performance concrete to a normal strength concrete.

Ghannam [24] 2015 studied the buckling of concrete-filled steel tubular slender columns. Twelve full scale column specimens of rectangular, and circular steel hollow sections. All columns were slender with various lengths and slenderness ratios and of cross-sectional dimension, Two different concrete mixes were used. Comparisons between normal and lightweight concrete filled steel columns for different columns cross sections using BS 5400 codes were carried out. The test results showed that both types of concrete filled columns failed due to overall buckling, while hollow steel columns failed due to local buckling at the ends. The results of the tested columns were presented as in the following procedures:

a. Sections filled with lightweight aggregate concrete failed due to local as well as overall buckling, and they were capable of supporting more than

92% of the ultimate strength . The ratio between experimental and design values ranges from 104% to 130%.

b. Sections filled with normal concrete failed due to overall buckling at sidelight, and they were capable of supporting more than 87% of the squash load. Design code values of failure loads, according to all design codes, were also compared with the experimental results. The ratios between the experimental failure loads to the design loads vary between almost 100% and 138%.

c. Bare steel sections failed due to excessive yielding and bulging (local buckling) at both top and bottom ends of the column specimens before reaching the plastic load, and they were capable of supporting more than 88% of the plastic load. The ratios between the experimental failure loads and the design loads range from 95% to 122%. All columns were tested under axial load. It can be seen from the load-deflection curves that the horizontal deflections in the major axis direction were very small and started to increase at loads more than 80% of the failure load.

2.4 Concluding remarks

In the review of the previous work on composite columns, it is found that few studies have been reported concerning the behavior and strength of PVC-concrete composite columns. In view of the shortage in the experimental work on PVC-concrete composite columns, a comprehensive study is required to provide database for the strength of such columns. This database requires further testing of columns having different tube sizes, slenderness ratios and concrete properties to identify the behavior and then propose a design approach of such composite columns to use in light construction.

CHAPTER THREE
Experimental WORK

CHAPTER THREE

EXPERIMENTAL WORK

3.1 INTRODUCTION

The experimental work was carried-out in the Construction Materials Laboratory of the College of Engineering, University of Misan.

test program involve two types of specimens according to loading conditions, composite mode and confining mode. It was aimed to investigate the structural behavior of plastic-concrete columns through a series 51 columns, divided into eight groups, four groups for long columns and four groups for short columns were tested. The considered parameters were the concrete compressive strength, plastic tube thickness, diameter of plastic tube and column slenderness ratio. This chapter presents specimens details and properties of the materials used to fabricate the specimens, fabrication process, instrumentation, and testing arrangement of the specimens.

3.2 Materials

Commercially available materials were used in this investigation which include cement, water, natural gravel, natural silica sand, silica fume, super plasticizer and plastic tube (PVC).

3.2.1 Cement

Ordinary Portland cement manufactured by Lafarge company was used throughout the investigation, the required quantity was brought to the laboratory and well stored in dry place and isolated from the ground. compressive test and setting time tests were conducted according to Iraqi standard No.8/1984 [25] The test results were presented in Table (3.1). Results show that the used cement conforms with the Iraqi standard No.5/1984 [26]. And ASTM C150[27]. Table (3.2) shows chemical composition of cement.

Table (3.1) physical properties of cement

Physical properties	Test results	Limits of Iraqi specification no 5/1984	ASTM C150
Fineness using blain air permeability apparatus (m^2/kg)	384	≥ 230	≥ 280
Setting time using vicat's method Initial (hours : min) Final (hours : min)	 2 : 00 3 : 45	 ≥ 0.45 min ≤ 10 hrs	
Soundness using autoclave method	0.22	< 0.8	
Compressive strength of mortar 3 days : MPa 7 days : MPa	 20.8 27.4	 ≥ 15 ≥ 23	 ≥ 12 ≥ 10

physical properties tests were done at laboratory of structural department in technical institute of misan.

Table (3.2) Chemical composition of cement

Oxide composition	Abrasion	Content present By weight	Limit of Iraqi standards No . 5/1984
Lime	Cao	60.12	---
Silica	Sio_2	19.8	---
Alumina	AL_2o_3	6.08	---
Iron oxide	Fe_2o_3	3.25	---
Sulphate	So_3	2.48	< 2.8%
Magnesia	Mgo	2.75	≤ 5 %
Loss on ignition	$L.O.I$	3.46	≤ 4 %
Insoluble residue	LR	1.07	≤ 1.5 %
Lime saturation factor	$L.S.F$	0.97	0.66 – 1.02
Main compounds (bogue's equations)			
Tricalicum silicate	C_3S	50.69	---
DI calcium Silicate	C_2S	18.28	---

Chemical composition of cement test were done at laboratory of structural department in technical institute of misan.

3.2.2 Water

Water used in making and curing of concrete was ordinary portable water according to ASTM C1602-12[28].

3.2.3 Aggregate

1- Fine aggregate : Natural silica sand from Zubair area in Basrah was used as fine aggregate. The sieve analysis test was conducted according to ASTM C136 [29]. The results conform to Iraqi standard No.45/1984 [30] (Zone 2) as shown in table (3.3). table (3.4) shows the chemical properties of fine aggregate.

Table (3.3) Grading of used sand

Sieve size (mm)	**Passing %**	**Passing of overall Limit of Iraqi standards % No . 45/1984**
4.75	99.2	90 – 100
2.36	91.8	75 – 100
1.18	78.5	55 – 90
0.6	56.2	35 – 59
0.3	22.7	8 – 30
0.15	3.4	0 – 10

Table (3.4) Chemical and physical properties of sand

Properties	**Test result**	**Limit of Iraqi specification no 45 /1984**
Specific gravity	2.67	---
Absorption	0.71	---
Sulfate content as SO_3 %	0.11	≤ 0.5

Chemical and physical properties of sand test were done at laboratory of structural department in technical institute of misan.

<u>2- Coarse aggregate:</u> Crushed natural gravel obtained from ali algarbi area in Misan was used. Its grading satisfied the limits of Iraqi standard No. 45/1984 [30] for graded gravel with maximum size of 12.5 mm. The sieve analysis test was conducted according to ASTM C136 [29].

Table (3.5) Grading of used gravel

Sieve size (mm)	**Passing %**	**Passing of the overall limit of Iraqi Standards % No. 45 /1984**
20	100	100
14	100	90 -100
10	83	50 – 85
5	5.2	0 – 10

3.2.4 Silica fume

Which is commercially called as silica fume or micro-silica. It is available at local markets with 20 kg sacks, micro silica granules are less than 0.1 microns. It was a chemical composition contains (Sio_2) the chemical composition of this type of silica used in the present work conform to ASTM C1240-04 [31] standard as shown in the Table (3.6).

Table (3.6) Chemical composition of silica fume.

Compound composition	**Chemical composition**	**Oxide content (%)**	**Limit of specification requirement ASTM C1240-04**
Lime	Cao	0.5	---
Iron oxide	Fe_2O_3	1.4	---
Alumina	AL_2O_3	0.5	---
Silica	Sio_2	92.1	85 (min)
Magnesia	MgO	0.3	---
Sulphate	SO_3	0.1	---
Potassium oxide	K_2O	0.7	---
Sodium oxide	Na_2o	0.3	---
Los on ignition	$L.O.I$	2.8	6 (max)

This technical description provided by the manufacture.

3.2.5 Superplasticizer

Superplasticizer type PC, 260 was used. It was imported from the Don construction company DCP construction chemicals company, this type of plasticizer conforms to ASTM C494-99[32]. This plasticizer was a free of chloride base on the polycarboxylic - ether - polymer with a long-chain especially was designed to enable a water content concrete to perform as more effectively, which directly affects in increasing the workability of the concrete and give it sufficient flow during mixing. The technical specification for this type of plasticizer is described in Table (3.7).

Table (3.7) Technical description of super plasticizer Flocrete PC 260.

Chemical base	Modified poly carboxylates based polymer
Freezing point	-7^{0}C approximately
Appearance / colors	Light yellow liquid
Specific gravity at 25^{0}C	1.1 ± 0.02
Air entrainment	Typically less than 2% additional air is entrained

This technical description provided by the manufacture.

3.2.6 Plastic tubes

The used plastic tubes used were commercially available tubes. It was polyvinylchloride ((PVC)) type, polymer was one of the most stable substances when high corrosion resistance is required. The tubes were of circular cross section manufactured by FABCO plastic factory limited in Saudi Arabia. The tubes of outer diameter 75 mm with thickness (2.2, 3.6, and 5.6 mm) and outer diameter of 63 mm with thickness (3 and 4.7 mm) were used throughout this investigation. The standard length of pipe was 6 m. Table (3.8) list Physical properties of the PVC according to FABCO plastic factory certification data sheet [33] which is meets the ASTM D - 1784 [34]. The mechanical properties of the PVC tubes were obtained by testing specimens from them and verified with the data provided by the manufacturer.

Table (3.8) Physical properties of the PVC.

NO.	Properties of PVC	Units	Values
1	Specific gravity at 23^0 C	g / cm^3	1.43
2	Softening point	C^0	82
3	Resistance to methylene chloride	%	< 3
4	Resistance to water absorption	Mg / cm^2	< 2
5	Resistance to alkaline	No effect	

This technical description provided by the manufacture.

3.2.6.1 Mechanical Properties of used PVC tubes

PVC Mechanical properties were obtained by testing specimens from the tubes and verified with the data provided by the manufacturer. To obtain the material properties of the tubes, prepared coupons from the tube were tested them for tensile. Although the nominal dimensions of the tube are known, the wall thickness and the outside diameter are measured at several locations, these values are measured to determining the cross-sectional properties. For each thickness of tube used, coupons were cut from the curved faces of the tubes in the longitudinal direction, the gauge length of the coupons specimens are (50 mm) and (13 mm) wide according to ASTM D638 – 02a[35], and the coupons were tested in (INSTRON) machine that used for tensile, compression test on various metals at the laboratory of Mechanic engineering , University of Basrah.. The output data of the test are of the applied stress and corresponding axial strain were recorded at regular intervals during test. Table (3.9) shows the material properties, which include the ultimate tensile strength and modulus of elasticity. It was found that the properties of the tubes are same for all thicknesses. Fig (3.1) shows the dimensions of the tension coupon. Plate (3.1) to (3.4) shows the test machine and specimens after and before testing. Figures from (3.8) to (3.17) show the stress-strain behavior and load–extension curve for tested coupons.

Table (3.9) PVC properties.

Properties	Units	Value
Tensile strength at break	MPA	47.07
Specific gravity	g/cm^3	1.43
Elongation	Extending / length	80%
Modulus of elasticity	MN/m^3	2000

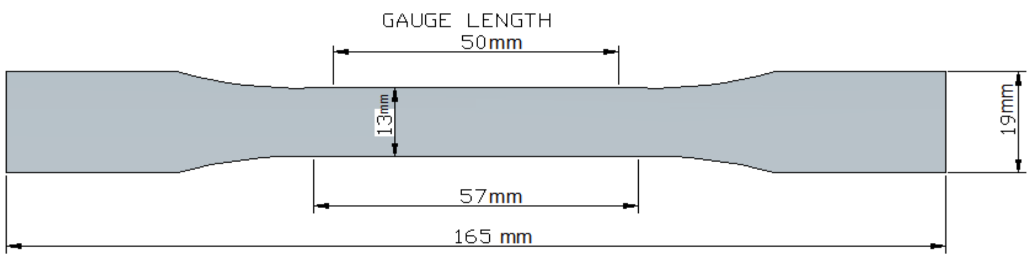


Figure (3.1) PVC tensile coupon dimensions according to (ASTM D638 – 02a) specification[35].

Plate (3.1) Tensile test machine for PVC coupons.

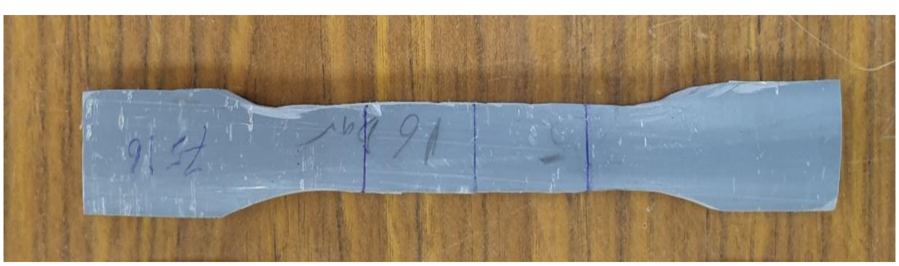


Plate (3.2) PVC tensile coupon.

Plate (3.3) Coupon arrangement in testing machine.

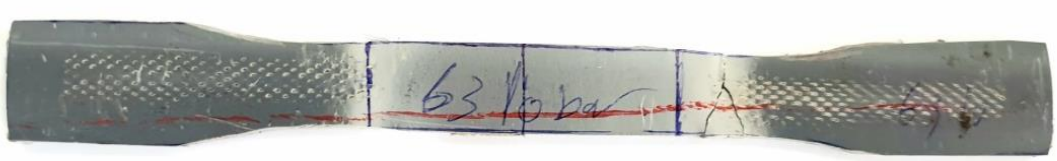


Plate (3.4) PVC coupon after failure.

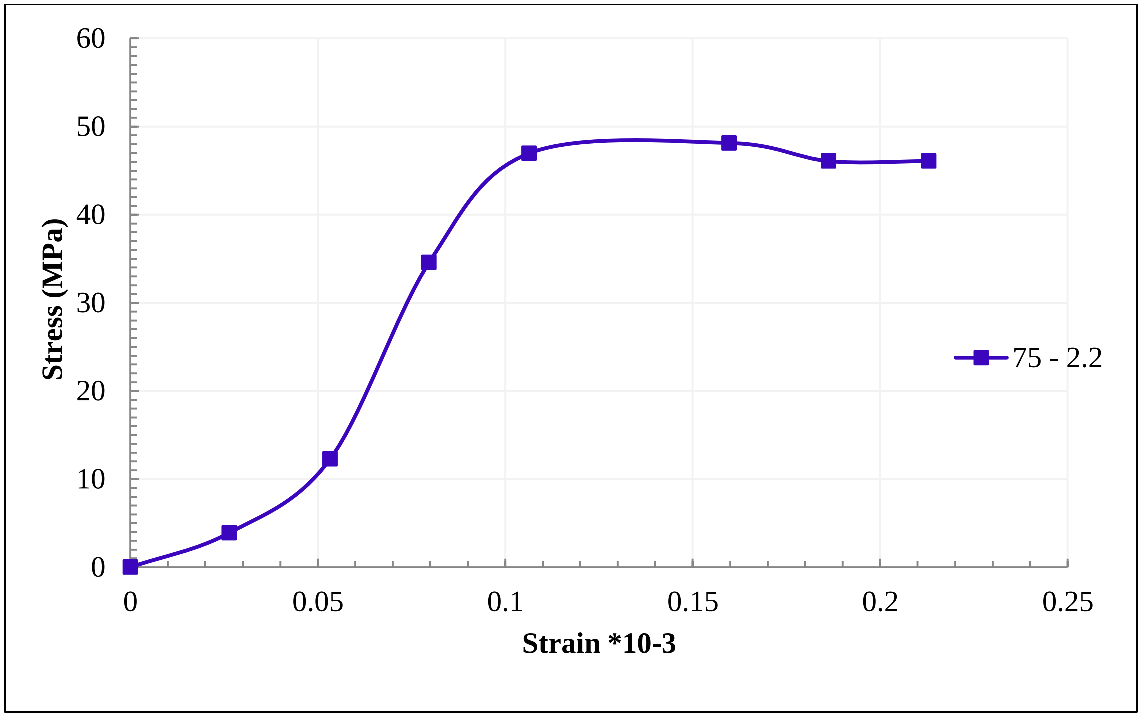


Figure (3.2) Stress-strain curve from coupon test for PVC of D= 75mm and tp=2.2mm.

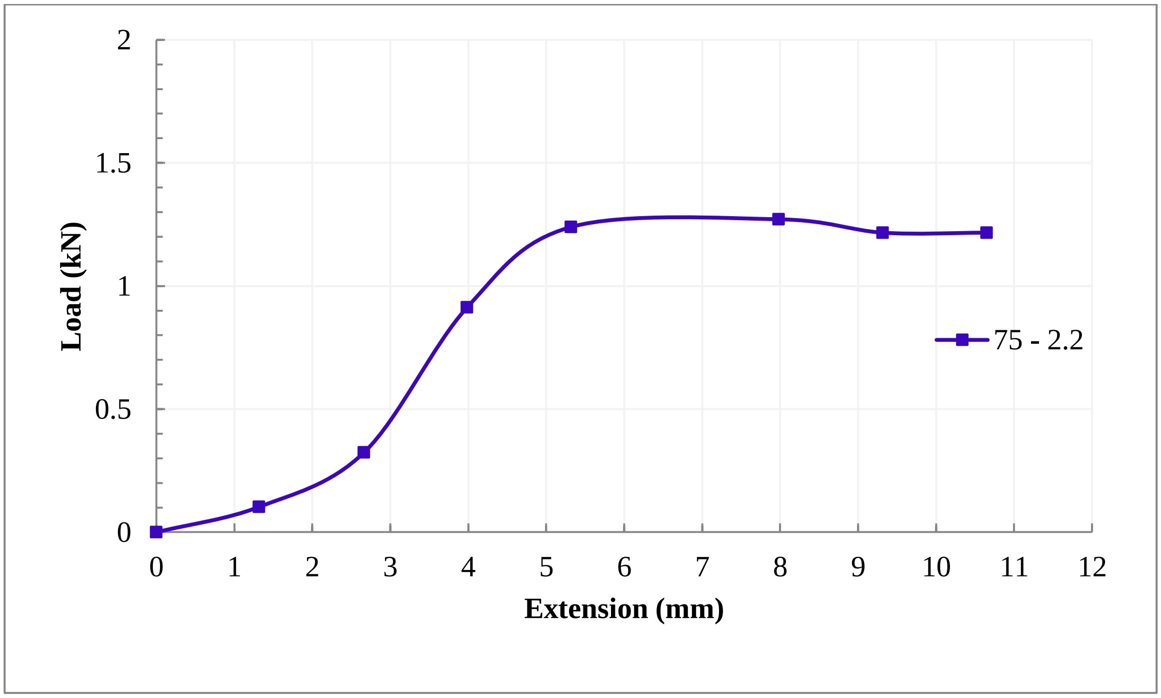


Figure (3.3) Load-extension curve from coupon test for PVC of D= 75mm and tp=2.2mm.

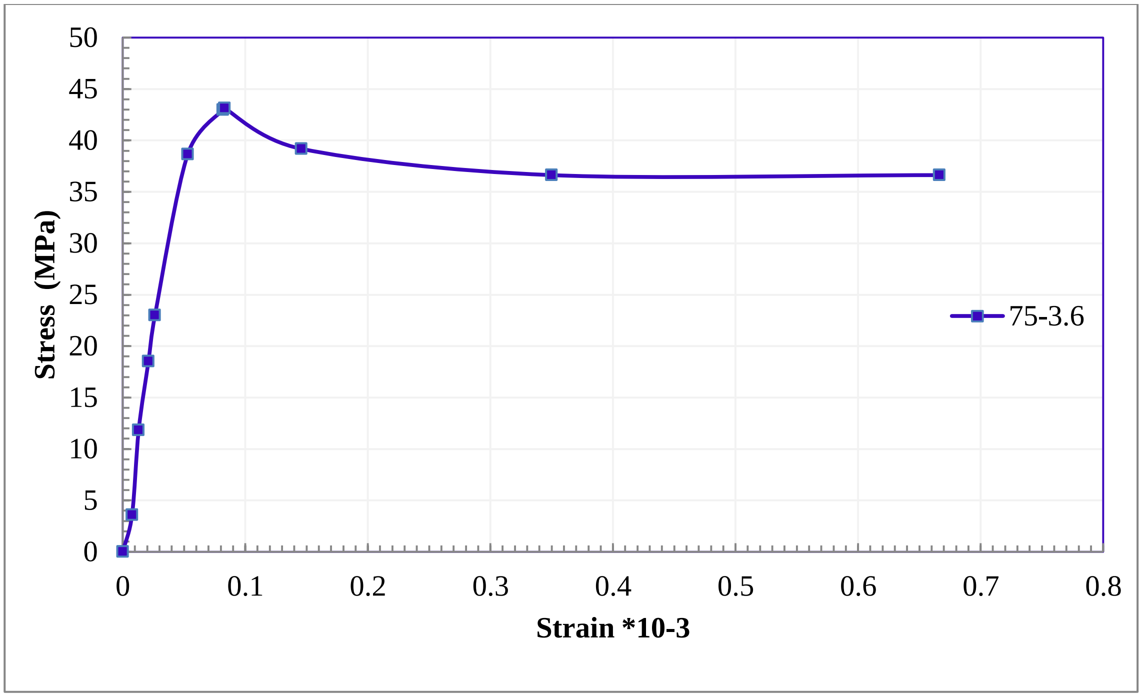


Figure (3.4) Stress-strain curve from coupon test for PVC of D= 75mm and tp=3.6mm.

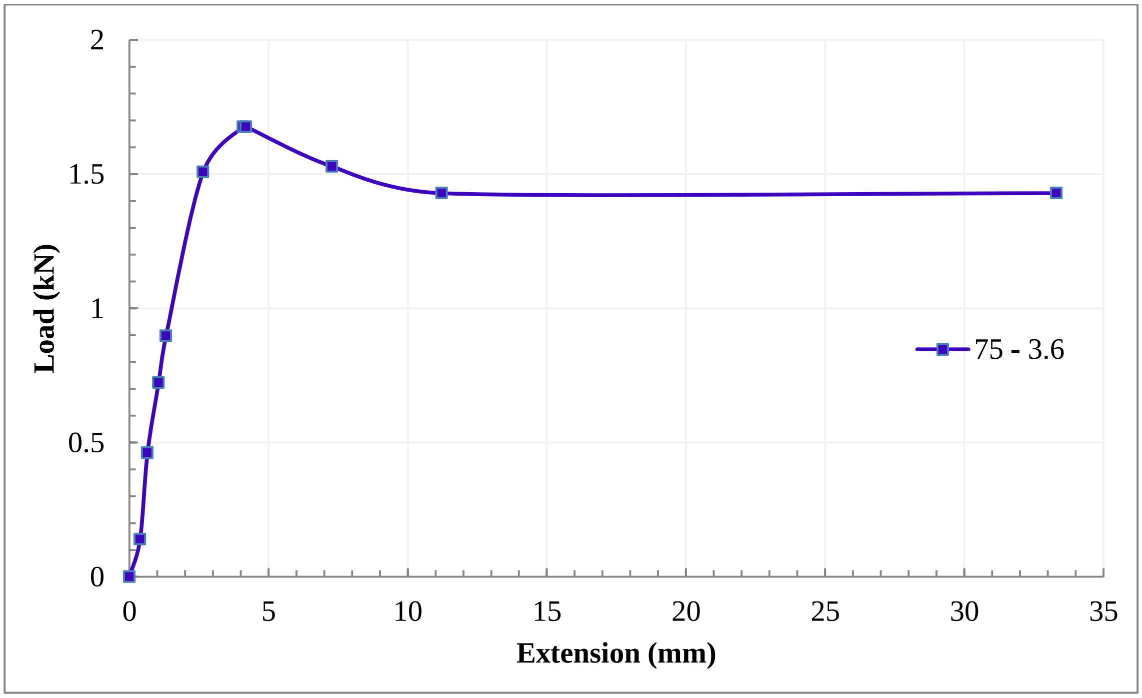


Figure (3.5) Load-extension curve from coupon test for PVC of D = 75mm and tp = 3.6mm.

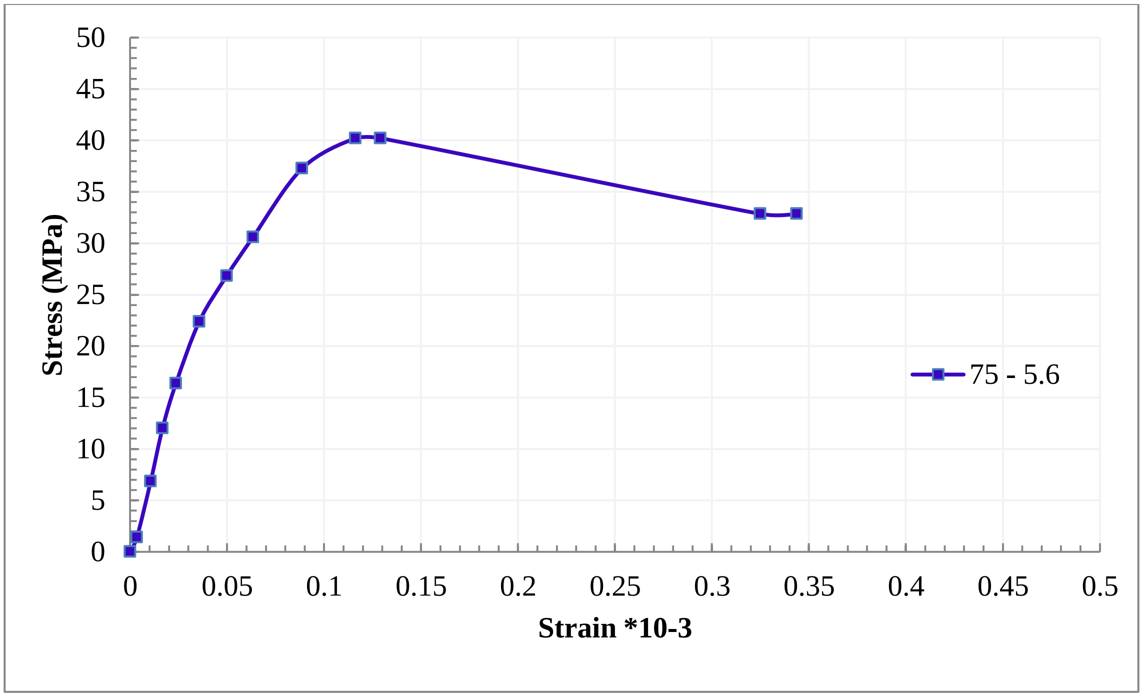


Figure (3.6) Stress-strain curve from coupon test for PVC of D= 75mm and tp=5.6mm.

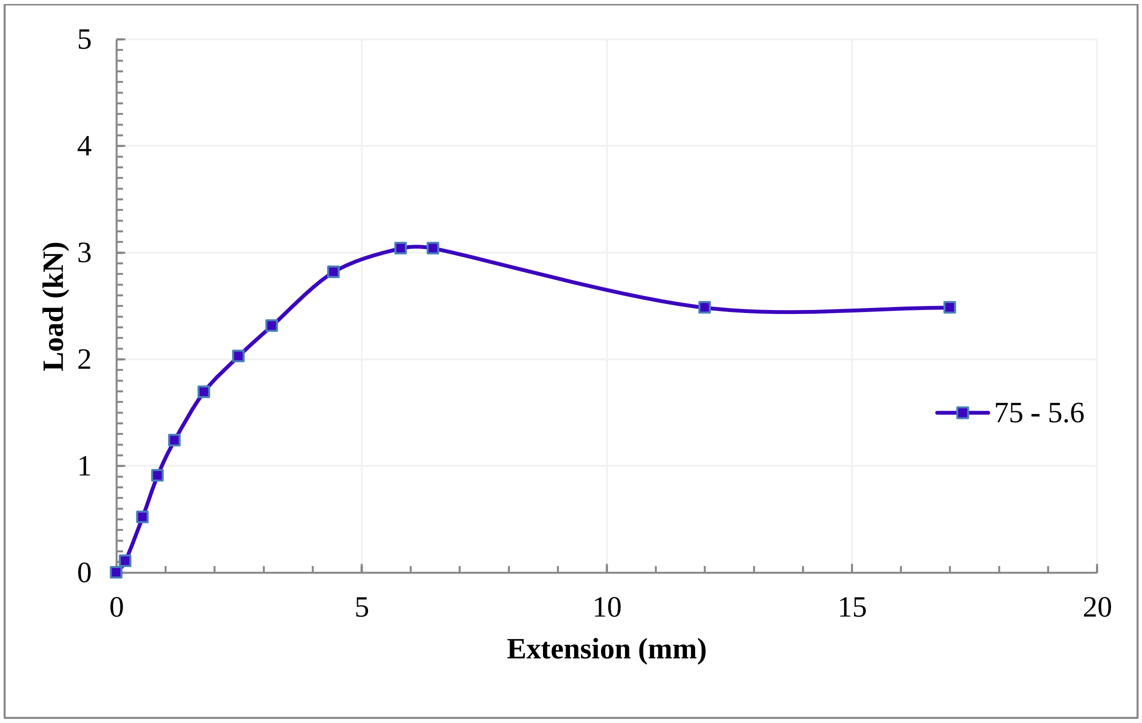


Figure (3.7) Load-extension curve from coupon test for PVC of D= 75mm and tp=5.6 mm.

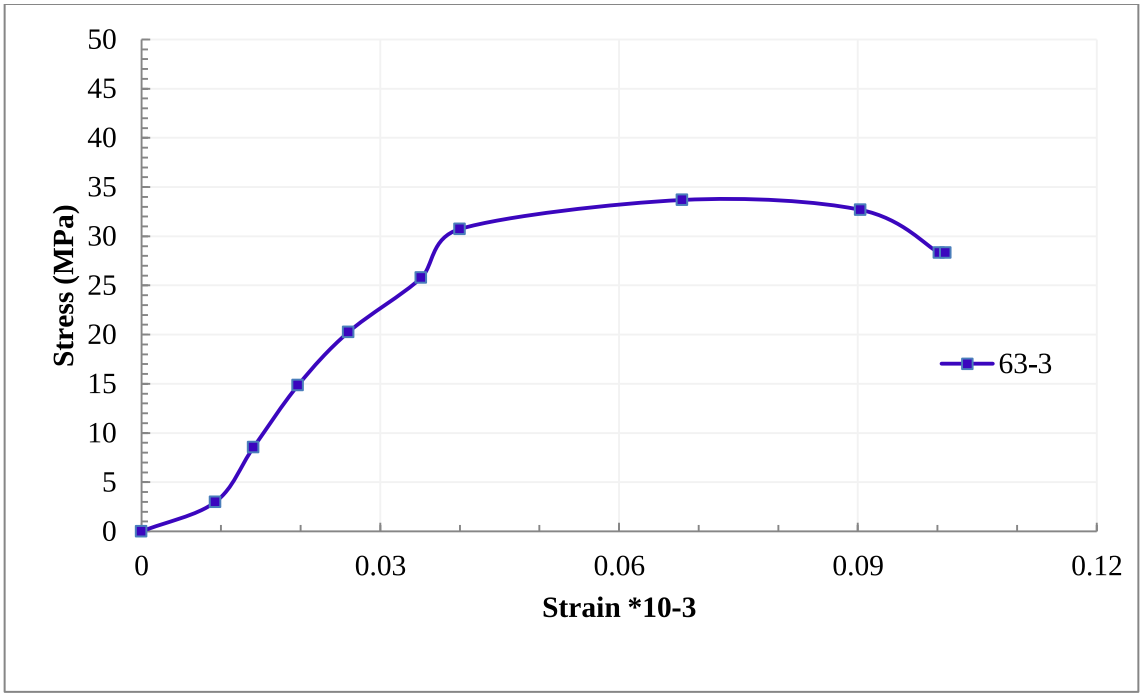


Figure (3.8) Stress-strain curve from coupon test for PVC of D= 63mm and tp=3mm.

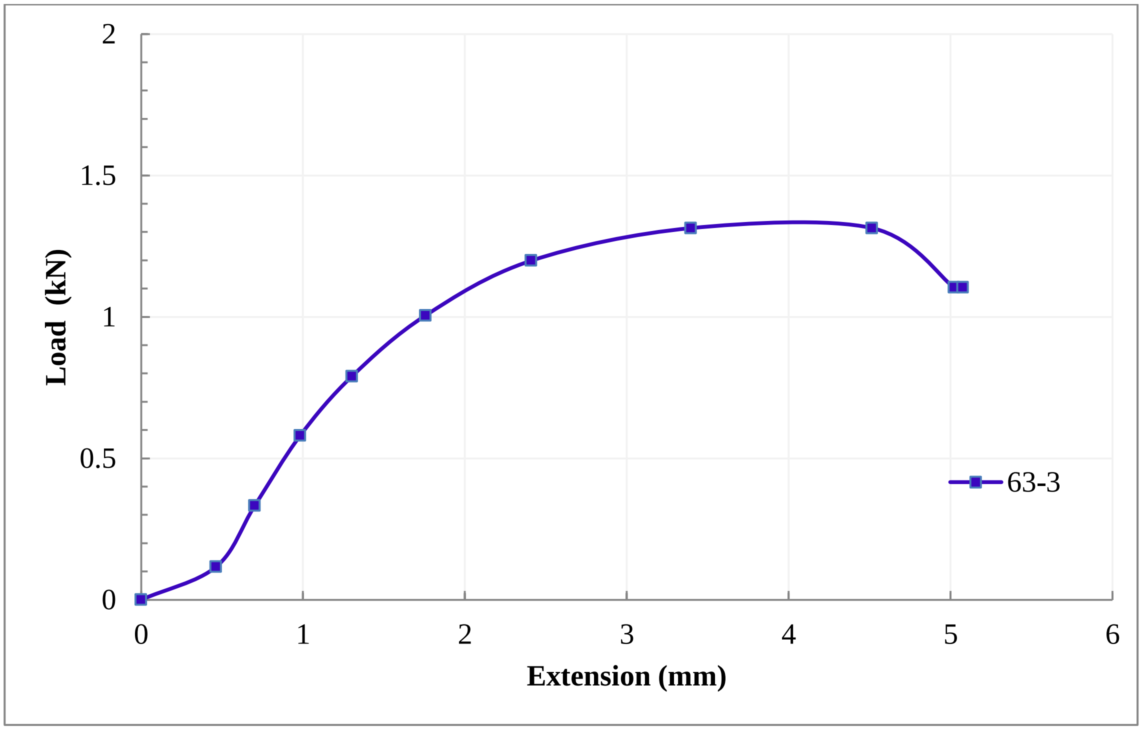


Figure (3.9) Load-extension curve from coupon test for PVC of D = 63mm and tp = 3mm.

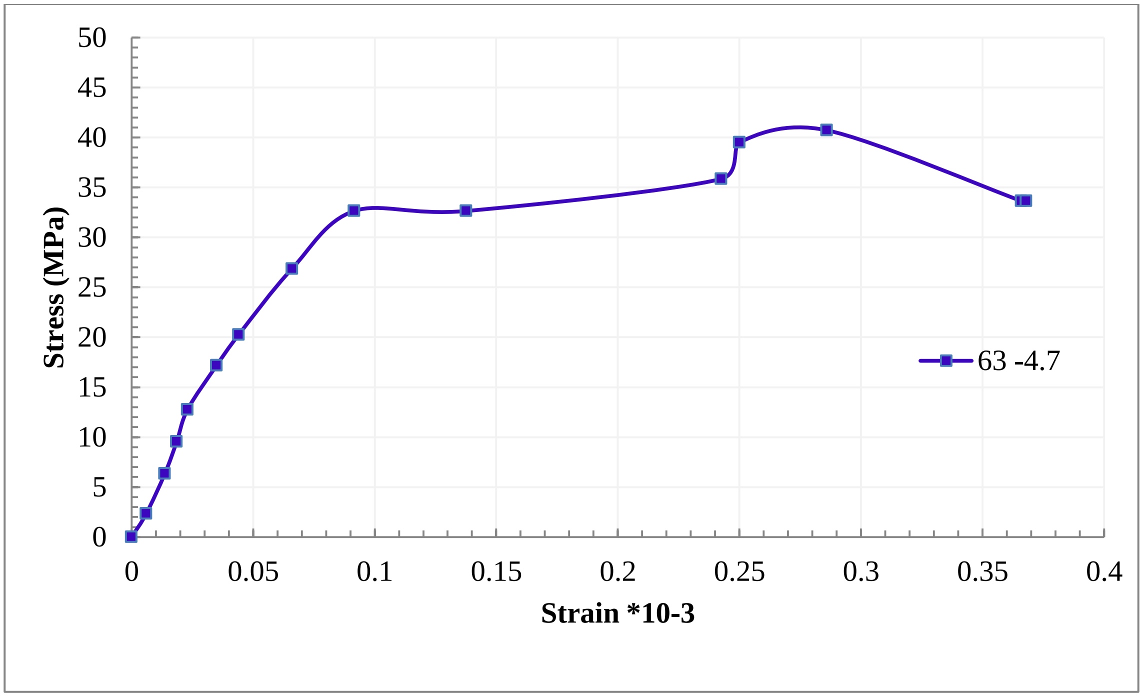


Figure (3.10) Stress-strain curve from coupon test for PVC of D = 63mm and tp = 4.7mm.

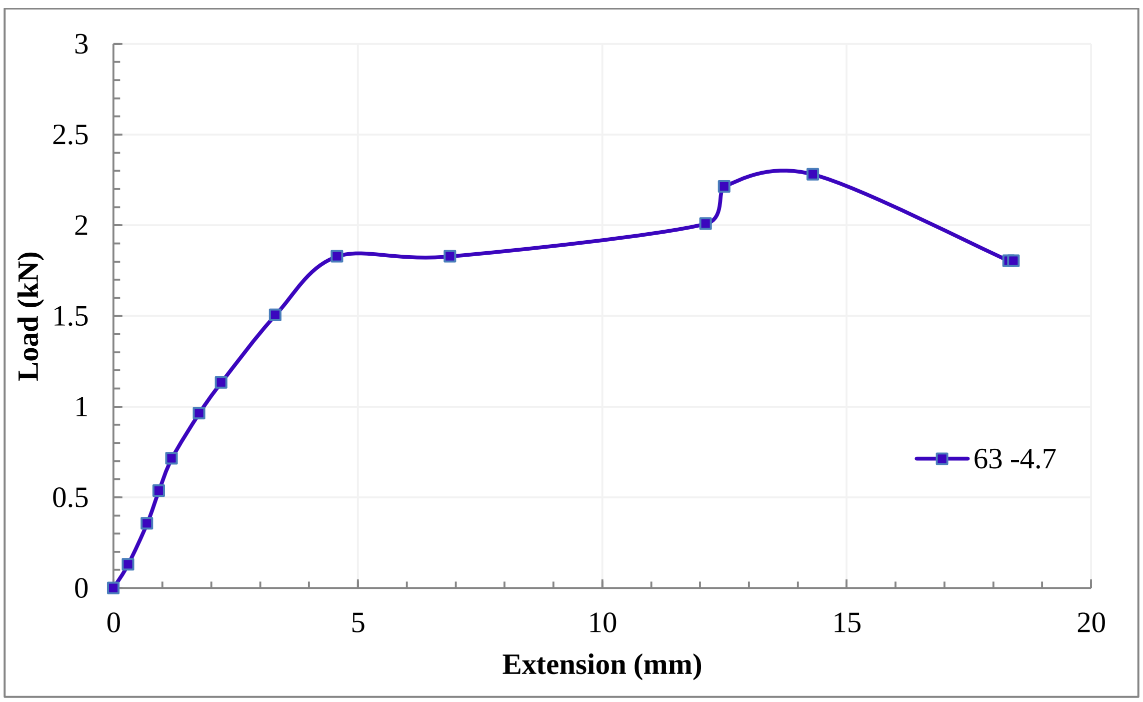


Figure (3.11) Load-extension curve from coupon test for PVC of D= 63mm and tp=4.7mm.

3.3 Concrete mix

Three concrete mixes were used to investigate the influence of the concrete strength on the behavior of plastic - concrete columns. Table (3.10) list mix proportions by weight.

Table (3.10) Mix proportions by weight

Cement, Kg/m^3	Silica Fume Kg/m^3	Binder, Kg/m^3	Sand, Kg/m^3	Gravel, Kg/m^3	Superplastizer		Water %
					%	Kg/m^3	
501.6	26.5	527.5	982.5	1274.5	0.2	1.1	35
501.6	53	527.5	982.5	1274.5	0.2	1.1	35
557.8	22.6	450	591.3	1087	0.2	0.9	48

3.4 Tested columns

A total of fifty one columns divided into eight groups (G1 to G8). For group (G1), five plastic pipes without filling concrete were prepared with height of 300 mm. For group (G2), four plastic pipes without filling concrete were prepared with height of 1100mm. for group (G3), five concrete columns without plastic casing were prepared with height of 300mm. For group (G4), five concrete columns without plastic casing were prepared with height of 1100mm. For group (G5), five composite plastic concrete columns were prepared with height of 300mm. For group (G6), five confined plastic concrete columns were prepared with height of 300mm. For group (G7) eleven composite plastic concrete columns were prepared with heights of (950, 1100, 1250mm). For group (G8) eleven confined plastic concrete columns were prepared with heights of (950, 1100, 1250mm). the studied variables were mode of loading, concrete compressive strength, plastic tube thickness, diameter of plastic tube and column slenderness ratio. Columns were tested under uniform compression load. Table (3.11) shows the details of columns. Fig(3.16) show modes of loading.

Table (3.11) Details of Columns.

Groups	Specimen	fc' MPa	L mm	tp mm	outer Dia. mm	Slenderness ratio (l/r = 4L/D)	D/tp	Fig.	plate
G1	SA1	–	300	2.20	75.00	16.00	34.09	3.12	3.5 a
	SB1			3.60	75.00	16.00	20.83		
	SC1			5.60	75.00	16.00	13.39		
	SD1			3.00	63.00	19.04	21.00		
	SE1			4.70	63.00	19.04	13.40		
G2	SA2	–	1100	2.20	75.00	58.67	34.09	3.12	3.7 b
	SB2			3.60	75.00	58.67	20.83		
	SC2			5.60	75.00	58.67	13.39		
	SD2			4.70	63.00	69.84	13.40		
G3	SA3	42.25	300	–	70.60	16.99	–	3.13	3.5 b
	SB3				67.80	17.69			
	SC3				63.80	18.80			
	SD3				57.00	21.05			
	SE3				53.60	22.38			
G4	SA4	42.25	1100	–	70.60	62.32	–	3.13	3.7 a
	SB4				67.80	64.89			
	SC4				63.80	68.96			
	SD4				57.00	77.19			
	SE4				53.60	82.08			
G5	SA5	42.25	300	2.20	75.00	16.00	34.09	3.14	3.5 c
	SB5			3.60	75.00	16.00	20.83		
	SC5			5.60	75.00	16.00	13.39		
	SD5			3.00	63.00	19.04	21.00		
	SE5			4.70	63.00	19.04	13.40		
G6	SA6	42.25	300	2.20	75.00	16.00	34.09	3.15	3.5 d
	SB6			3.60	75.00	16.00	20.83		
	SC6			5.60	75.00	16.00	13.39		
	SD6			3.00	63.00	19.04	21.00		
	SE6			4.70	63.00	19.04	13.40		
G7	SA7	42.25	1100	2.20	75.00	58.67	34.09	3.14	3.6
	SB7	42.25	1100	3.60	75.00	58.67	20.83		
	SC7	42.25	1100	5.60	75.00	58.67	13.39		

Continue to table (3.11) Details of Columns.

Groups	Specimen	fc' MPa	L mm	tp mm	Outer Dia. mm	Slenderness ratio (l/r = 4L/D)	D/tp	Fig.	Plate
G7	SD7	34.70	1100	3.60	75.00	58.67	20.83	3.14	3.6
	SE7	58.80	1100	3.60	75.00	58.67	20.83		
	SF7	42.25	950	3.60	75.00	50.67	20.83		
	SG7	42.25	1250	3.60	75.00	66.67	20.83		
	SH7	42.25	1100	3.00	63.00	69.84	21.00		
	SI7	42.25	1100	4.70	63.00	69.84	13.40		
	SJ7	34.70	1100	3.00	63.00	69.84	21.00		
	SK7	58.80	1100	3.00	63.00	69.84	21.00		
G8	SA8	42.25	1100	2.20	75.00	58.67	34.09	3.15	3.7 c
	SB8	42.25	1100	3.60	75.00	58.67	20.83		
	SC8	42.25	1100	5.60	75.00	58.67	13.39		
	SD8	34.70	1100	3.60	75.00	58.67	20.83		
	SE8	58.80	1100	3.60	75.00	58.67	20.83		
	SF8	42.25	950	3.60	75.00	50.67	20.83		
	SG8	42.25	1250	3.60	75.00	66.67	20.83		
	SH8	42.25	1100	3.00	63.00	69.84	21.00		
	SI8	42.25	1100	4.70	63.00	69.84	13.40		
	SJ8	34.70	1100	3.00	63.00	69.84	21.00		
	SK8	58.80	1100	3.00	63.00	69.84	21.00		

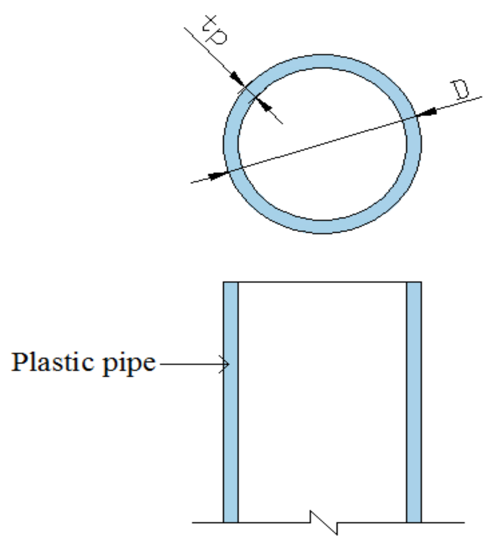


Figure (3.12) Plastic tube without filling concrete

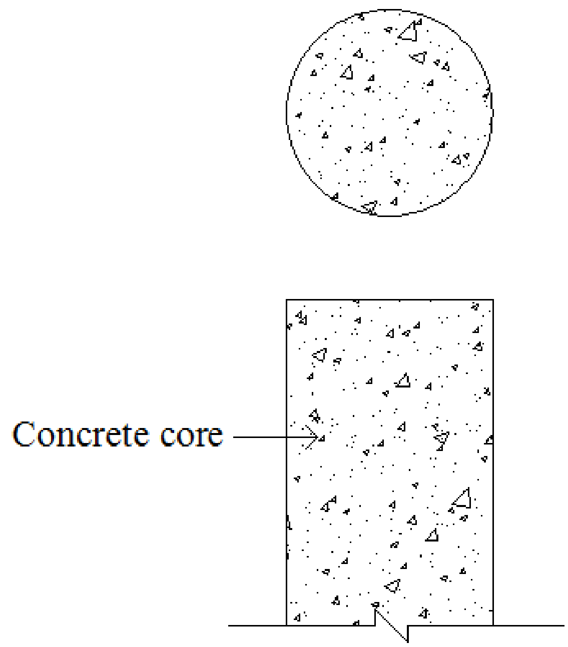


Figure (3.13) Concrete column witout plastic casing

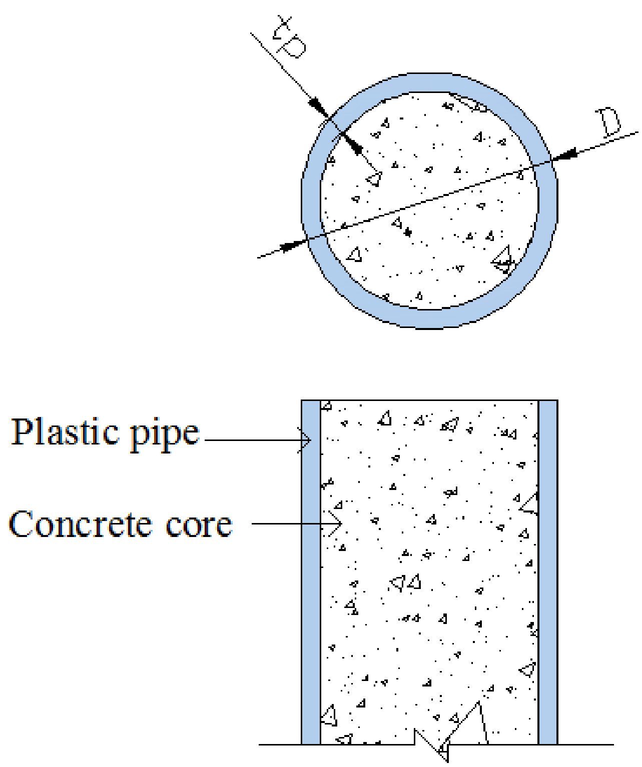


Figure (3.14) Composite plastic concrete column

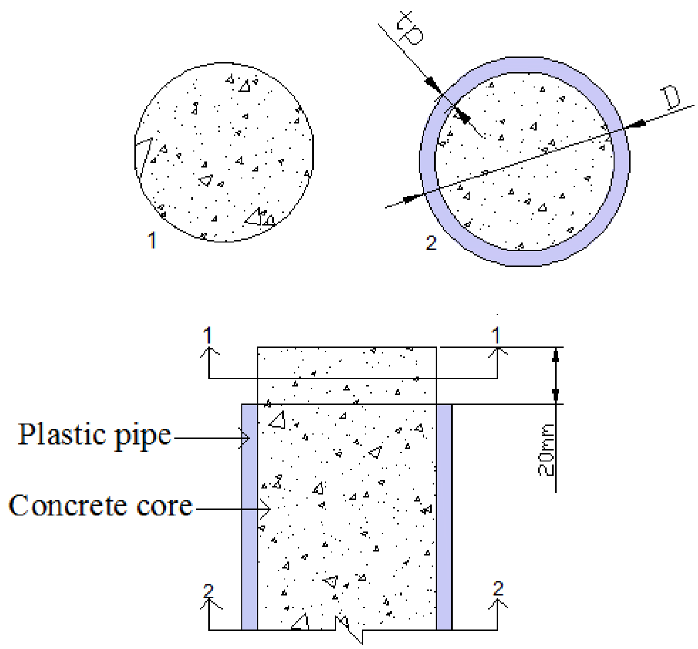


Figure (3.15) Confined plastic concrete column

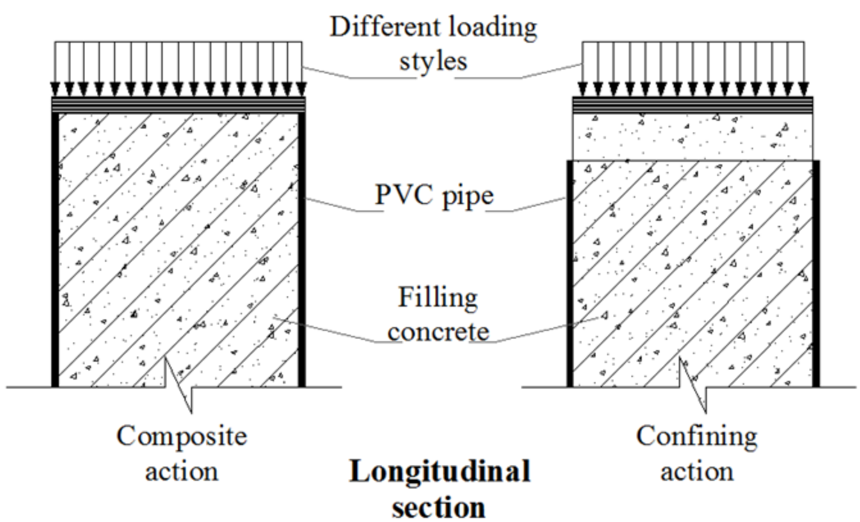


Figure (3.16) Modes of loading

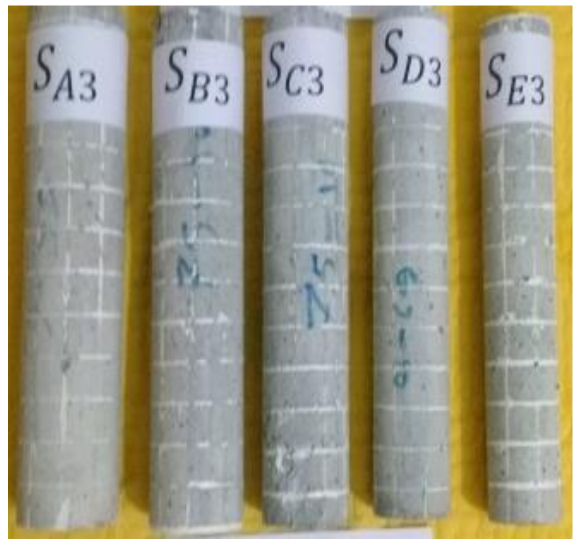
3.4.1 Confined mode of loading

Eleven long composite column and five short composite columns were tested by applying load upon concrete part of columns without applying load on plastic tube.

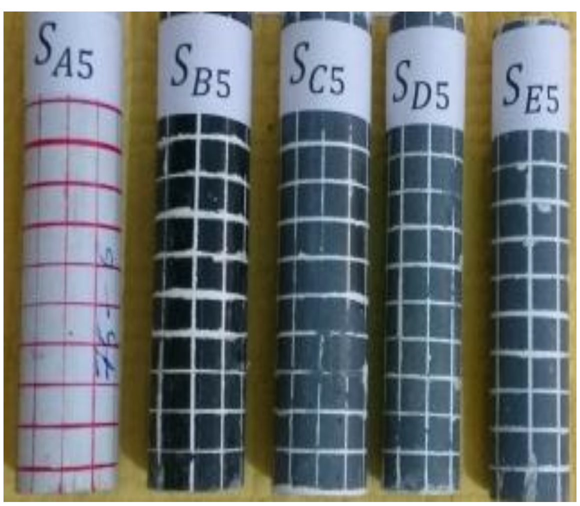
3.4.2 Composite mode of loading

Eleven long and five short PVC – concrete columns were tested by applying load upon plastic tube and concrete core. Plate (3.5) shows short columns groups. Plate (3.6) shows slender composite columns while plate (3.7) shows slender confined columns and plastic and concrete column.

a- PVC tubes



b- Concrete core



c- Composite Mode

d- Confining Mode

Plate (3.5) Short Columns groups

Plate(3.6). Slender composite columns

a-Concrete column b- PVC column c- Slender confined columns

Plate(3.7) Concrete, PVC and Slender confined columns.

3.5 Fabrication of the column specimens

The desired length of PVC tubes were cut and cleaned and the bottom of tubes are closed with nylon to prevent the leakage of concrete. The tubes are positioned vertically by Making a wooden datum to install the tubes vertically when casting as shown in Plate (3.8). The tubes are filled with concrete in approximately of 10 cm layers and each layer was compacted by a steel rod as shown in plate (3.9). After 24 hours after casting, the columns were putted in the curing tank for 28 days. During casting, three (100×100×100 mm) cubes , three (100×200 mm) cylinders and three (100×100×500mm) prisms were made for each mix. The cubes and cylinders and prisms were compacted by a steel rod as the columns specimens, and were cured in the same curing tank. After the period of curing, the columns were painted with white color. The compressive strength of concrete was obtained by testing three cubes according to BS1881[36]. The cylinder compressive strength was evaluated by testing cylinders according to ASTM C39 [37]. Testing cylinders for Splitting test were obtained according to ASTM C496 – 04[38].

Plate (3.8) Wooden datum.

Plate (3.9) Casting column specimens.

The modulus of rupture was obtained by testing three prisms according to ASTM C293-02 [39]. Table (3.13) show results of concrete properties, plate (3.10) shows the testing of specimens for determining the properties of concrete.

Table (3.12) Concrete properties.

Batch	Compressive strength, f'_c	unit weight γ, kN/m^3	Rupture modulus fr, MPa
I	42.25	23	3.1
II	34.8	23	2.3
III	58.7	23	4.1



a b c

d

Plate (3.10) Shows testing specimens for determining properties of concrete.

3.6 Instrumentation and Test Setup

All specimens were tested under uniaxial pressure at laboratory of the University of Misan, College of Engineering. Top and bottom faces of the columns were grinded and made smooth and leveled with an epoxy to surface maintain uniformity of loading on the surface as shown in plate (3.11). The column specimen was centered in the testing machine to ensure that the compressive axial load applied without any eccentricity. Both ends were strengthened with tighten steel rings, to ensure that the failure would not occur at specimens' ends[10].

Plate (3.11). Column face after leveling.

Plate (3.12) Column with steel ring strengthen

3.6.1 Short Column Testing

All short columns were tested by A hydraulic testing machine (MATEST) which was used to apply a uniform compressive load, as shown in plate (3.13). Two dial gauges with a magnetic base were used , first one fixed vertically and the other was fixed horizontally to denote the axial and lateral displacements. The accuracy of these dial gauges was 0.01 mm.

Plate (3.13). Short Column testing

3.6.2 Long Columns Testing

All long columns were test in hydraulic compressive machine with a capacity of 600 KN. All required fittings were made to fit the column specimens within the testing machine space, two caps were made and placed at the top and bottom of testing machine to ensure the safety of persons during test as shown in plate (3.14). Dial gauges with a magnetic base were fixed vertically and horizontally to denote the vertical and horizontal displacements. Because of the columns was circular in section, the dial gauge nail will slip when the column displaced. Square base made for horizontal dial gauge and placed around the column with point installation, without applying any pressure on the column as shown in plate (3.15), the accuracy of all these dial gauges used are 0.01 mm.

Plate (3.14). Safety cup

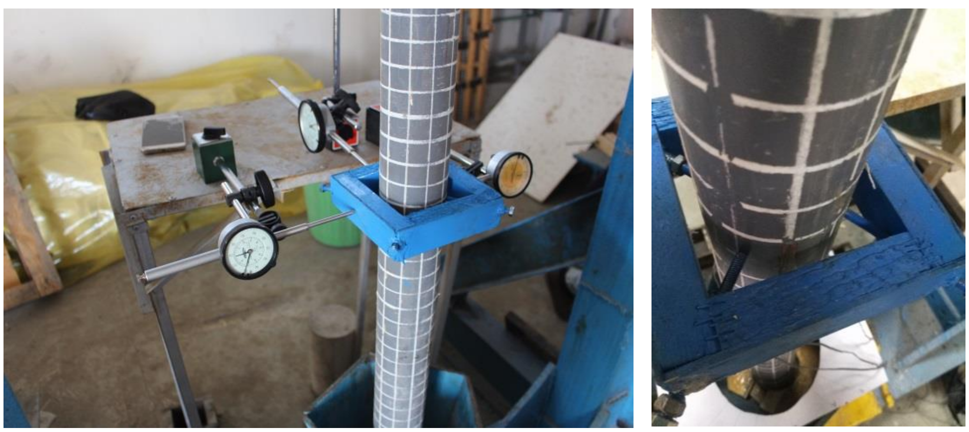


Plate (3.15). Dial gauges arrangement.

For measurement of strains on the surface of the column, hoop strain at middle height of the specimen was digitally recorded by an electrical strain gauges and saved by digital data collecting system, strains were procured by

Tokyo Sokki Kenkyujo company limited in Japan. After cleaning the column surface at strain locations from dust and another material such paint, strain gauges glued to the specimens along the circumference of the column with an angle equal to 120^{o} between each strain gauge as in the Fig(3.16). The properties of strain gages were summarized in the Table (3.12). Fig (3.17) show the strain gauge arrangement for both composite and confined condition and Figure (3.18) show sport of column which is the same for upper and lower support. Fig(3.19) show column arrangement at testing device. Fig (3.20) depicted test of both ends pinned specimen.

Table (3.13) Properties of strain gages.

No .	**Property**	**Value**
1 -	Gauge type	PFL – 30 – 11
2 -	Gauge length	30 mm
3 -	Gauge factor	2.13
4 -	Gauge resistance	120 ± 0.3 Ω

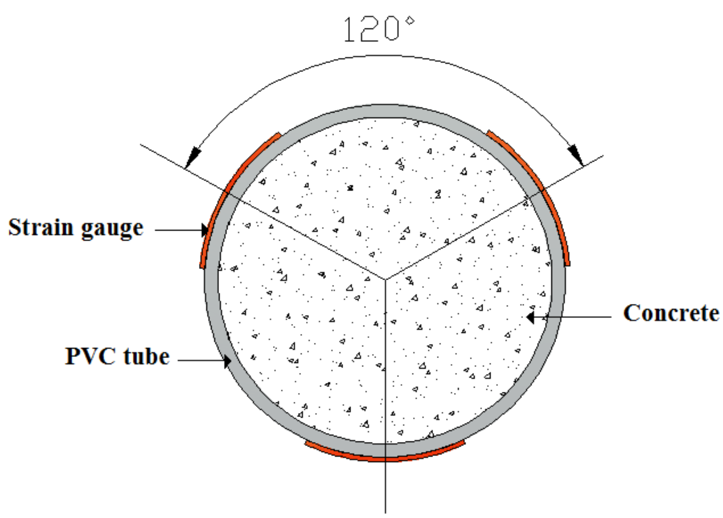


Figure (3.16) Section at mid height of column shows the strain gauge arrangement and the angle between strain gauges.

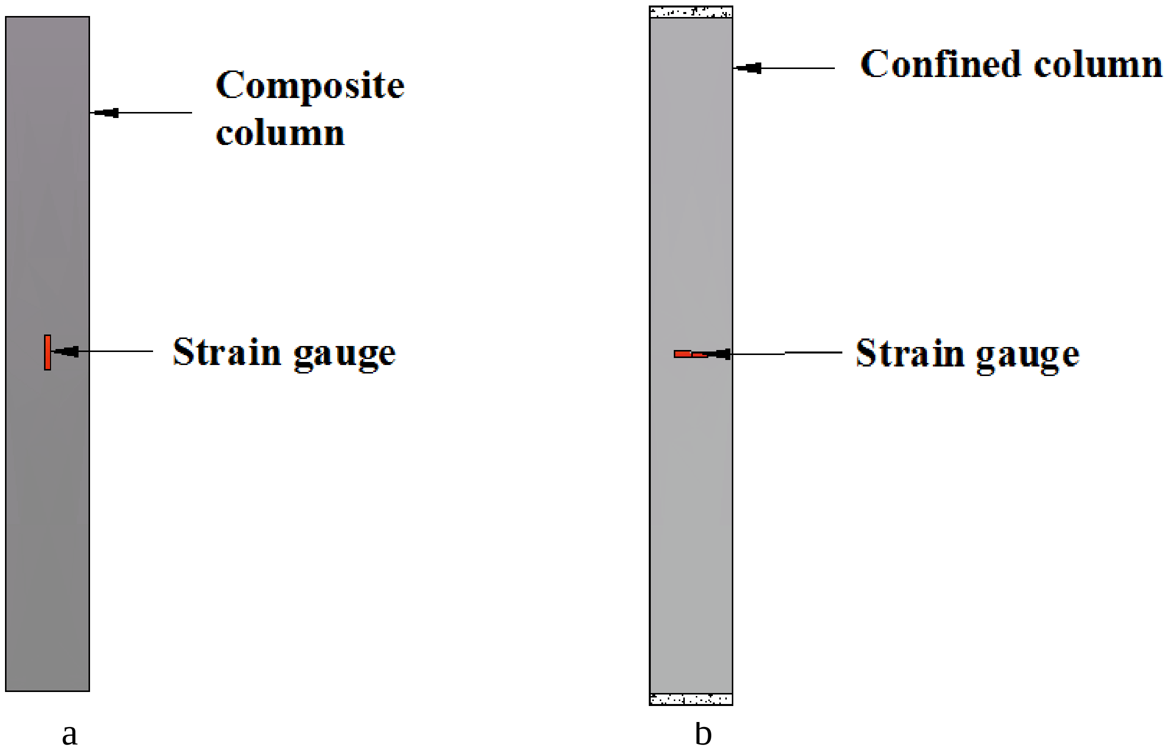


Figure (3.17) Strain gauge arrangement at composite and confined columns.

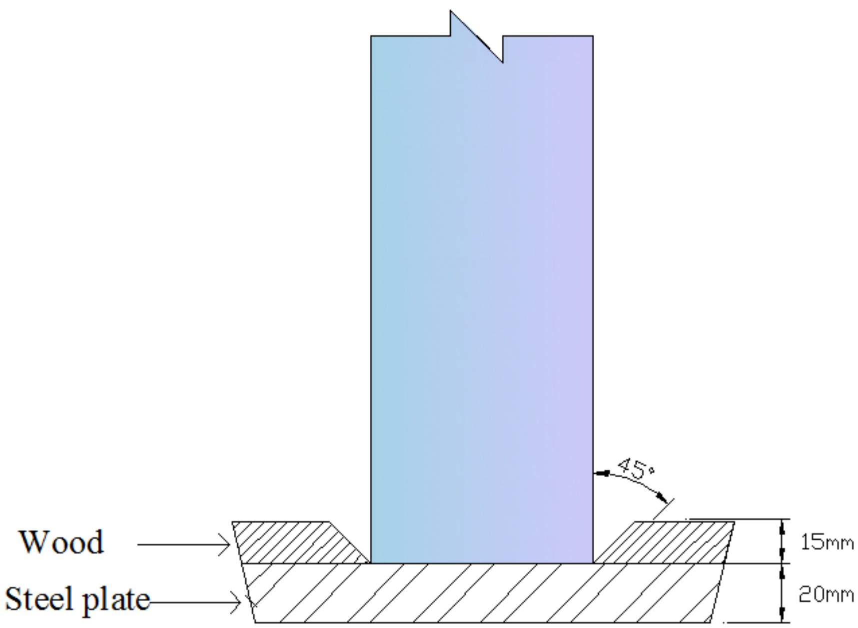
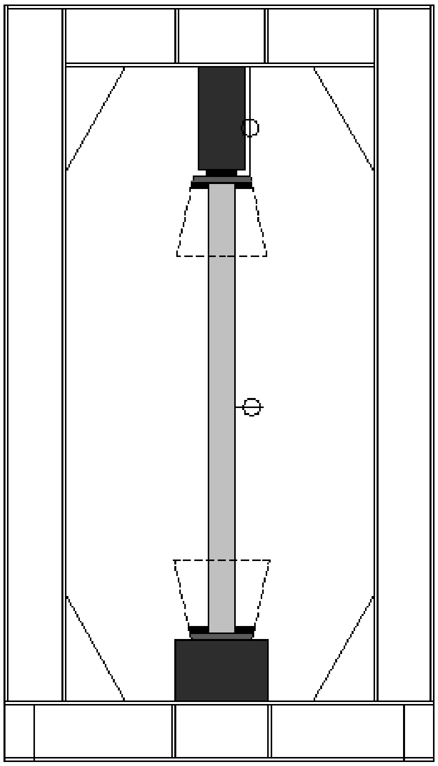
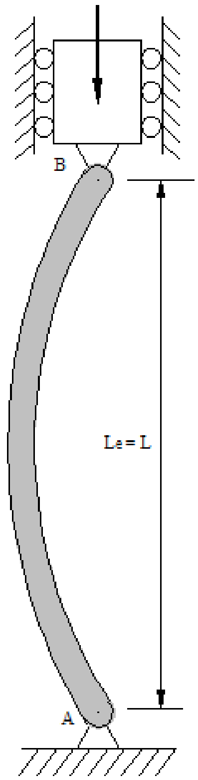


Figure (3.18) Column support



Figure(3.19) Test setting



Figure(3.20) Test modeling

Plate (3.16) Test setting of specimens

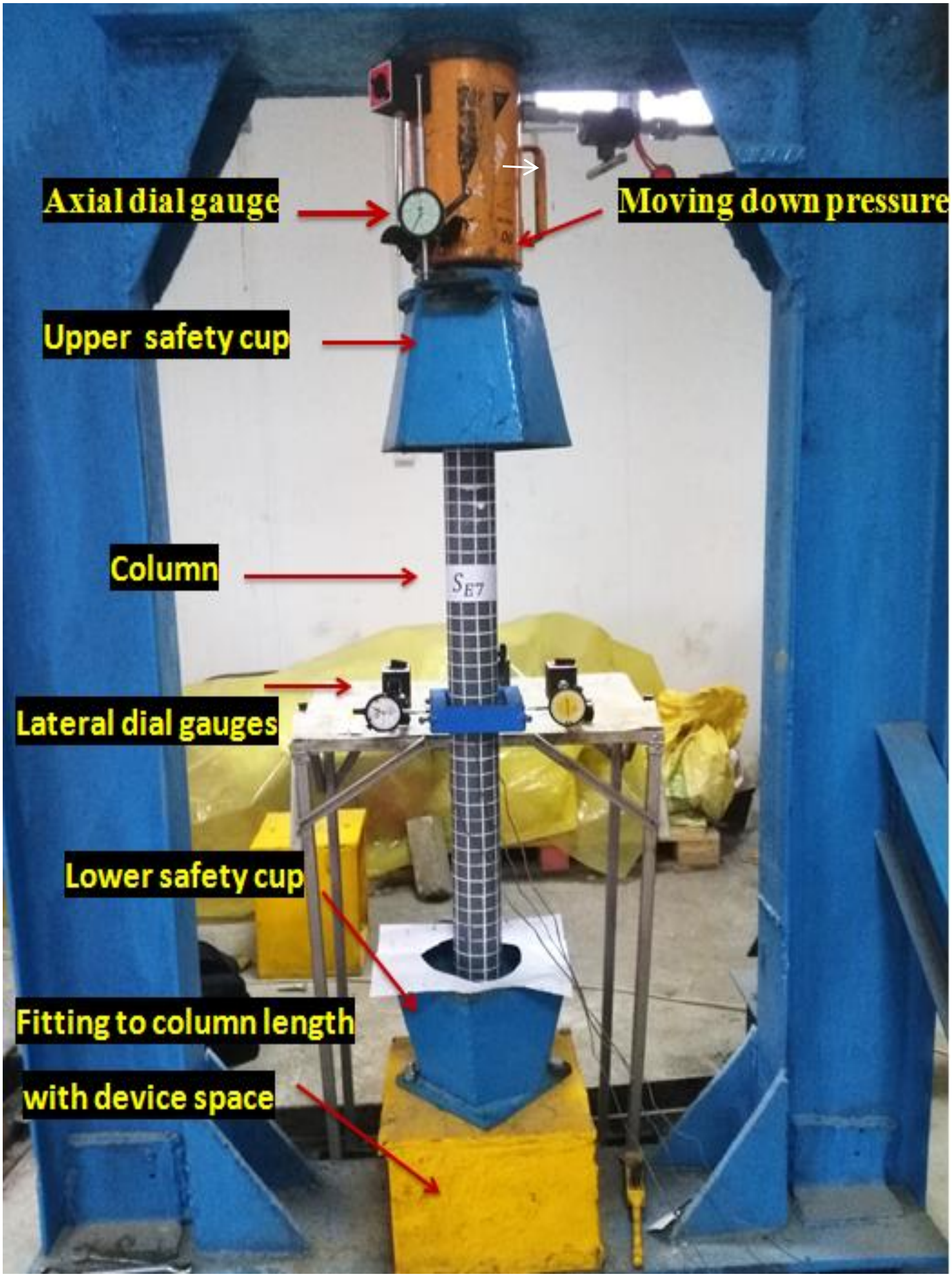


Plate (3.17) Column installed with full fitting and tools

CHAPTER FOUR
RESULTS
AND DISCUTION

***CHAPTER* FOUR**

RESULTS AND DISCUTIONS

4.1 Introduction

This chapter presents the results of the experimental program, including the load deformation response and stress strain behavior and failure modes of short and slender PVC-concrete columns of different modes (composite and confining mode) subjected to uniform axial loading. The test program involves two modes of loading, composite and confined mode, totally of 51 columns were tested. The parameters considered were the concrete compressive strength, plastic tube thickness, diameter of plastic tube and column slenderness ratio.

4.2 PVC – Concrete Short Columns Behaviour

Total of twenty short columns with constant compressive strength and length . Table (4.1) depicted short specimens' results and Table (4.2) shows short columns comparative results. Sustained loading resistance of concrete composite with PVC in short columns exhibited more strength improving (in respect to concrete core) than these of PVC confined concrete where upgrading rates varied from 1.56 to 2.25 for composite mode verse varying from 1.55 to 2.16 for confining mode. It was found that the PVC concrete composite column resists more strength than the summation of its constitutes. In scope of ductility, specimens of PVC confined concrete exhibited more axial and lateral deformations than corresponding samples of composite mode. For composite mode, axial deformation ranged from (3.98 to 9.08 mm) and lateral deformation ranged (0.62 to 1.42 mm). For confined mode, axial deformation ranged from (6.42 to 10.45mm) and lateral deformation ranged from (0.85 to 1.65 mm).

Table (4.1) Short specimens results.

Groups	Specimen code	Description	L/r	tp (mm)	D/tp	fc' (MPa)	P_u (kn)	Axial displacement, mm	Lateral displacement, mm
G1	SA1	short plastic tube , without filling concrete	16.00	2.2	34.09	–	26.00	8.00	0.80
	SB1		16.00	3.6	20.83		40.00	9.33	2.45
	SC1		16.00	5.6	13.39		65.10	11.00	2.90
	SD1		19.04	3	25.00		28.00	8.25	1.42
	SE1		19.04	4.7	15.96		46.00	11.00	1.89
G3	SA3	Short concrete columns , without plastic casing	16.99	–	–	42.25	125.18	1.53	0.22
	SB3		17.69				118.90	2.95	0.43
	SC3		18.80				115.50	1.01	0.15
	SD3		21.05				89.20	2.10	0.32
	SE3		22.38				70.00	1.40	0.21
G5	SA5	Composite short plastic concrete columns	16.00	2.2	34.09	42.25	208.70	3.98	0.62
	SB5		16.00	3.6	20.83		253.20	4.50	0.70
	SC5		16.00	5.6	13.39		259.90	8.41	1.31
	SD5		19.04	3	25.00		139.00	7.36	1.15
	SE5		19.04	4.7	15.96		153.60	9.08	1.42
G6	SA6	Confined short plastic concrete columns	16.00	2.2	34.09	42.25	197.00	7.10	0.85
	SB6		16.00	3.6	20.83		232.30	6.42	0.78
	SC6		16.00	5.6	13.39		238.70	10.10	1.59
	SD6		19.04	3	25.00		138.40	6.72	1.06
	SE6		19.04	4.7	15.96		151.50	10.45	1.65

Table (4.2) short columns comparative results.

Group	Specimens	P_u (KN)	fc'/fyp	P'cm/P'c	P'cn/P'c	P'cm/P'cn
G5	SA5	208.70	**0.85**	1.67		
	SB5	253.20		2.13		
	SC5	259.90		2.25		
	SD5	139.00		1.56		
	SE5	153.60		2.19		
G6	SA6	197.00	**0.85**		1.57	1.06
	SB6	232.30			1.95	1.09
	SC6	238.70			2.07	1.09
	SD6	138.40			1.55	1.00
	SE6	151.50			2.16	1.01

4.3 PVC – Concrete Slender Columns behavior

Table (4.3) depicted slender specimens' results and Table (4.4) shows Long columns comparative results. Although, the same previous positive enhancement of utilizing of PVC are assigned for slender columns of two modes used, the upgrading rates of slender samples are more than corresponding to the short samples as shown in Table (4.4) The related average ratios are (1.64 to 2.42) for composite mode and (1.34 to 2.04) for confining mode. However, simple difference in upgrading ductility is assigned where slender specimens of PVC composite concrete exhibited axial and lateral deformations slightly larger than corresponding samples of confined mode.

Table (4.3) Long specimens results

Groups	Specimens	Description	L/r	fc'	Tp	D/tp	Pu, kN	Axial displacement, mm	Lateral displacement, mm
G2	SA2	Long PVC tube, without filling concrete	58.67	–	2.2	34.09	3.46	20.00	–
	SB2		58.67		3.6	20.83	6.73	26.00	–
	SC2		58.67		5.6	13.39	11.98	39.00	–
	SD2		69.84		3	13.40	5.91	–	–
G4	SA4	Long concrete columns	62.32	42.25	–	–	56.70	4.80	6.05
	SB4		64.89	42.25			53.13	5.54	0.00
	SC4		68.96	42.25			49.58	2.10	0.00
	SD4		77.19	42.25			34.50	0.43	0.00
	SE4		82.08	42.25			27.67	0.40	0.00
G7	SA7	Composite Slender PVC-Concrete Colum	58.67	42.25	2.2	34.09	93.27	13.00	9.83
	SB7		58.67	42.25	3.6	20.83	108.30	11.12	11.56
	SC7		58.67	42.25	5.6	13.39	120.00	10.34	54.08
	SD7		58.67	34.7	3.6	20.83	65.01	18.89	11.45
	SE7		58.67	58.8	3.6	20.83	114.00	16.80	6.10
	SF7		50.67	42.25	3.6	20.83	121.00	12.10	20.20

Continuous to table (4.3) Long specimens results

Groups	**Specimens**	**Description**	**L/r**	**fc'**	**Tp**	**D/tp**	**Pu, kN**	**Axial disp, mm**	**Lateral disp,mm**
G7	SG7	Composite Slender PVC-Concrete Column	66.67	42.25	3.6	20.83	108.30	18.83	7.28
	SH7		69.84	42.25	3	21	58.10	16.00	4.24
	SI7		69.84	42.25	4.7	13.4	62.00	9.28	15.08
	SJ7		69.84	34.7	3	21	33.64	13.05	45.19
	SK7		69.84	58.8	3	21	72.00	13.40	12.65
G8	SA8	Confined slender PVC-Concrete Column	58.67	42.25	2.2	34.09	76.80	10.00	23.43
	SB8		58.67	42.25	3.6	20.83	88.50	11.80	12.82
	SC8		58.67	42.25	5.6	13.39	101.50	11.00	3.61
	SD8		58.67	34.7	3.6	20.83	53.13	10.90	3.38
	SE8		58.67	58.8	3.6	20.83	92.98	17.23	26.40
	SF8		50.67	42.25	3.6	20.83	103.61	8.40	1.28
	SG8		66.67	42.25	3.6	20.83	70.80	12.62	42.58
	SH8		69.84	42.25	3	21	50.07	10.54	5.13
	SI8		69.84	42.25	4.7	13.4	53.20	9.28	2.59
	SJ8		69.84	34.7	3	21	33.79	12.08	12.70
	SK8		69.84	58.8	3	21	60.05	15.01	26.08

Table (4.4) Long columns comparative results.

Group	Specimens	P_u (KN)	fc'/fyp	Pcm/Pc	Pcn/Pc	Pcm/Pcn
G7	SA7	93.27	1.006	1.645		
	SB7	108.30	1.006	2.039		
	SC7	120.00	1.006	2.42		
	SD7	65.01	0.826	1.884		
	SE7	114.00	1.4			
	SF7	121.00	1.006			
	SG7	108.30	1.006			
	SH7	58.10	1.006			
	SI7	62.00	1.006			
	SJ7	33.64	0.826			
G8	SK7	72.00	1.4		1.354	1.21
	SA8	76.80	1.006		1.666	1.22
	SB8	88.50	1.006		2.047	1.18
	SC8	101.50	1.006		1.54	1.22
	SD8	53.13	0.826			1.23
	SE8	92.98	1.4			1.17
	SF8	103.61	1.006			1.53
	SG8	70.80	1.006			1.16
	SH8	50.07	1.006			1.17
	SI8	53.20	1.006			1.00
	SJ8	33.79	0.826			1.20

4.4. Variation of Strength Capacity

4.4.1. PVC concrete columns in comparison to its constitutes

Figures (4.1),(4.2), (4.3) and (4.4) illustrate variation of strengths of short and slender PVC concrete columns in comparison to its constitutes. The obtained test results of PVC-concrete columns capacity are more than of the summation of strengths related to corresponding PVC and concrete cores. This observation is the same for short or slender columns. In spite of slender PVC exhibited small resistance due to assigned elastic local buckling, they highly improved slender composite samples where elastic local buckling is eliminated.

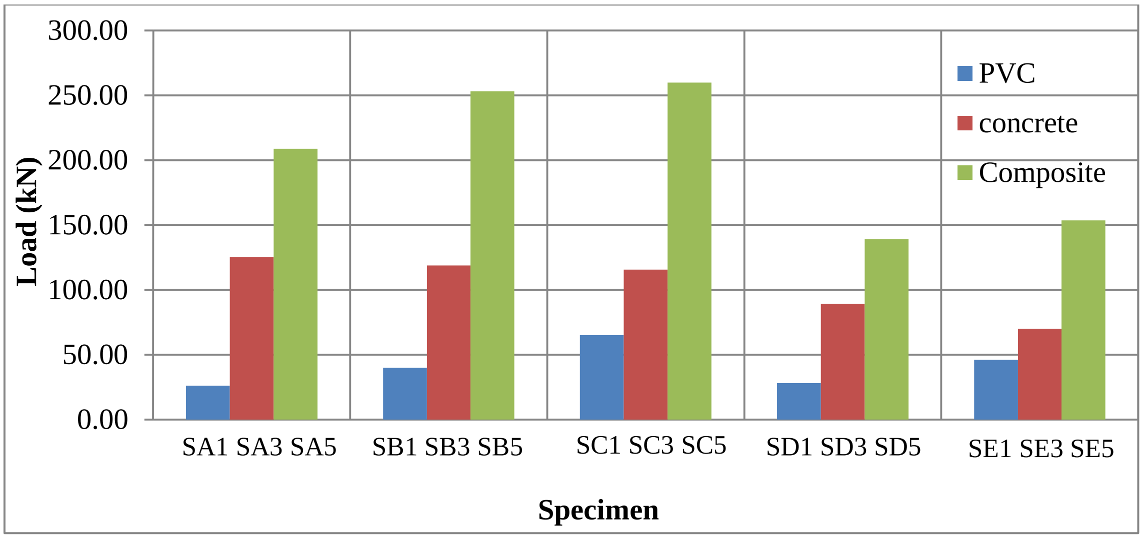


Figure (4.1) Variation of ultimate strength of short composite specimens in compare with its constitutes.

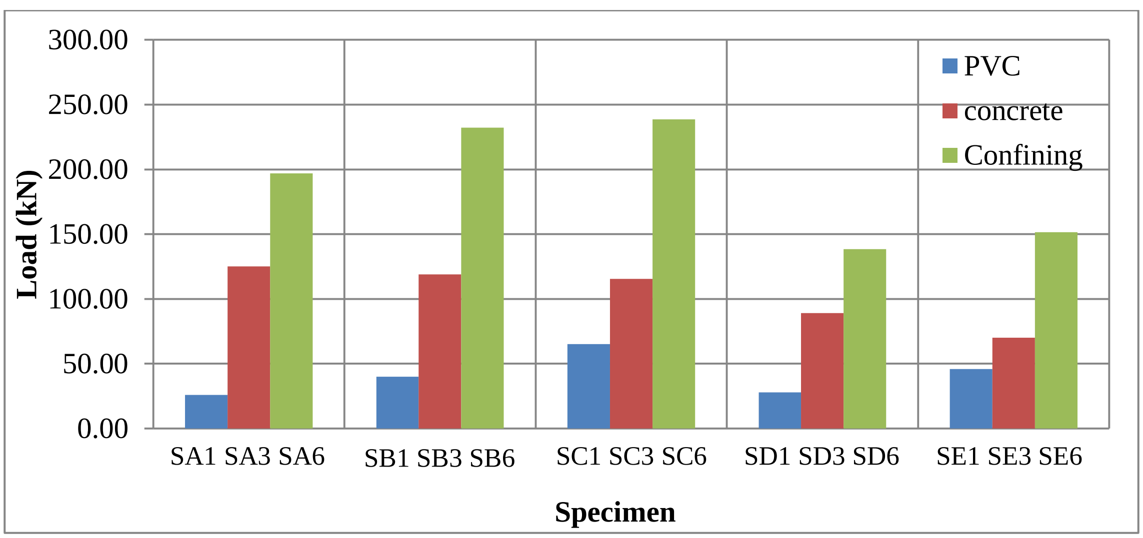


Figure (4.2) Variation of ultimate strength of short confined specimens in compare with its constitutes.

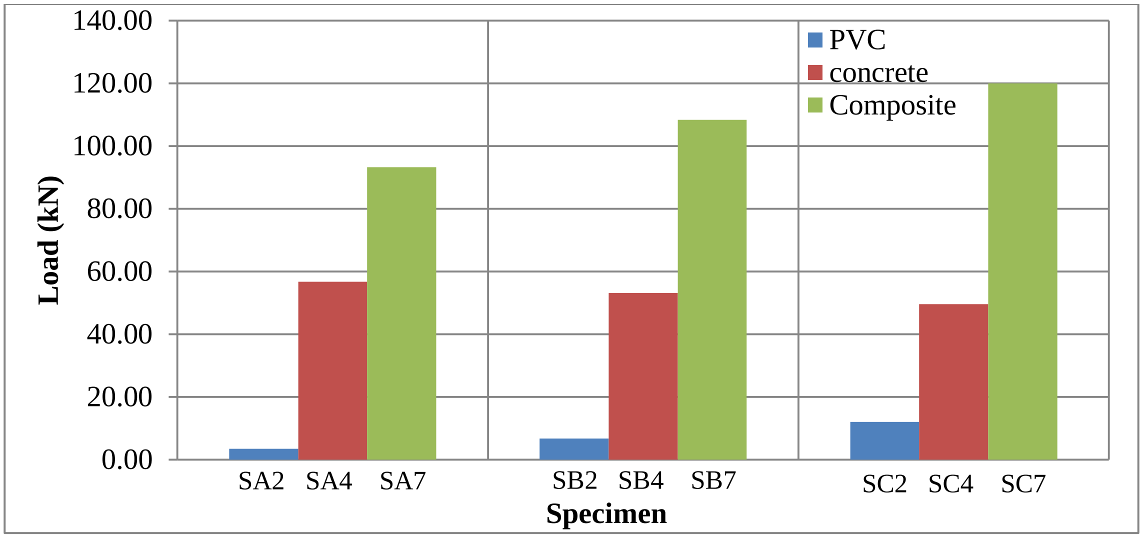


Figure (4.3) Variation of ultimate strength of slender composite specimens in compare with its constitutes.

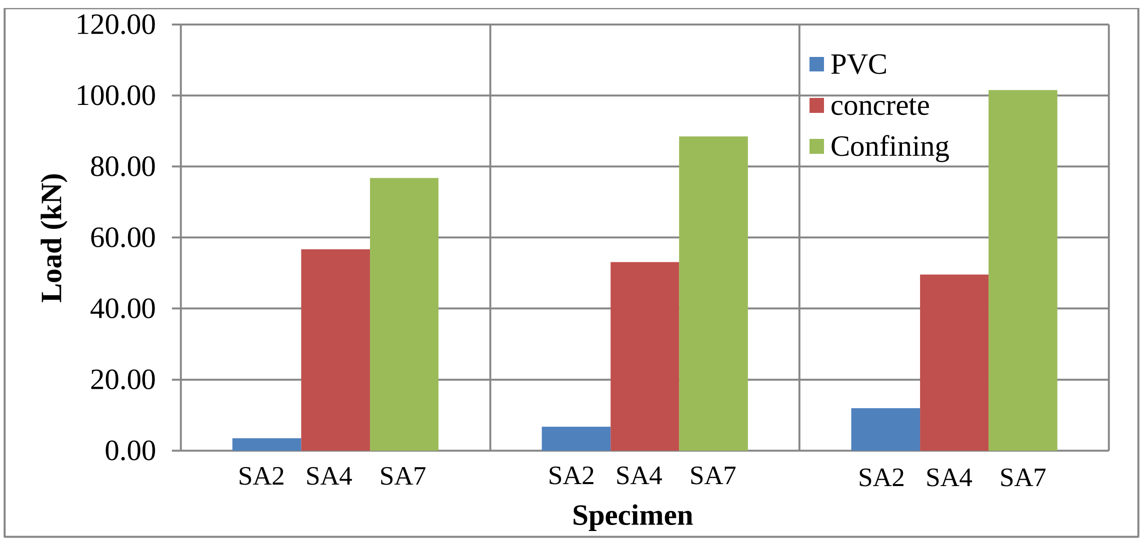


Figure (4.4) Variation of ultimate strength of slender confined specimens in compare with its constitutes.

4.4.2 Effect of Slenderness Ratio

Figures (4.5) to (4.7) depicted Influence of slenderness on ultimate strength of short and slender composite and confined columns in comparing with their constitutes. The figures revealed the same trend of strength reduction due to slenderness increasing is assigned for columns of composite or confining modes.

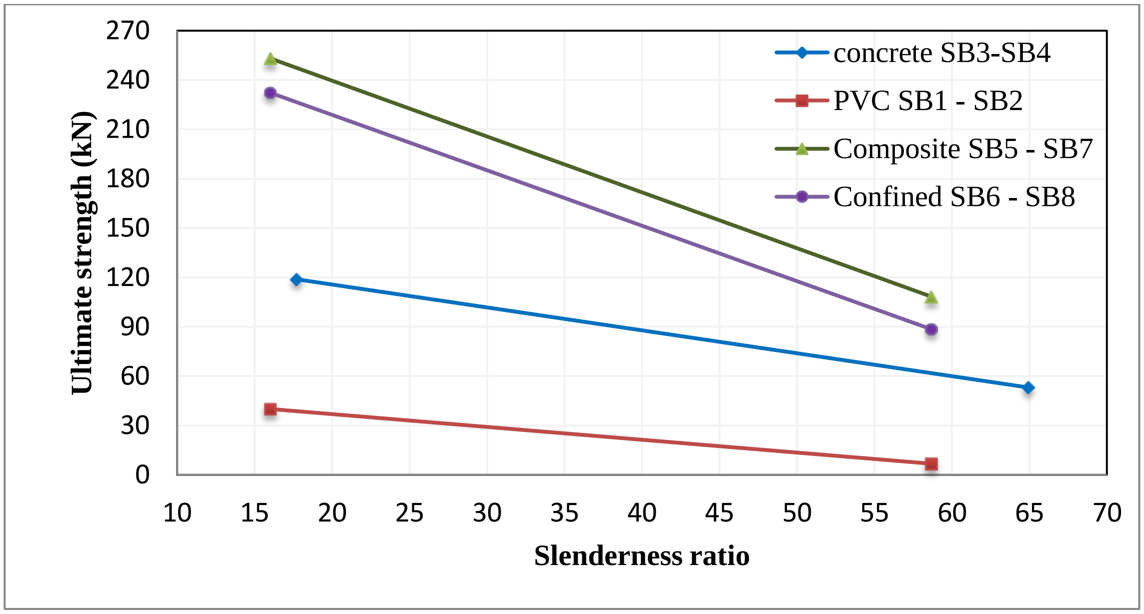


Figure (4.5) Influence of specimens slenderness on ultimate strength of composite and confined columns in comparing with their constitutes.

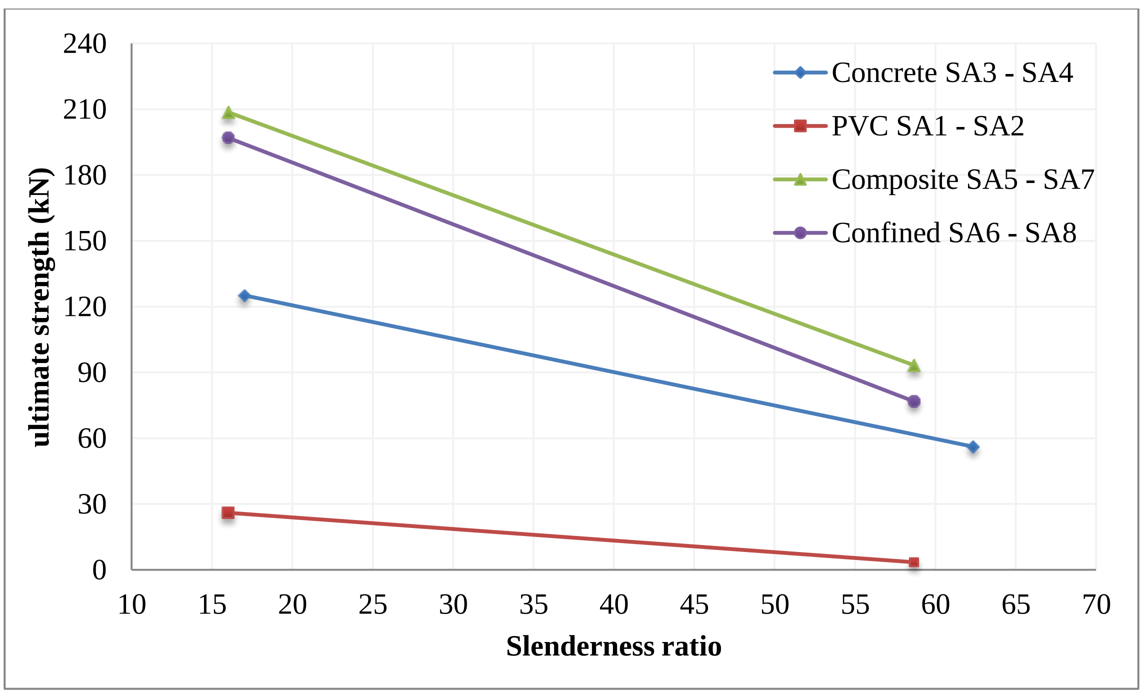


Figure (4.6) Influence of specimens slenderness on ultimate strength of composite and confined columns in comparing with their constitutes.

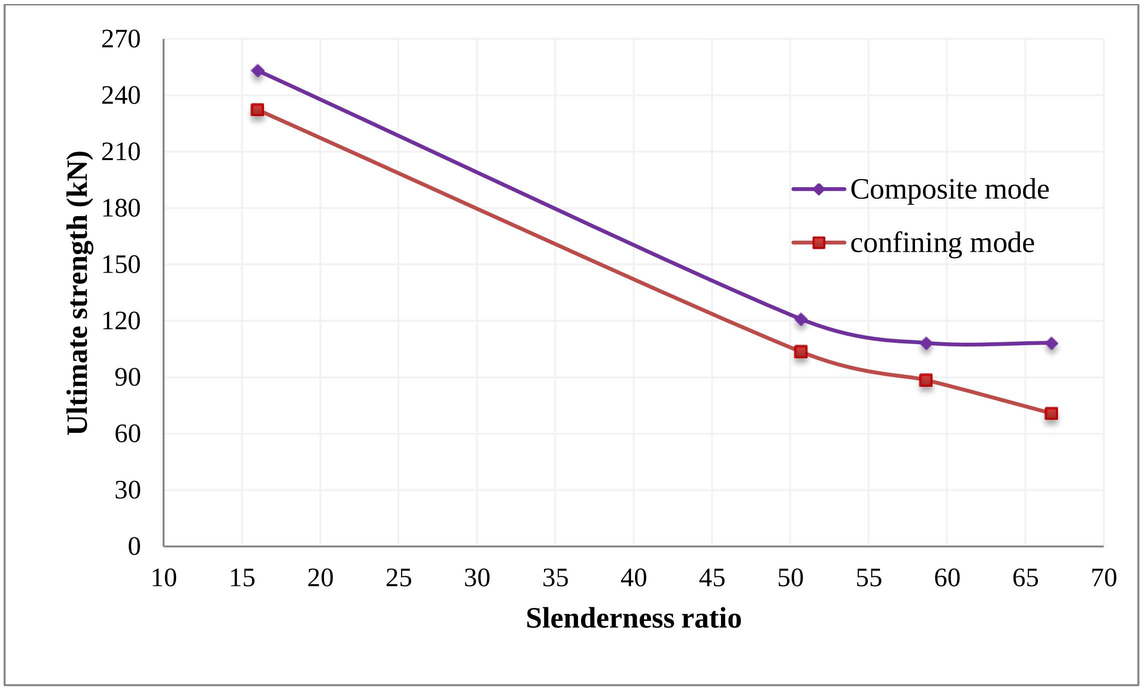
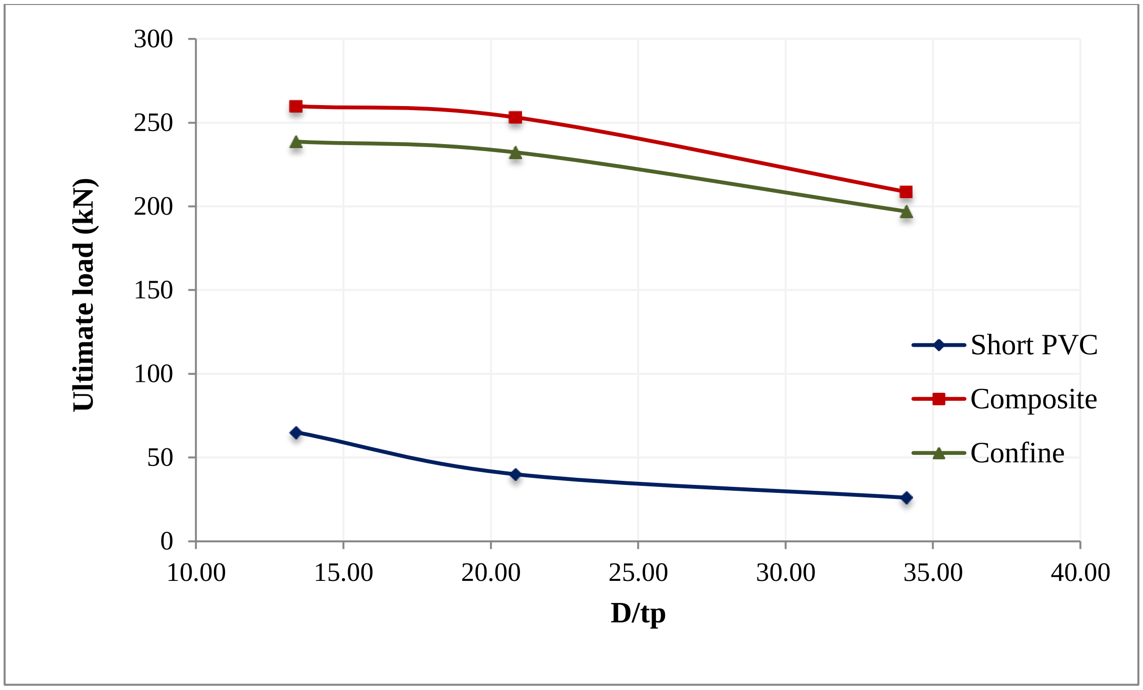


Figure (4.7) Effect of columns slenderness on ultimate strength of composite and confined columns.

4.4.3 Diameter/ thickness (D/tp) effect

In this study the PVC tube used with variable diameters and thickness. Outer diameter of (75mm) with thickness of (2.2, 3.6 and 5.6 mm) and outer diameter of (63mm) with thickness of (3 and 4.7 mm) are selected. Figure (4.8) and (4.9) depict the effect of (D/tp) on ultimate strength of short columns and slender columns respectively. The trend of slender PVC concrete columns is exhibited more dropping as (D/tp) increase. This could be due to failure mode of slender column which is effected by local buckling more than corresponding short column. PVC tube thickness leads to greater increase in ultimate strength and the corresponding strain of the composite columns. This could be attributed to effect of PVC as reinforcement in respect to overall section area.



Figure(4.8) Effect of PVC section slenderness on ultimate strength of short specimens

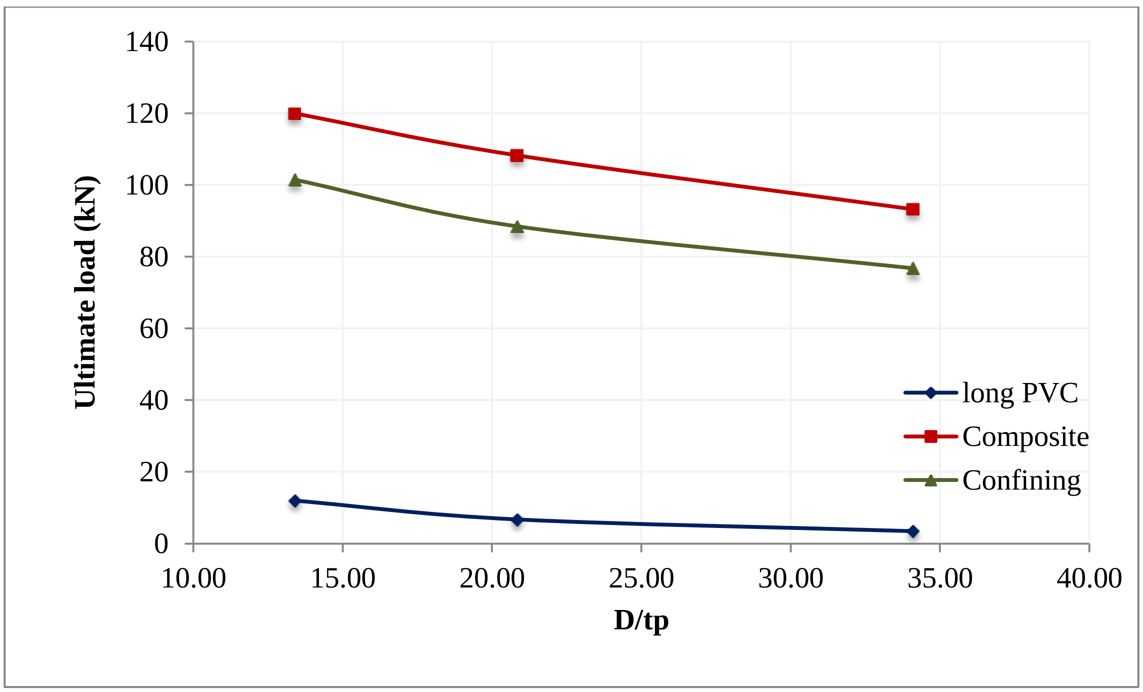


Figure (4.9) Effect of PVC section slenderness on ultimate strength of slender specimens

Figure (4.10) illustrated the effect of D/tp for PVC section on ultimate strength of PVC specimens of difference lengths, since PVC tubes are thin-walled, and buckling is a main consideration in failure. The interaction between local and global (Euler) column buckling for slender columns is attainted, strength dropping is more than corresponding short specimens as shown in fig. (4.10), while local buckling happens in short columns that are fail due to yielding of PVC, as compression strength of the PVC is not attainted, the column compressed longitudinally an expansion as hoop deformations within length are developed.

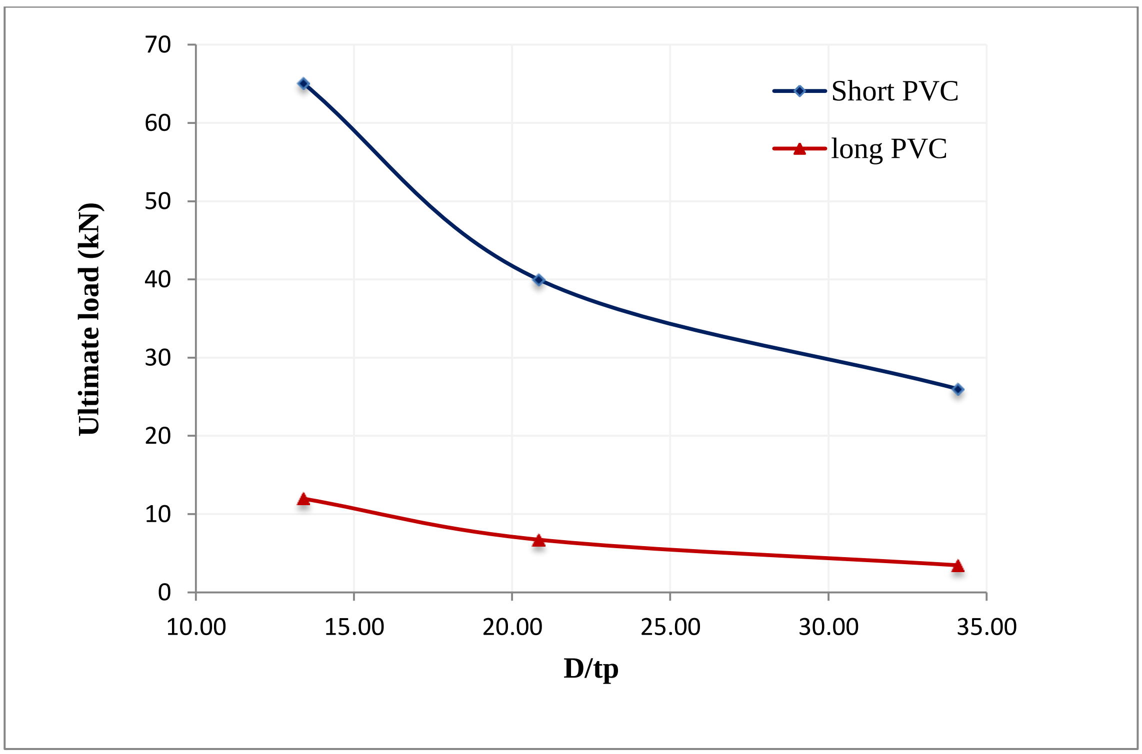


Figure (4.10) Effect of D/tp on ultimate strength of PVC specimens of difference lengths

From Figures (4.11) and (4.12), it can be seen that the same trend of strength dropping as D/tp increase for both composite and confined mode at constant slenderness ratio and concrete strength.

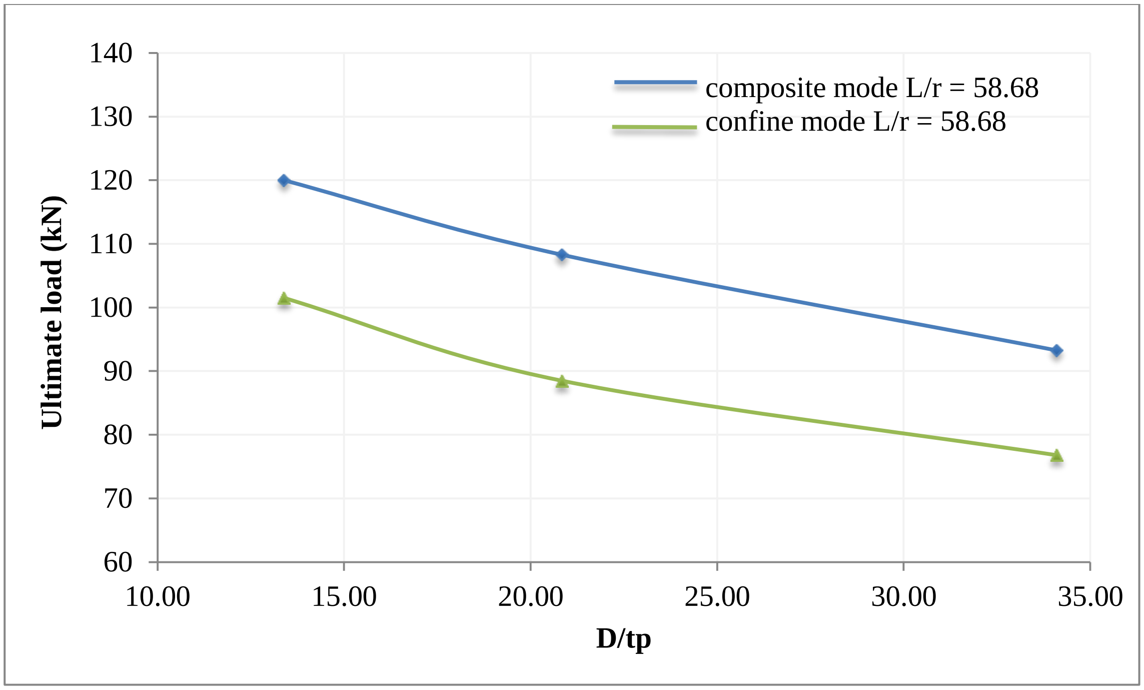


Figure (4.11) Effect of PVC section slenderness on ultimate strength of long composite and confined columns, L/r = 58.68

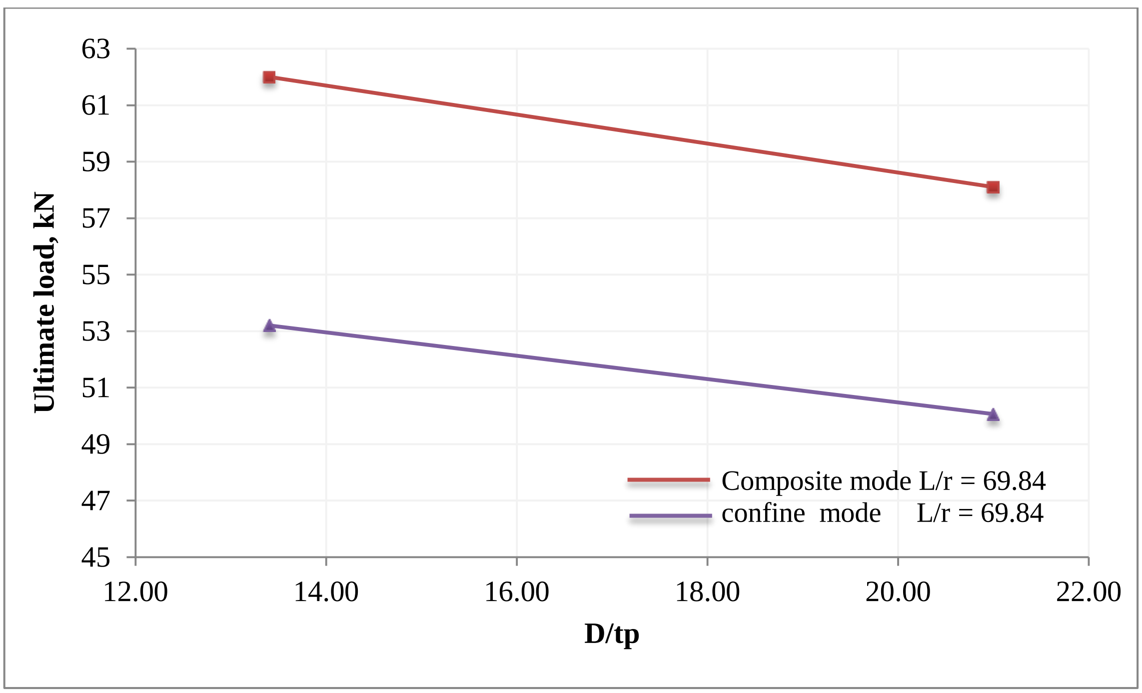


Figure (4.12) Effect of PVC section slenderness on ultimate strength of long composite and confined columns, L/r =69.84

4.4.4 Composite verse confining mode

Figures (4.13) and (4.14) clearly showed variation of strength upgrading ratios of composite and confining modes in respect to concrete core for short and slender specimens. The developed strengths of slender composite specimens in respect to slender confined specimens ratio (Pcm/Pcn) is more than the corresponding ratio of short specimens ((P'cm/P'cn), the same finding is assigned for improving strength ratio in respect to concrete core, this variation could be related to dilation of PVC casing specimens where specimens length extremely effect tube expansion which is more promote in short length.

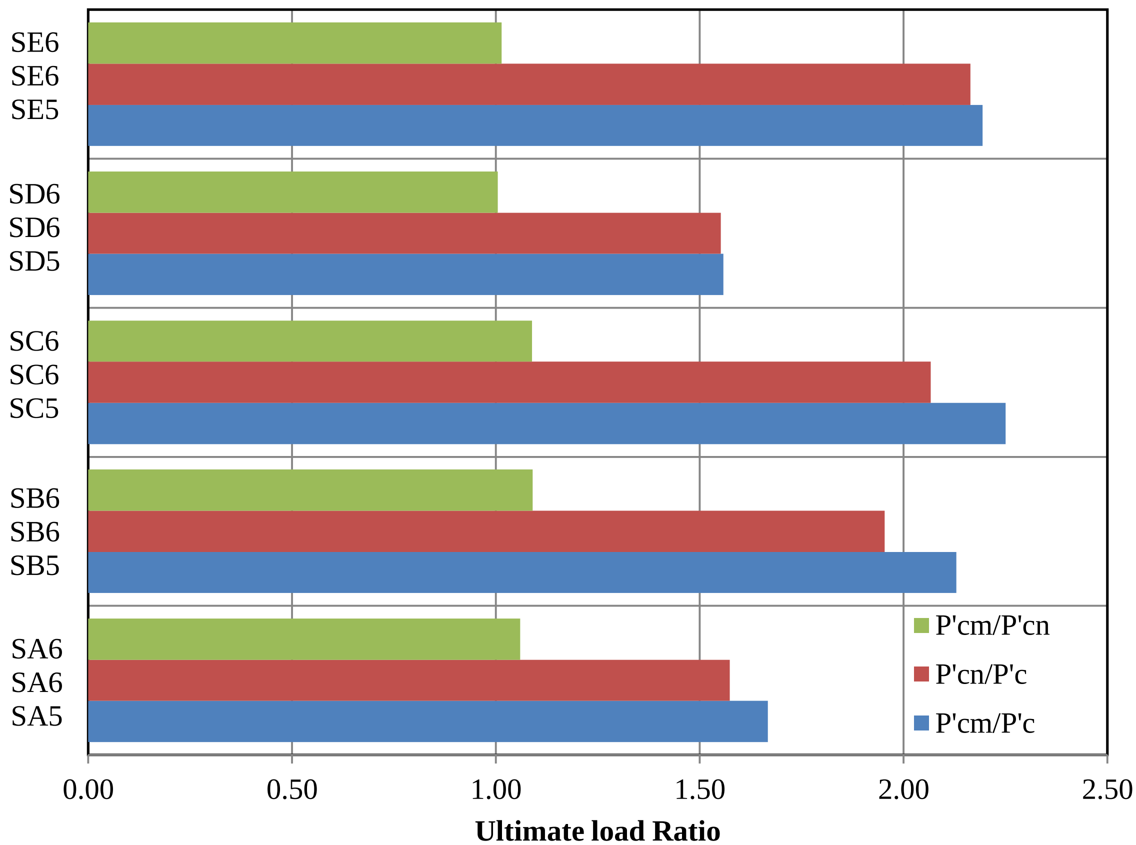


Figure (4.13) Variation of upgrading ratios of composite and confining modes in respect to concrete core –short specimens

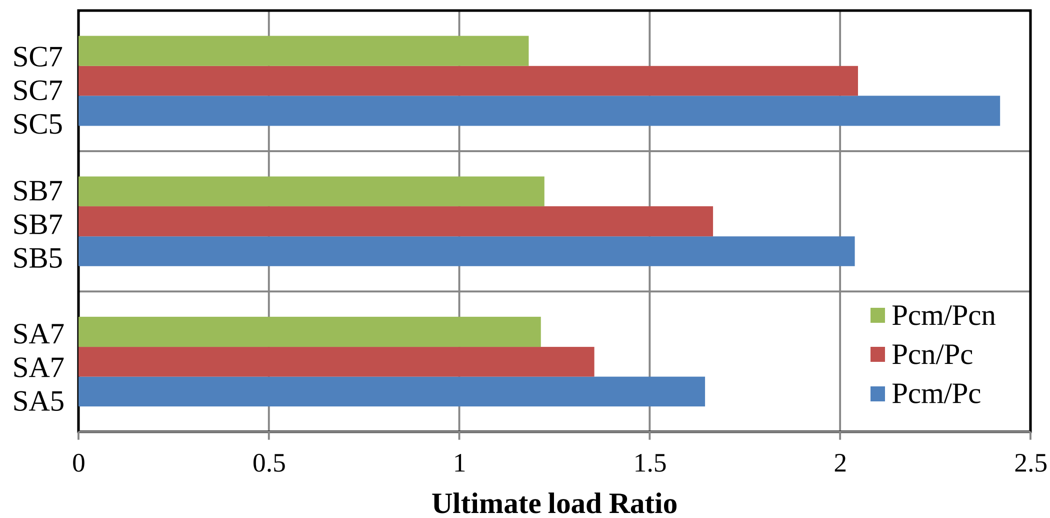


Figure (4.14) Variation of upgrading ratios of composite and confining modes in respect to concrete core –slender specimens.

4.4.5 Concrete Compressive Strength to PVC Strength Effect (fc'/fyp)

The effect of compressive strength of filling concrete on columns strengths are shown in Figs (4.15) to (4.18). For all tested columns with different loading modes and various slenderness ratio, ultimate strength is increased as fc' increased. Furthermore, influencing rate decreased with fc'/fyp increasing. The best improving rate correspond to fc'/fyp = 0.86

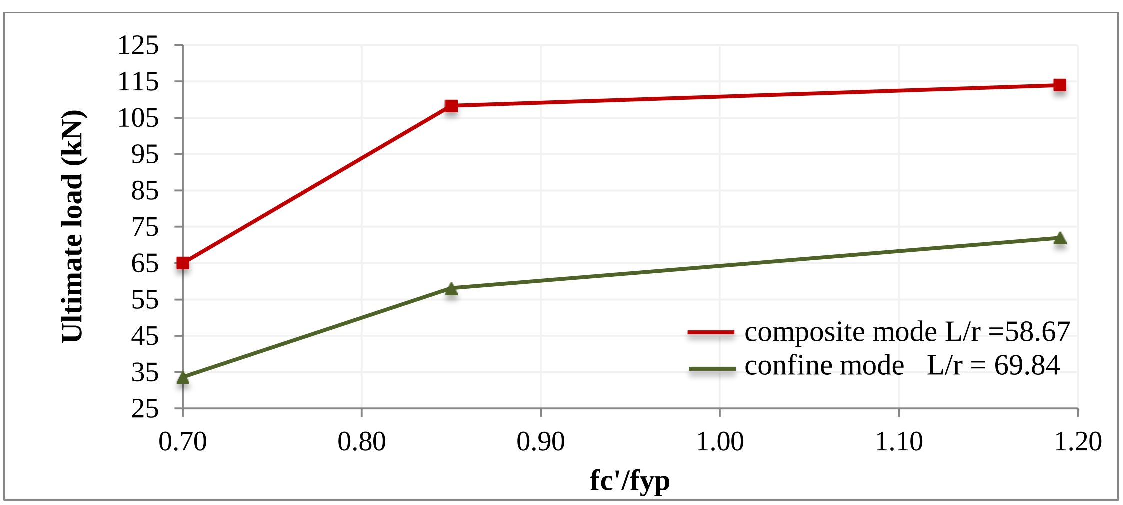


Figure (4.15) Effect of concrete compressive strength on ultimate strength

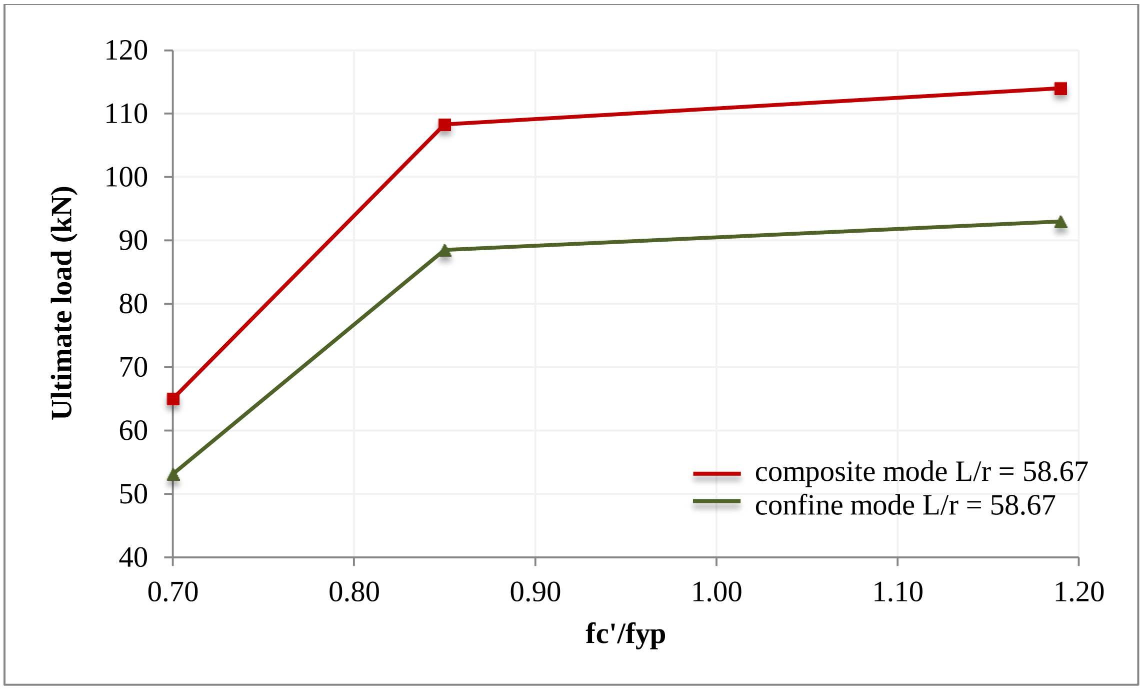


Figure (4.16) Effect of filling columns concrete compressive strength on ultimate strength of long columns with constant D/tp

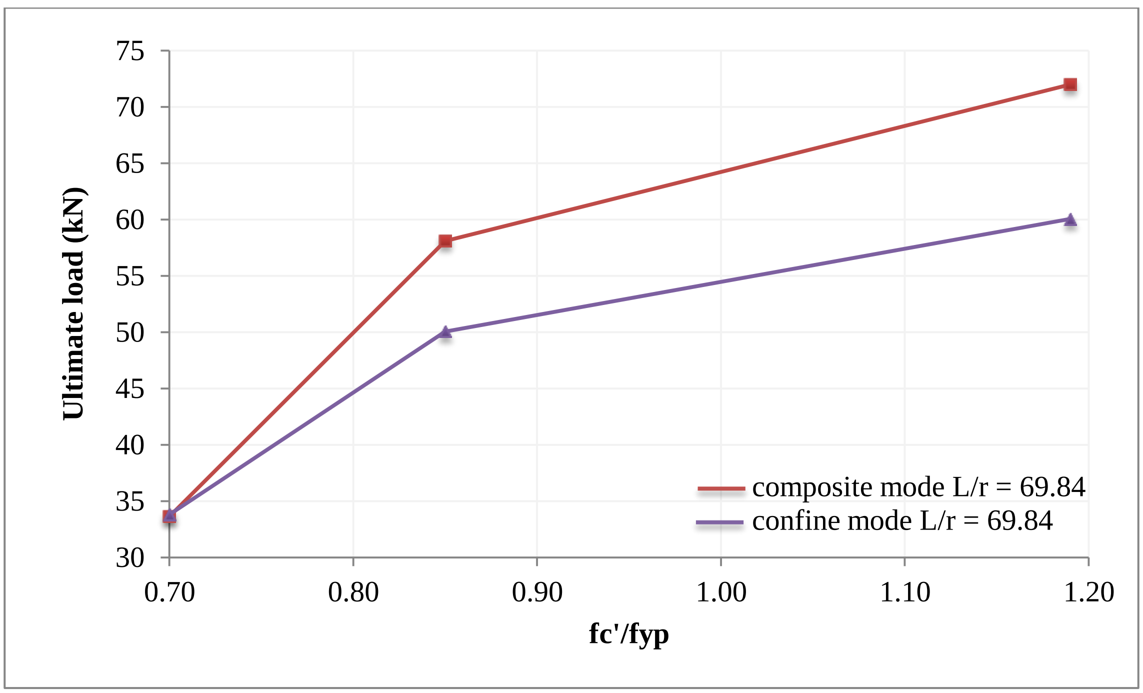


Figure (4.17) Effect of filling columns concrete compressive strength on ultimate strength of long columns with constant D/tp

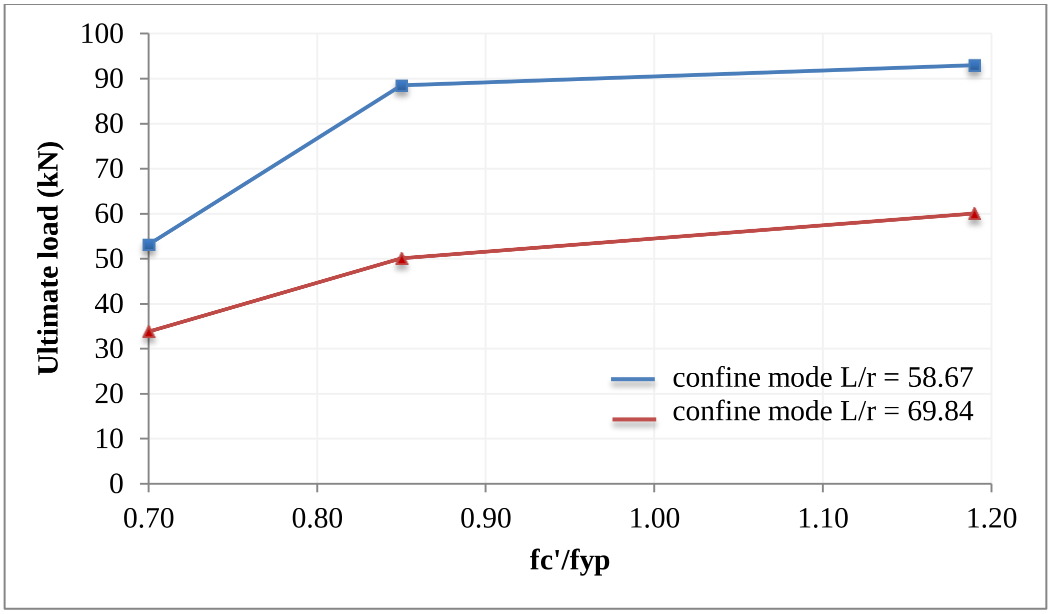
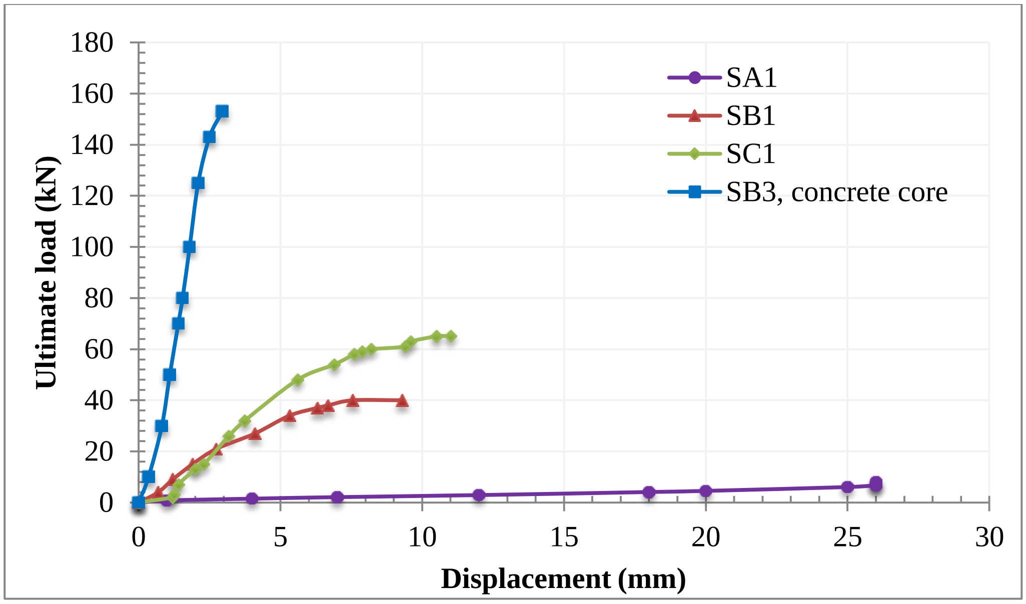


Figure (4.18) Effect of filling columns concrete compressive strength on ultimate strength of long confined columns of constant D/tp

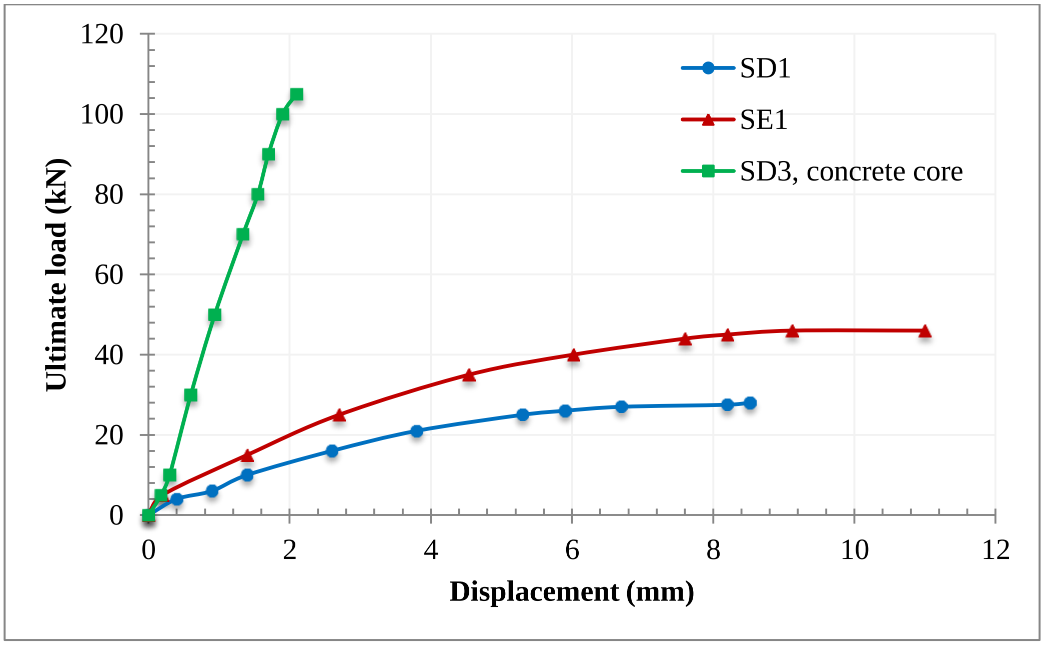
4.5 Load Desplacement Response

4.5.1 Short Specimens

For composite mode, the filling concrete is under triaxial compression due to PVC tube casing, which is under vertical compression and transverse tension. The triaxial stress state causes a reduction of the axial compressive strength of the PVC tube while there is an increase in the longitudinal compressive strength of the concrete. The interaction between the tube and the concrete filling works beneficially and leads to an ultimate load exceeding the sum of the uniaxial compression loads of PVC tube and concrete. While for confining mode PVC contributes to enhancing filling concrete strength without vertical compression and dominate lateral expansion. Figs. (4.19) to (4.21) presented Load – axial deformation response of specimens of composite and confining mechanism, for different slenderness ratios, the comparison showed clearly verified the positive enhancement of composite mechanism in scope of strength and stiffness upgrading, as much as verified the positive enhancement of confining mechanism in scope of ductility and energy absorption upgrading.

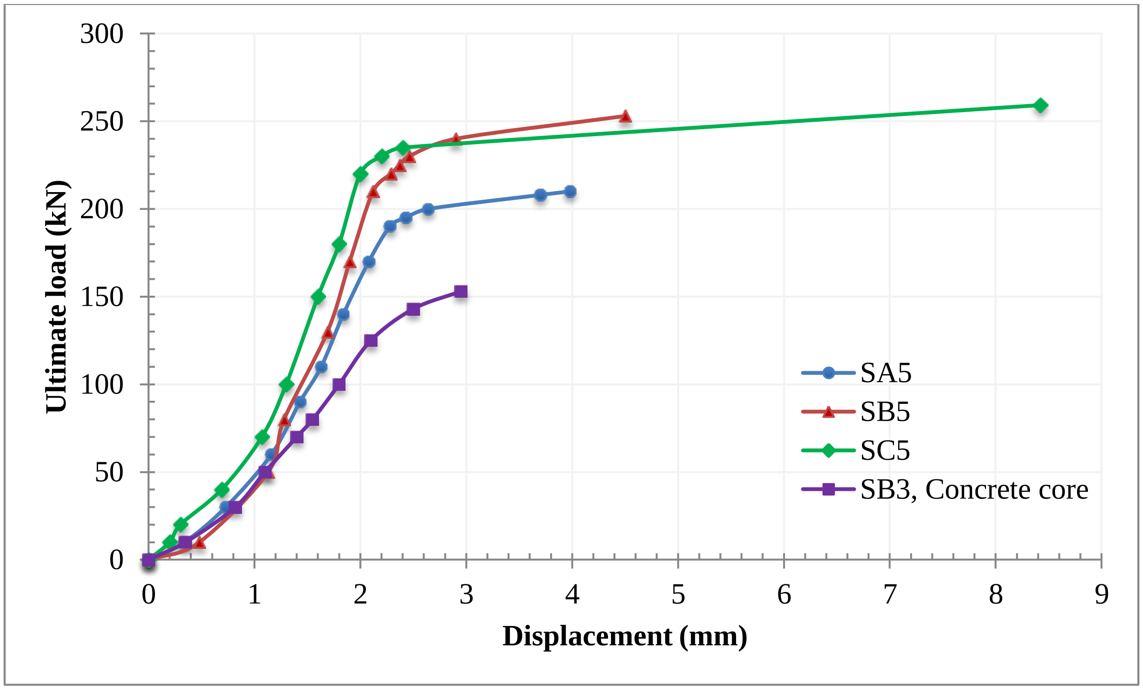


a. L/r =16

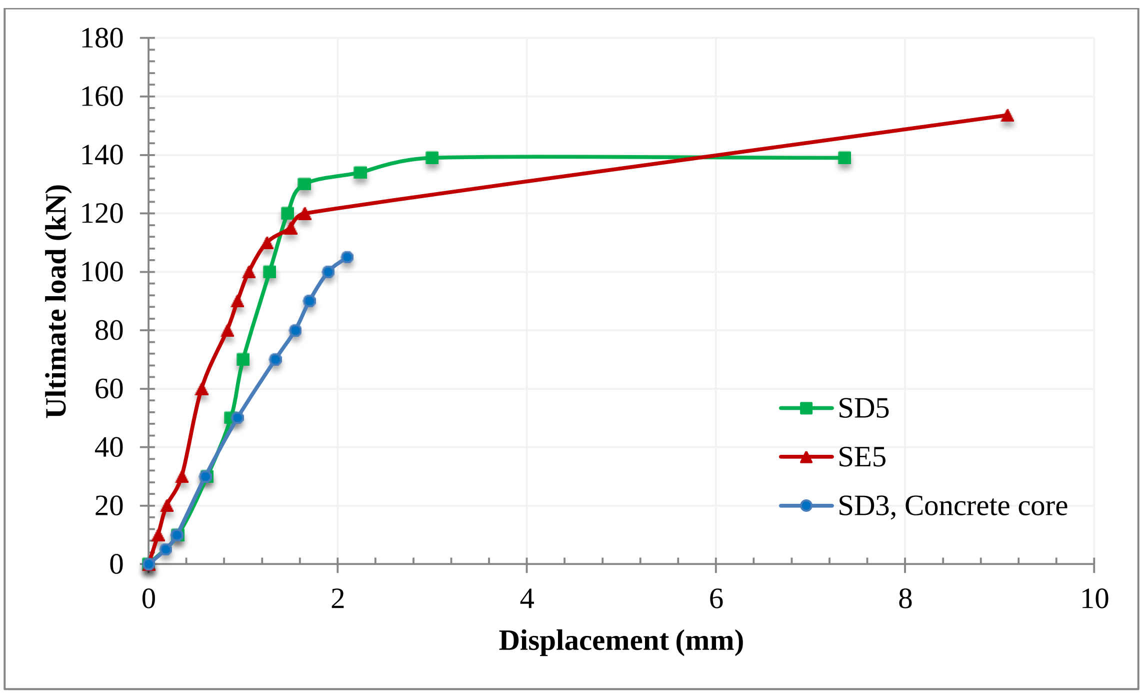


b. L /r =19.04

Figure (4.19) Load – axial deformation of individual components

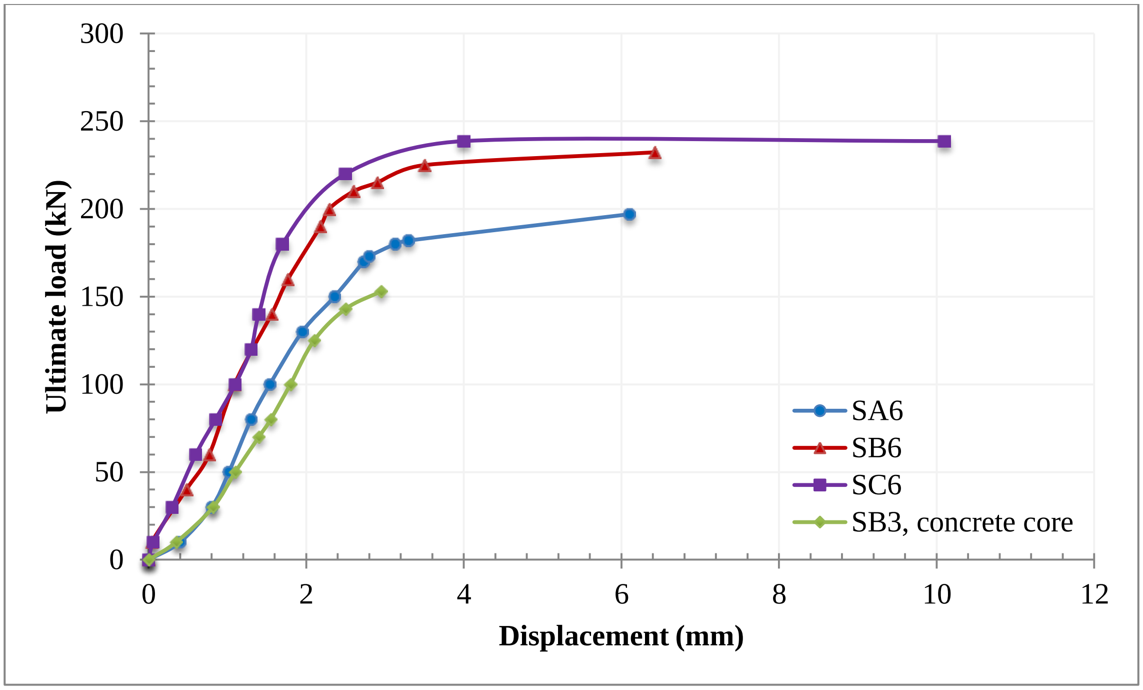


a. L/r = 16

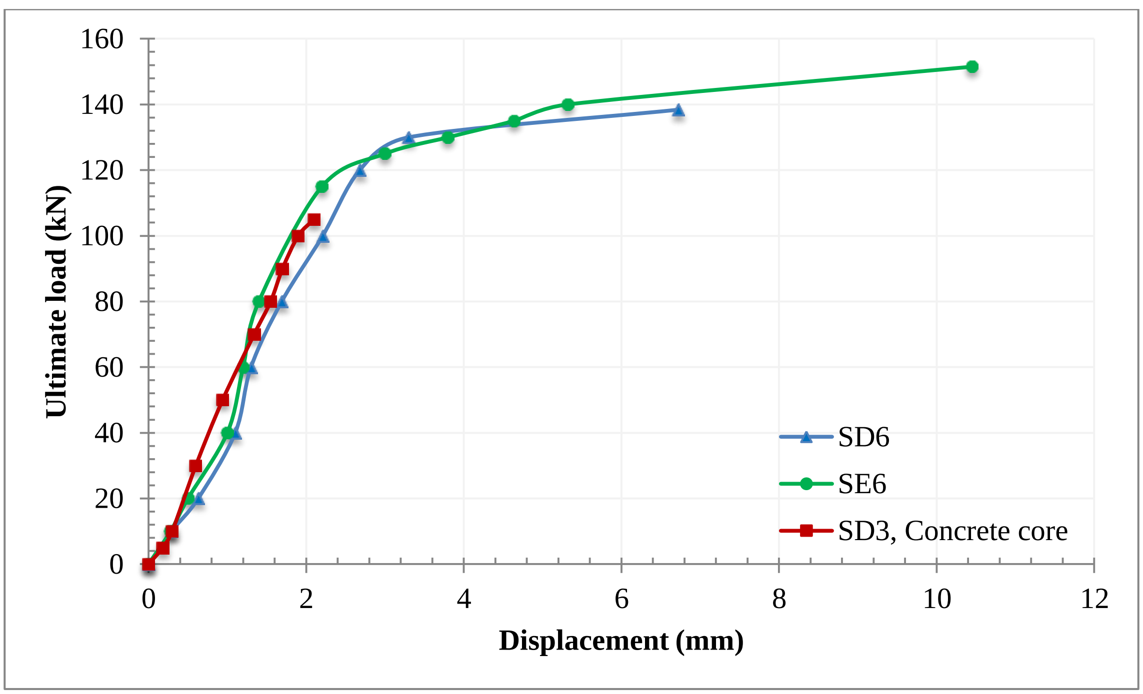


b. L/r =19.04

Figure (4.20) Load – axial deformation of composite specimens



a. L/r =16



b. L/r =19.04

Figure (4.21) Load – axial deformation of confined specimens

4.5.2 Slender specimens

4.5.2.1 Load –axial deformation response

The assigned strength upgrading for composite mode relate to attaint of PVC as reinforcement while assigned enhancing in confining mode relates to confining efficiency to upgrading filling concrete strength where difference of the Poisson's ratios between PVC tube and the concrete is affected columns resistance. Poisson's ratio of PVC is about 0.41 in the elastic range.[5] Thus in case of loading on the entire section in the initial stage of loading the PVC tube and the concrete act separately due to the faster expansion of the PVC tube in radial direction. rapidly and further loading leads to lateral expansion greater than that of the PVC tube. Figures (4.22) and (4.23) illustrate the effect of (D/tp) on load axial deformation response for different modes. Sections with low (D/tp) are provided more strength enhancing compared with different other modes. Figure (4.24) and (4.25) depicts the effect of column slenderness ratio (L/r) on load –axial deformation response for different modes. As slenderness increased, loading capacity decreased, the response of confining mode is term of ductility is more sensitive to slenderness than composite mode. Figure (4.26) and (4.27) exhibited comparison of PVC-concrete column behavior verse its constitutes. In both modes, the strength is more than summation of constitutes strength, the behavior of columns of different modes are the same in spite of indicated different strength capacity, also for both mode, PVC-concrete column behavior didn’t like behavior of their constitutes. Figure (4.28) clearly shown load – axial deformation of considered PVC tubes throughout this study, strength and ductility is effected by section compactness, for all section, the behavior characteristics by distinguished yielding response and sustained plastic deformation. Figure (4.29) illustrated load – axial deformation comparison of composite and confined in term of corresponding concrete cores, because that the concrete has no reinforcement that it fails with low strength and undergoes low deformations up to failure. While the PVC tube provides lateral confinement and sharing the load applied with concrete, thus the composite column fails with higher strength and undergoes high deformations than plain concrete column, initial behavior is depended on concrete stiffness. Figure (4.30) exhibited comparison of load – axial deformation of composite and confined columns compared with PVC, constant L/r and D/tp, columns of composite mode provided more strength capacity and relatively more plastic deformation than corresponding confining mode. Figures depicts that PVC-concrete load axial deformation response dominated by PVC tubes plastic behavior. Figs (4.31) to (4.34) depicts that composite mode is the efficient mode in slender PVC-concrete columns where the comparison with load - deformation response confirm that stiffness, strength capacity and ductility of columns of composite mode are more than those of corresponding columns of confining mode having various slenderness and D/tp.

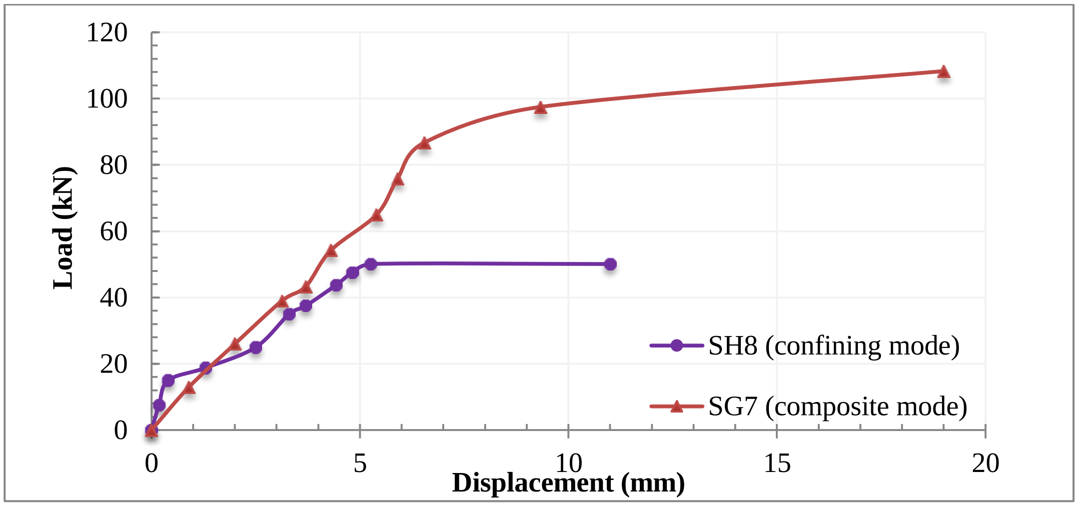
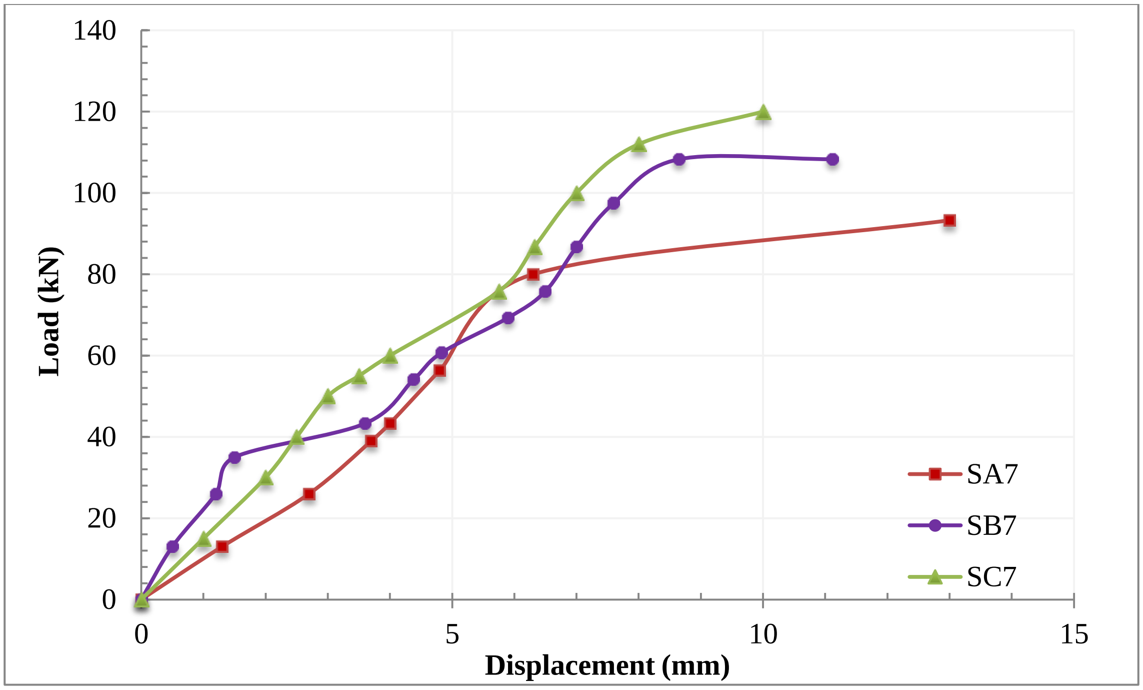
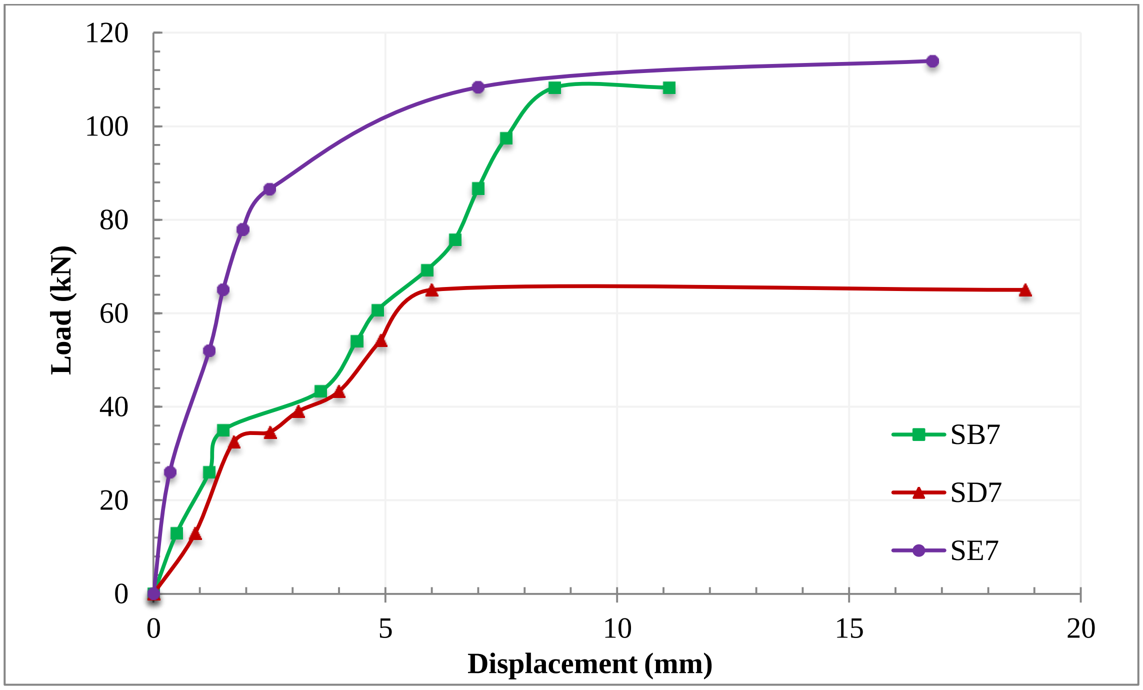


Figure (4.22) Load – axial deformation behavior comparison of composite and Confined columns D/tp =21, L/r = 69.84

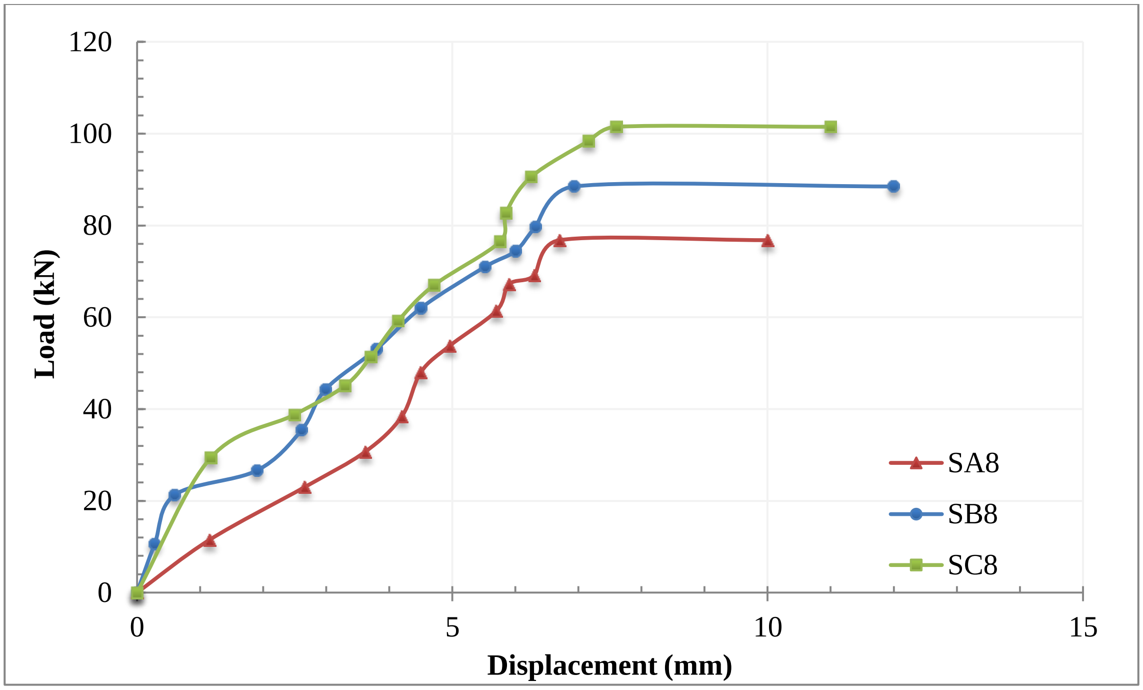


a. Columns SA7, SB7 and SC7

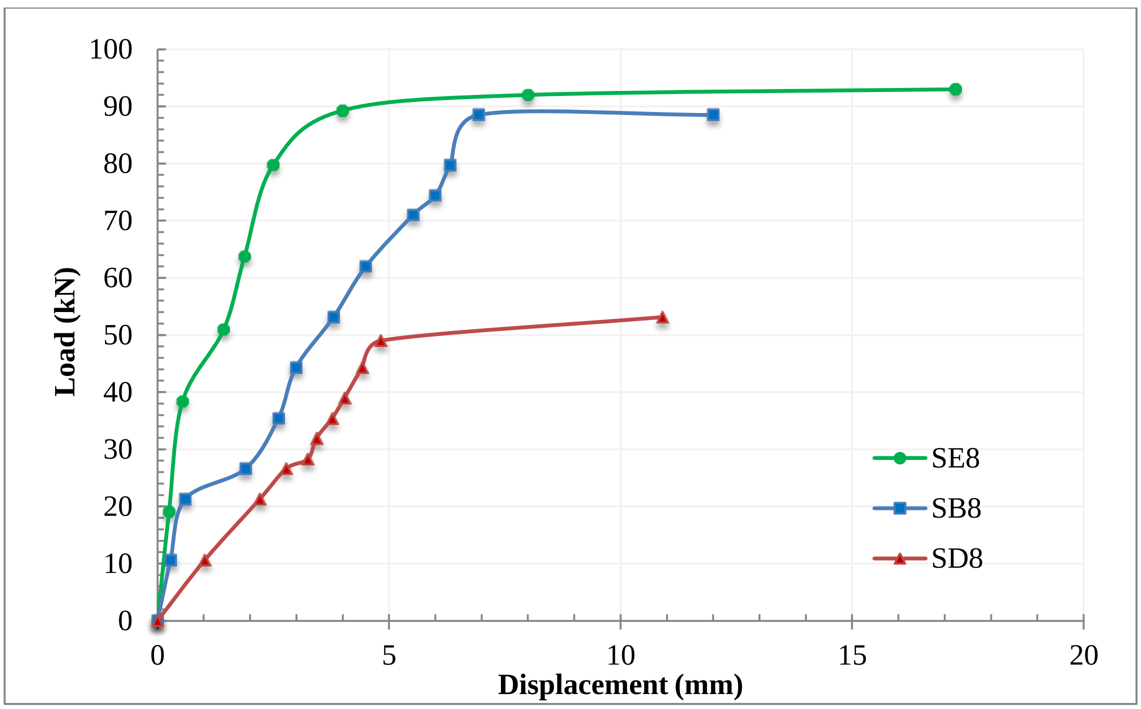


b. Columns SB7, SD7 and SE7

Figure (4.23) Load – axial deformation of composite specimens of various D/tp



a. Columns SA8, SB8 and SC8



b. Columns SE8, SB8 and SD8

Figure (4.24) Load – axial deformation of confined specimens of various D/tp

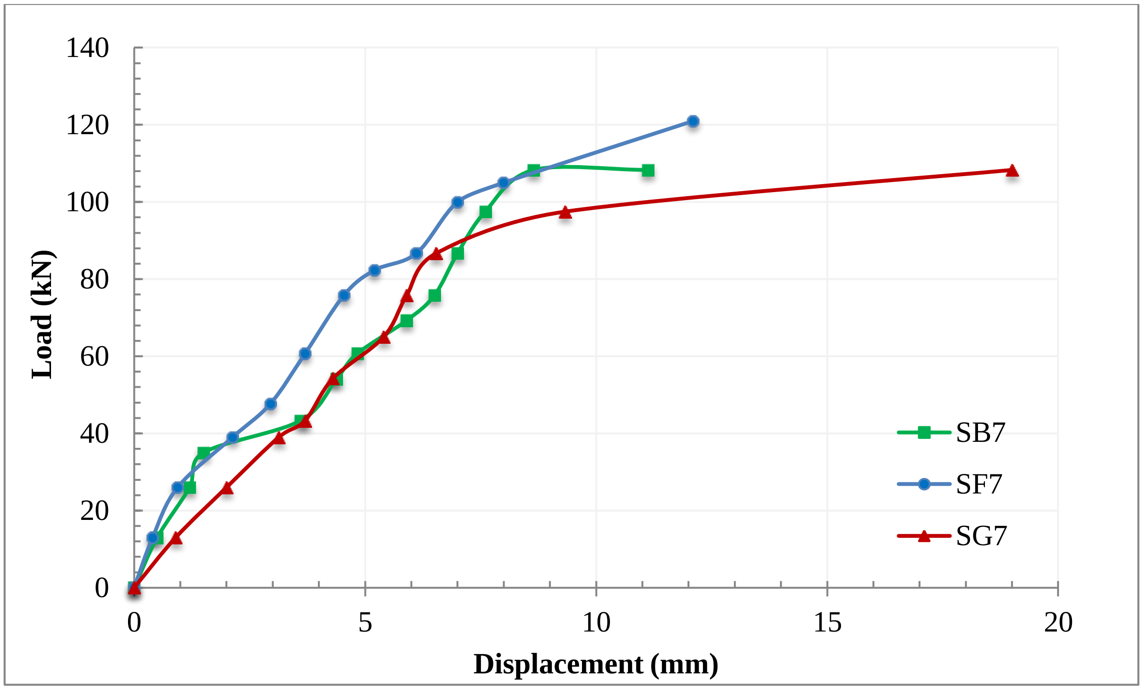


Figure (4.25)Load – axial deformation of composite specimens various L / R

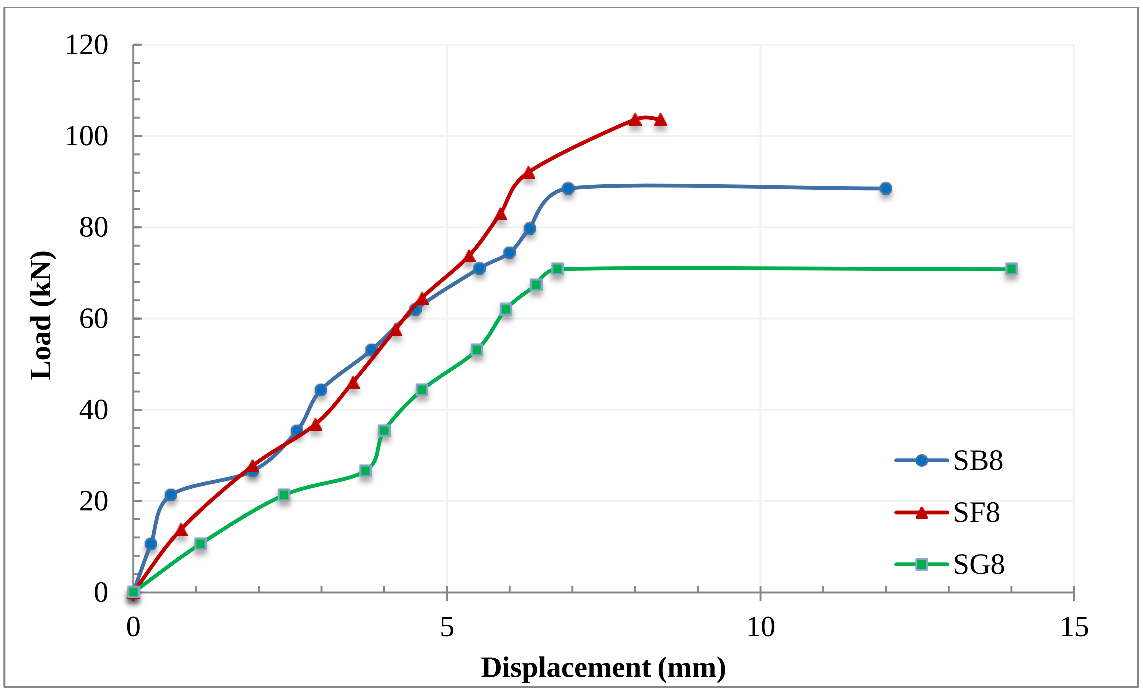


Figure (4.26) Load – axial deformation of confined specimens various L / R

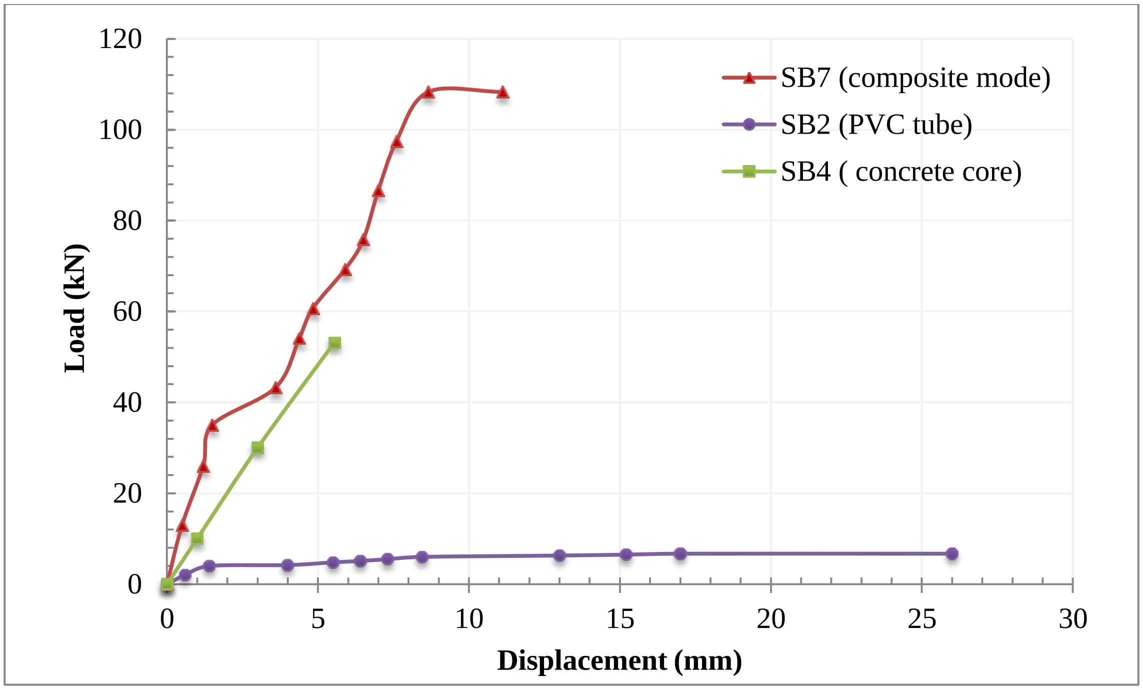


Figure (4.27) Load – axial deformation comparison of composite column to its constitutes

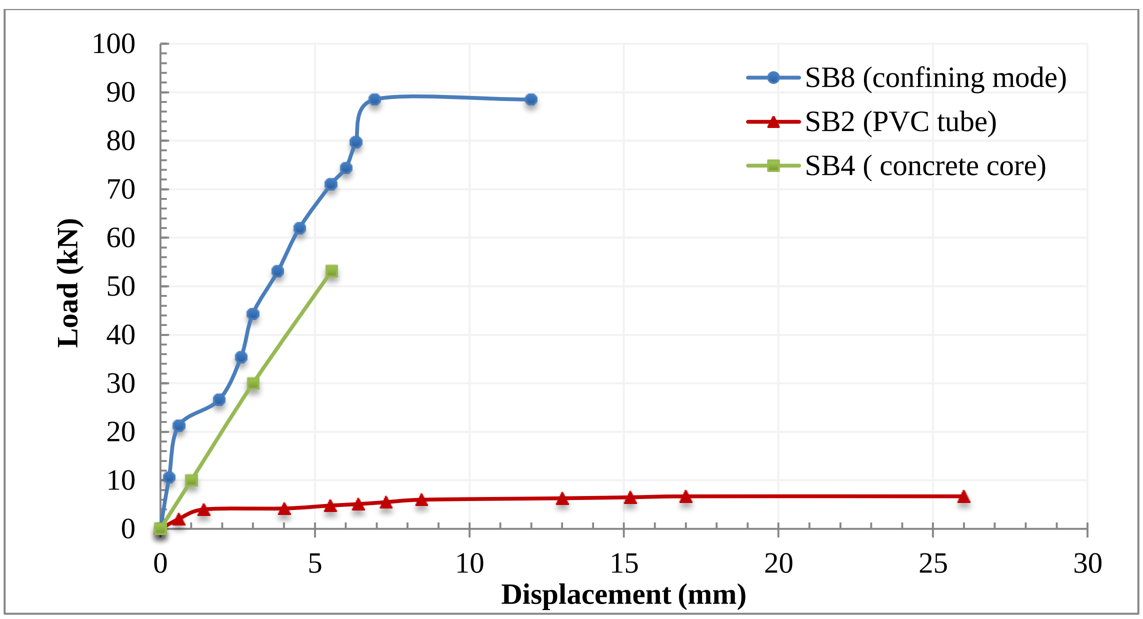


Figure (4.28) Load – axial deformation comparison of confined column in term of its constitutes

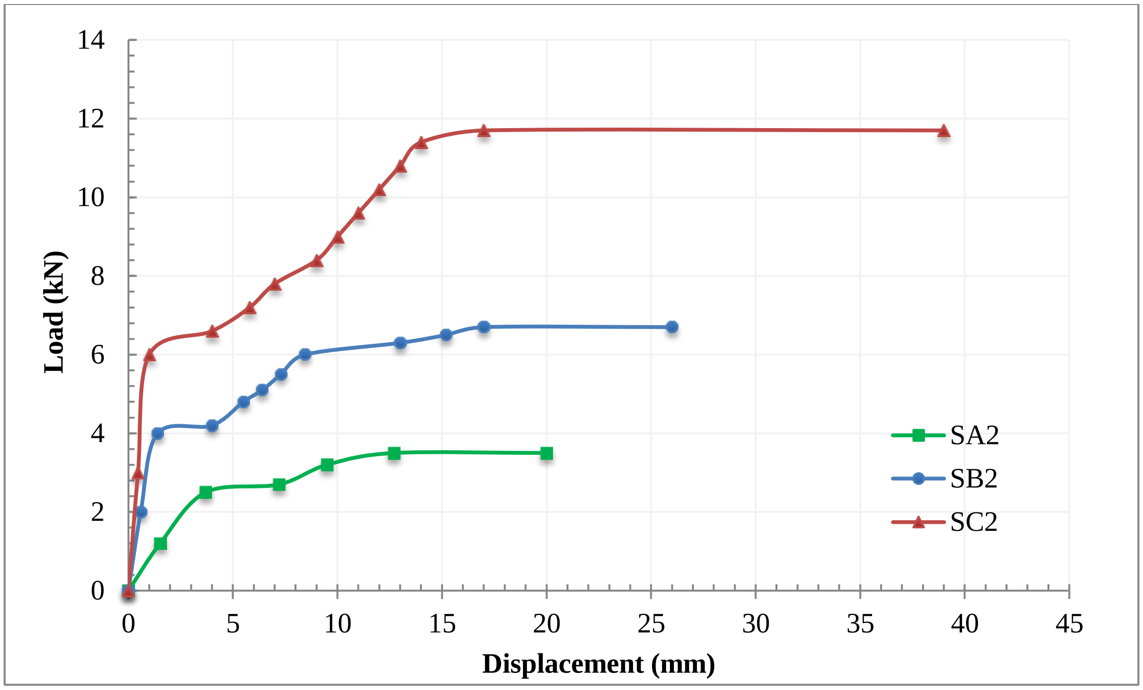


Figure (4.29) Load – axial deformation comparison of PVC tubes

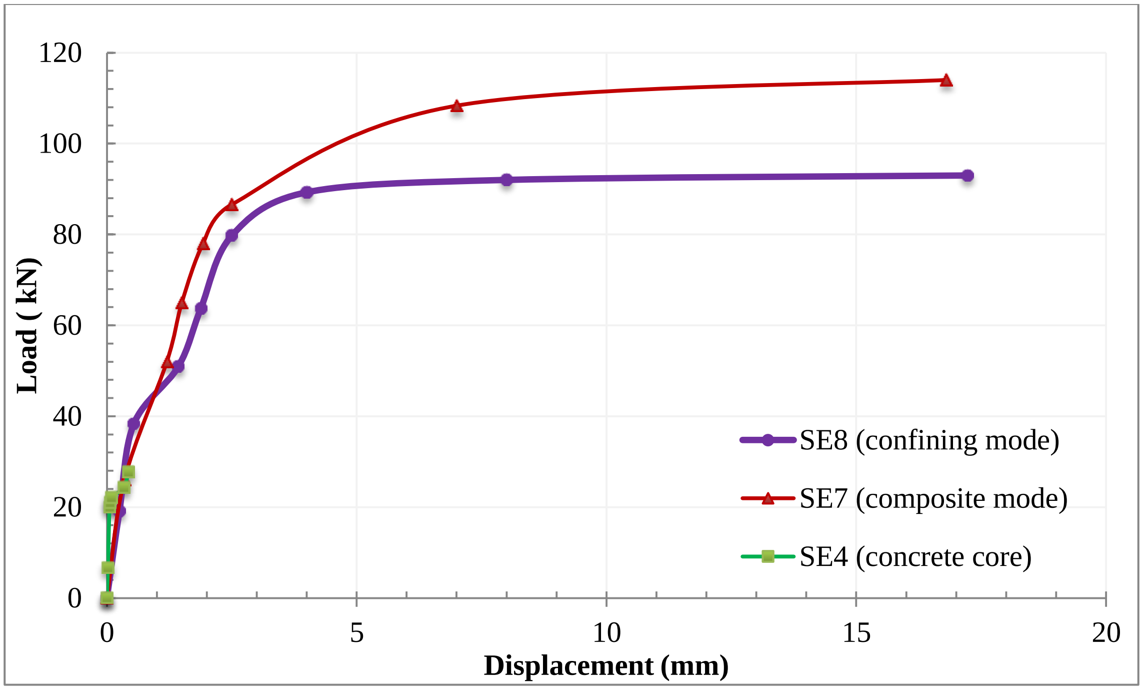
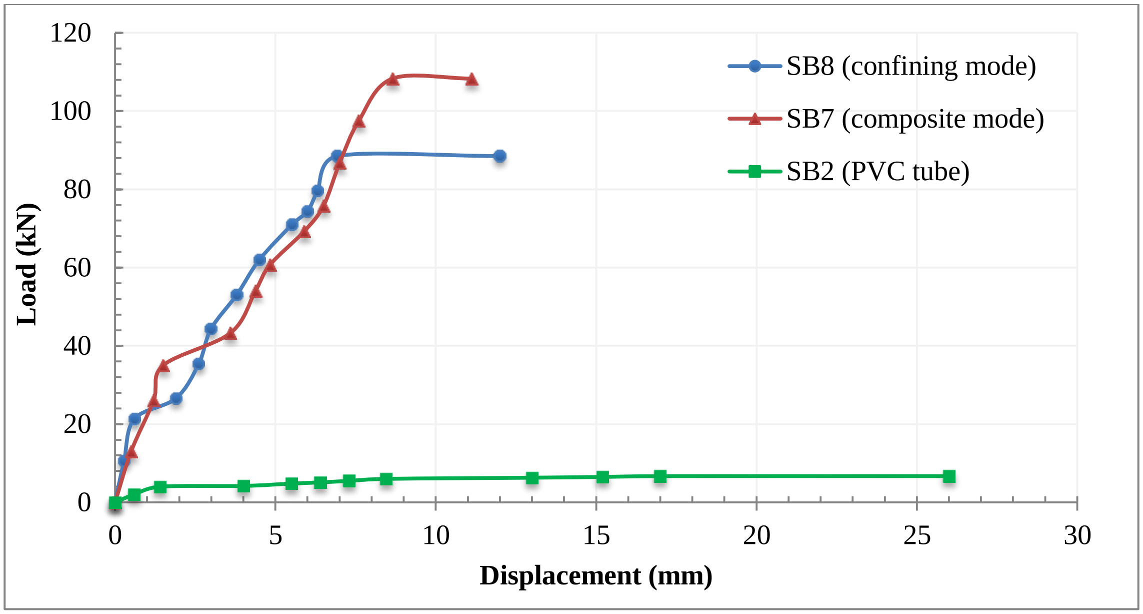
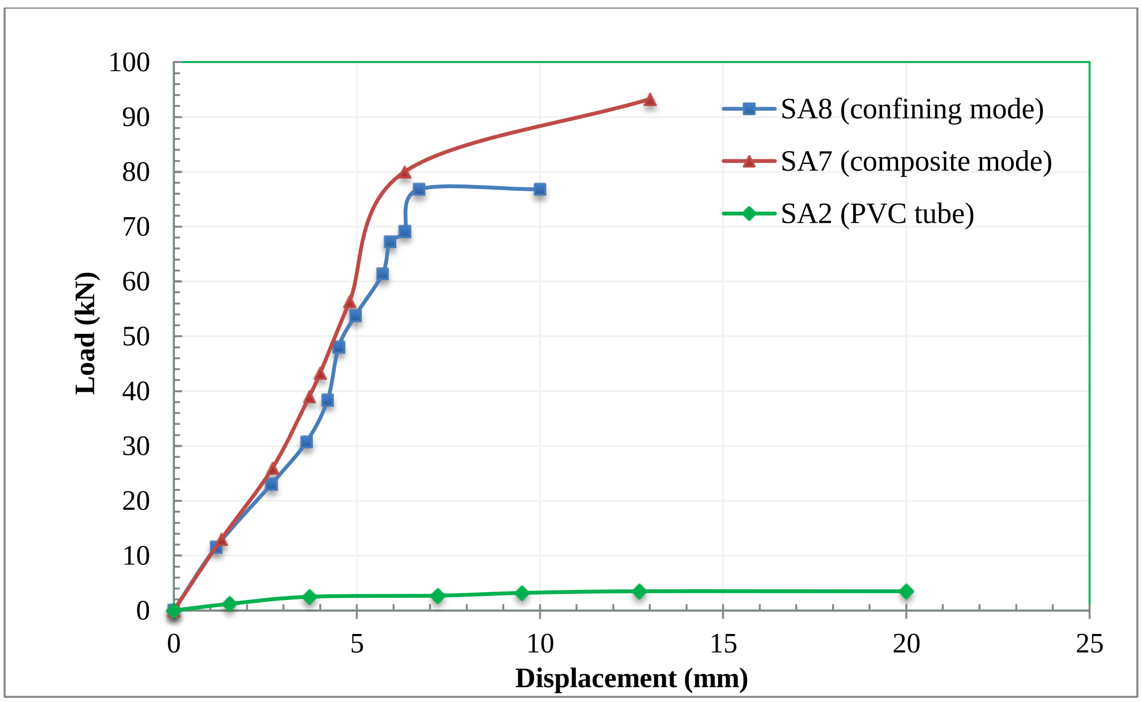


Figure (4.30) Load – axial deformation comparison of composite and confined and concrete columns

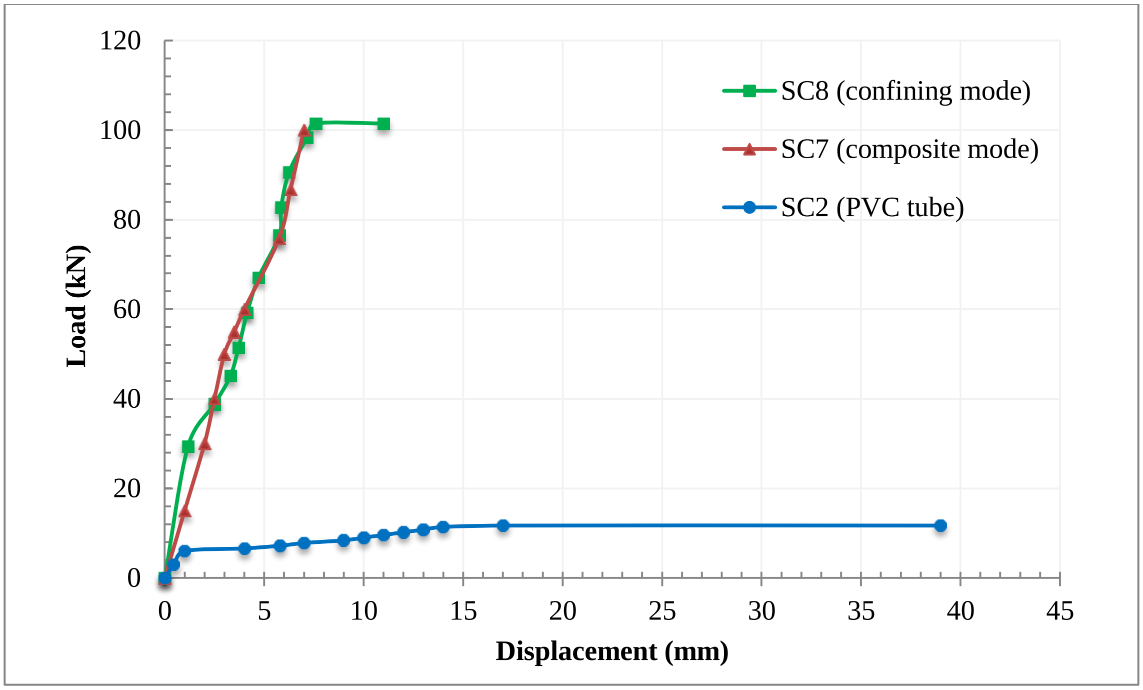


a. Columns SB8, SB7 and SC2

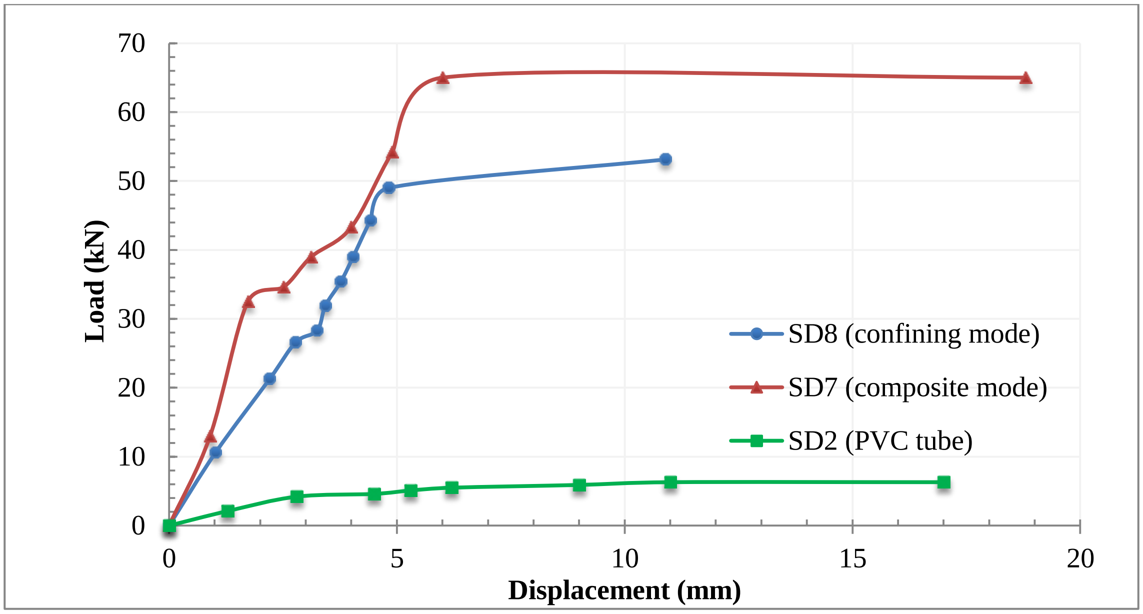


b. Columns SA8, SA7 and SA2

Figure (4.31) Load – axial deformation comparison of composite and confined columns and PVC for various L / R and D/tp.

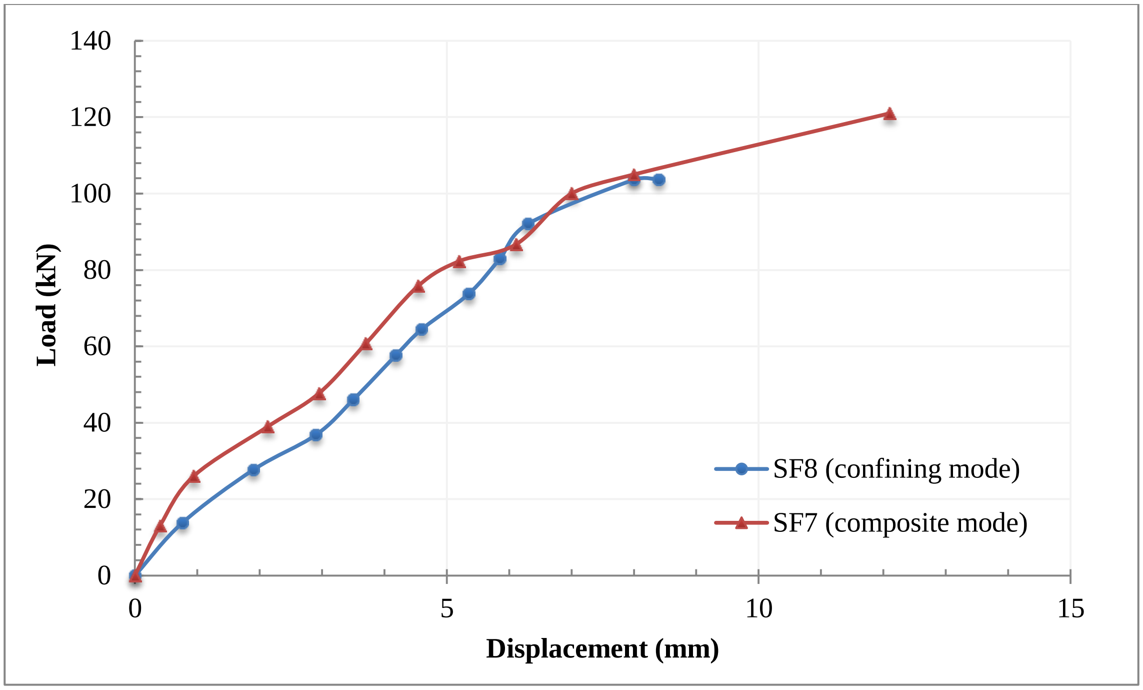


a. Columns SC8, SC7 and SC2

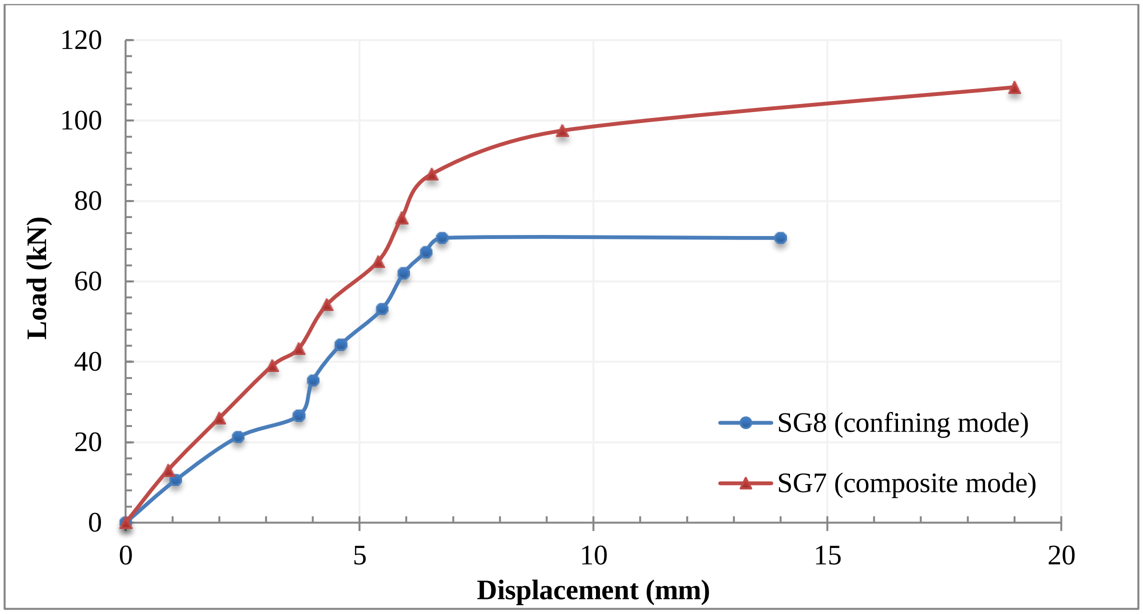


b. Columns SD8, SD7 and SD2

Figure (4.32) Load – axial deformation comparison of composite and confined columns and PVC

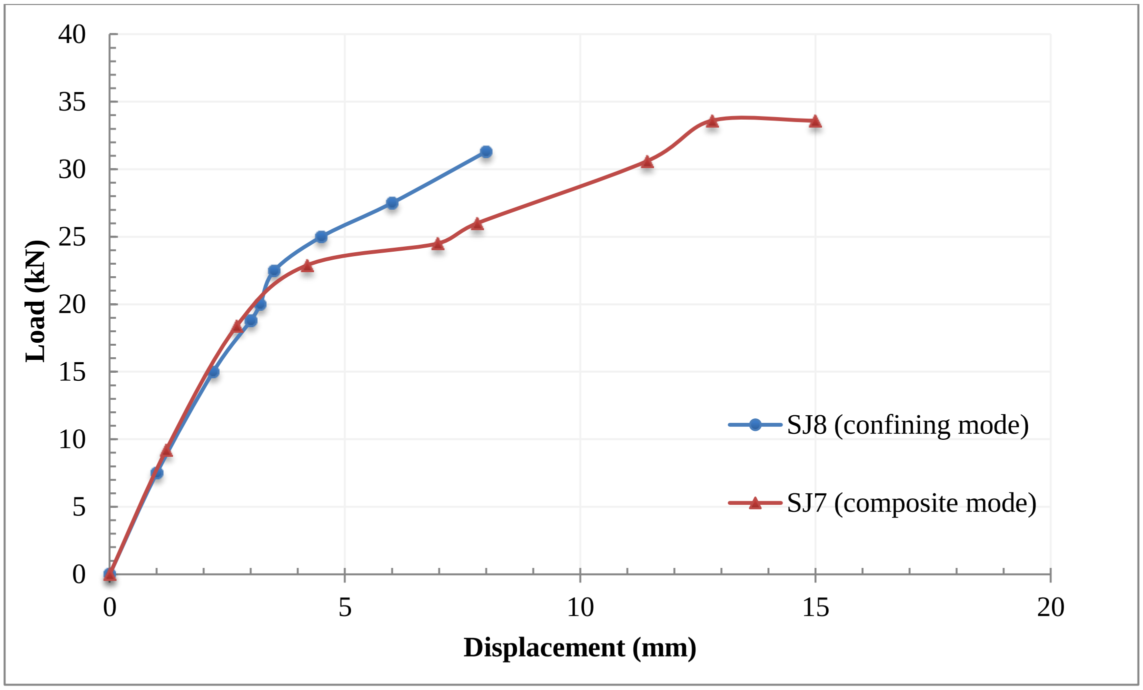


a. Columns SF8 and SF7

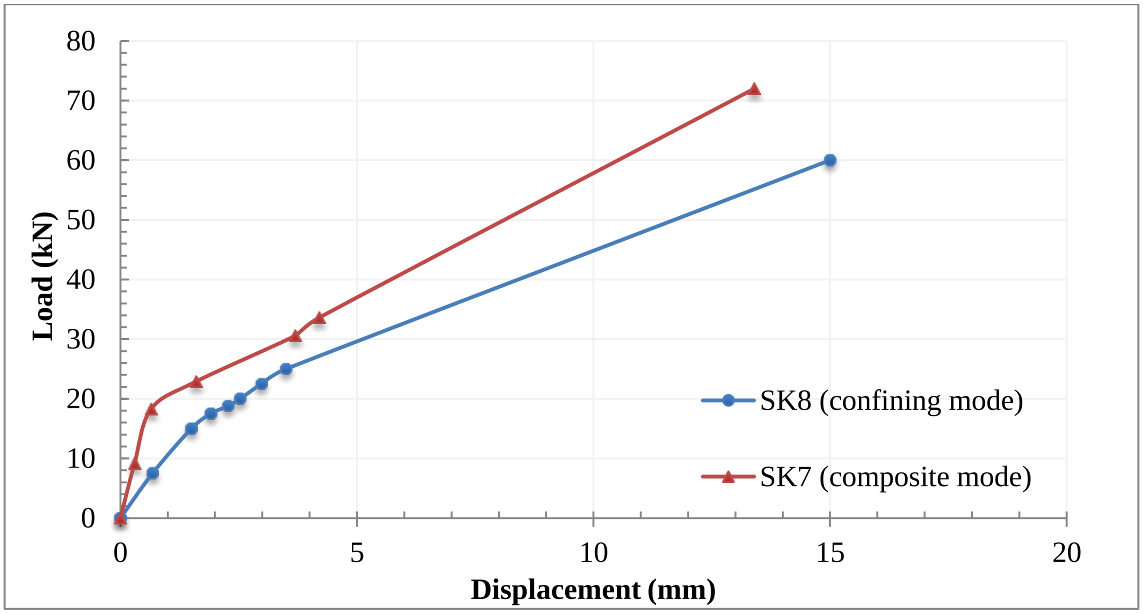


b. Columns SG8 and SG7

Figure (4.33) Load – axial deformation behavior comparison of composite and Confined columns



a. Columns SJ8 and SJ7



b. Columns SK8 and SK7

Figure (4.34) Load – axial deformation behavior comparison of composite and Confined columns

4.5.2.2 Load - lateral deformation responce

In scope of lateral deformation, the initial behavior of PVC concrete column is similar to that of plain concrete column, this is due to the fact that the confining effect of PVC tube 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 PVC tube is activated and starts to gradually restrain the rapid growth of the lateral strains.

Figure (4.35) indicates load – lateral deformation trending of used PVC tubes of different compactness, the slender section of tp=2.2 mm assign elastic buckling where other section which are of tp=5.6 mm assigned inelastic buckling where yielding stage is more significant.

Generally, the same effectiveness of slenderness and D/tp which is assigned in axial deformation is observed in lateral expansion. The effect of D/tp on load lateral deformation response is illustrated in Figs. (4.36) and (4.37) for composite and confining mode respectively. Figs. (4.38) and (4.39) exhibits the effect of column slenderness on load – lateral deformation for composite and confining modes.

Comparison of columns response for lateral expansion in term of columns constitutes are shown in Figures (4.40) and (4.41), the present of PVC tube extremely enhanced lateral expansion reduction, confining mode assigned as best on in term of stiffness enhancement while composite mode is the best in term of ductility improving.

Load-lateral deformation comparison of composite and confined columns of various column slenderness and PVC section compactness in respect to PVC tube behavior is shown in Figs. (4.42) to (4.45) where specimens behavior absolutely differ from that of casing PVC tube.

Load-lateral deformation comparison of composite and confined columns of various column slenderness and PVC section compactness in respect to concrete core behavior is shown in Fig. (4.41) which is indicated that initial behavior of filling concrete is dominated specimens stiffness. PVC-concrete mode effectiveness on Load-lateral deformation comparison of composite and confined columns of various column slenderness and PVC section compactness is shown in Fig. (4.42) and (4.43) which depict that composite mode is the efficient one in term of stiffness, strength capacity, ductility.

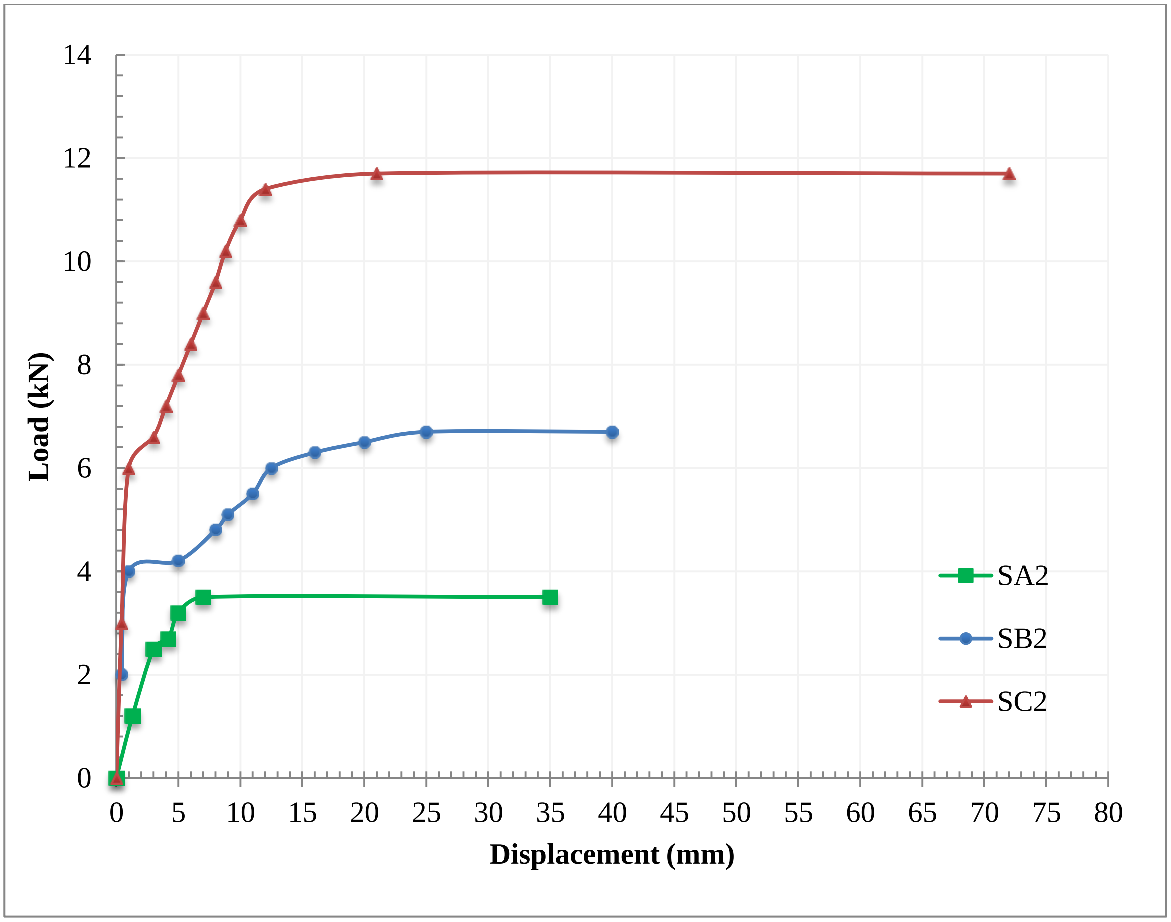
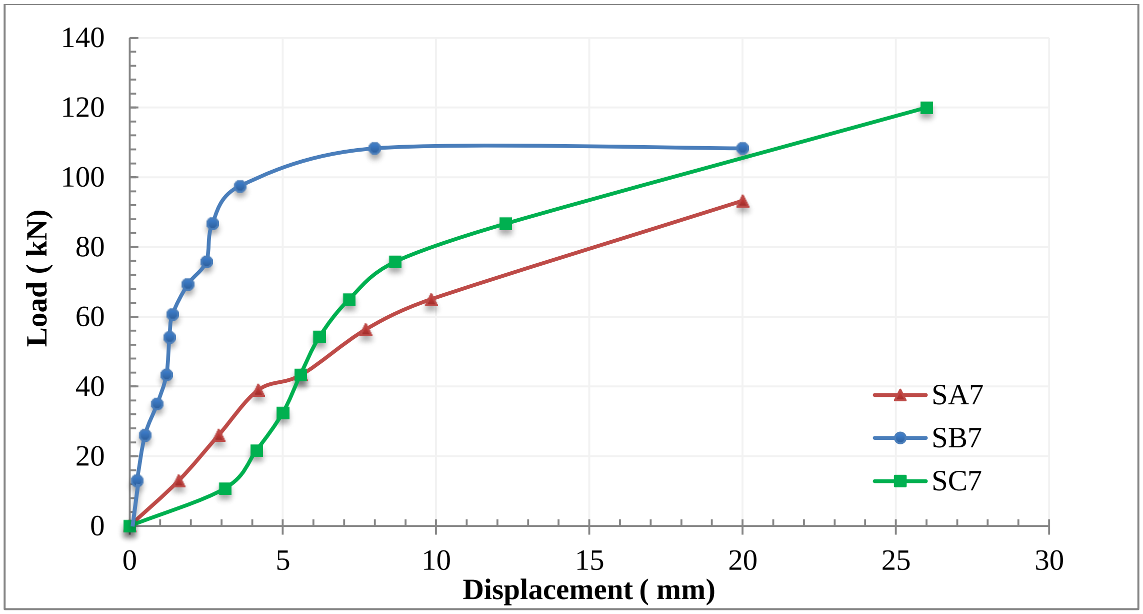
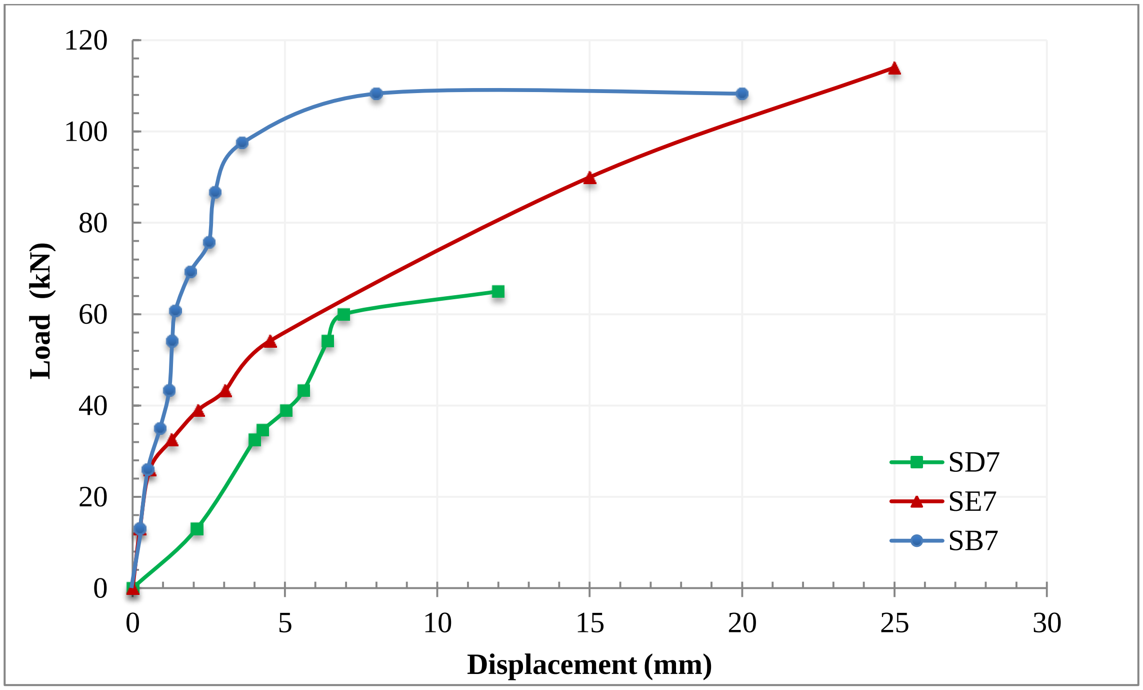


Figure (4.35) Load – lateral deformation comparison of PVC tubes

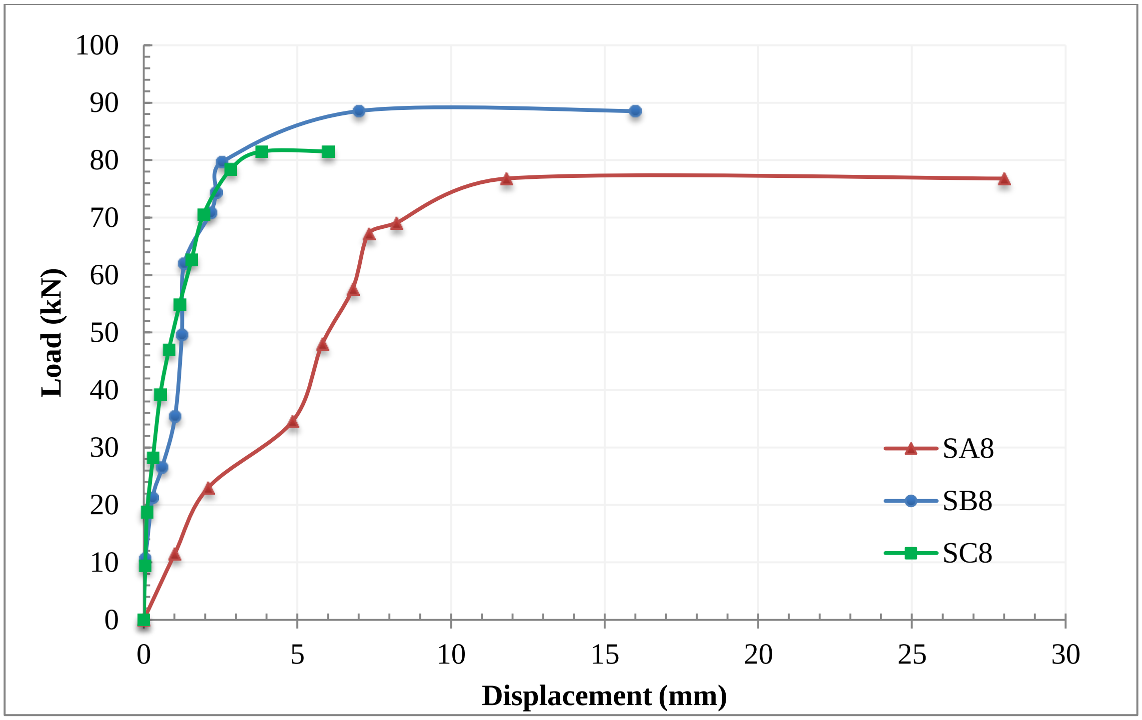


a. Columns SA7, SB7 and SC7

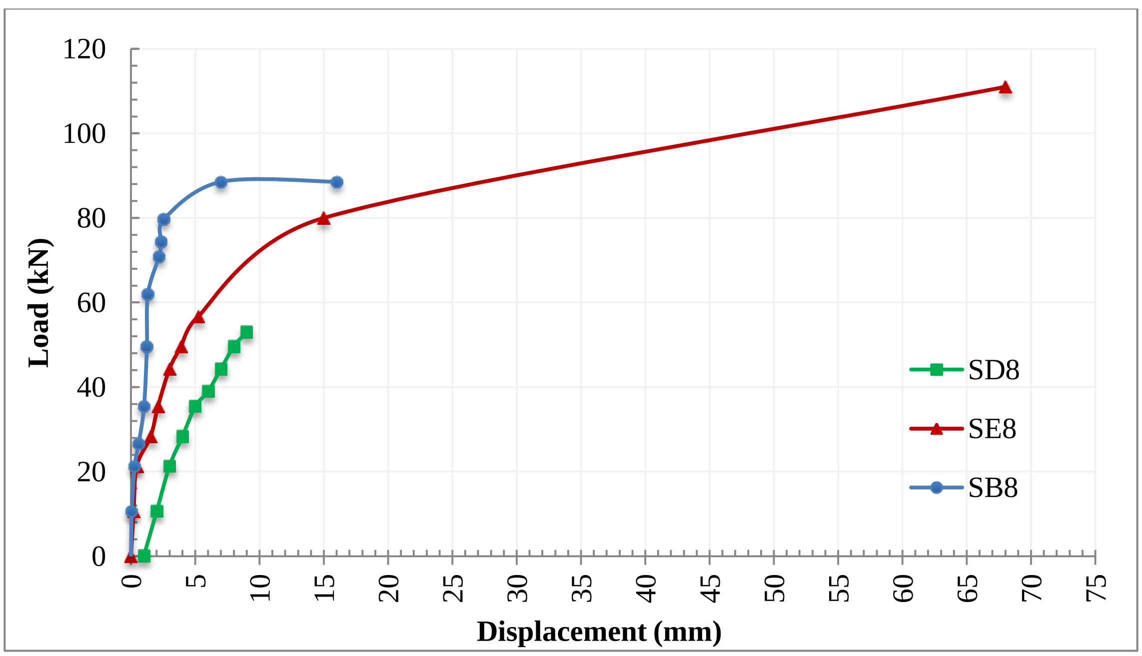


b. Columns SD7, SE7 and SB7

Figure (4.36) Load – lateral deformation of composite specimens of various D/tp



a. Columns SA8, SB8 and SC8



b. Columns SD8, SE8 and SB8

Figure (4.37) Load – lateral deformation of confined specimens of various D/tp

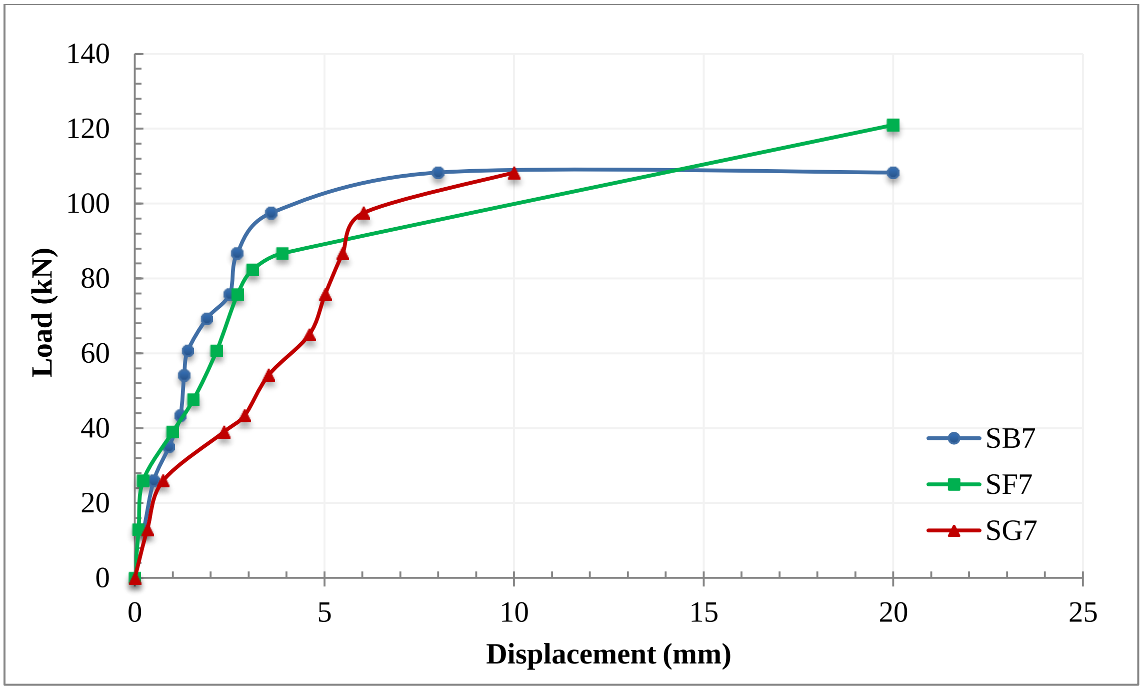


Figure (4.38) Load – lateral deformation of composite specimens various L / r

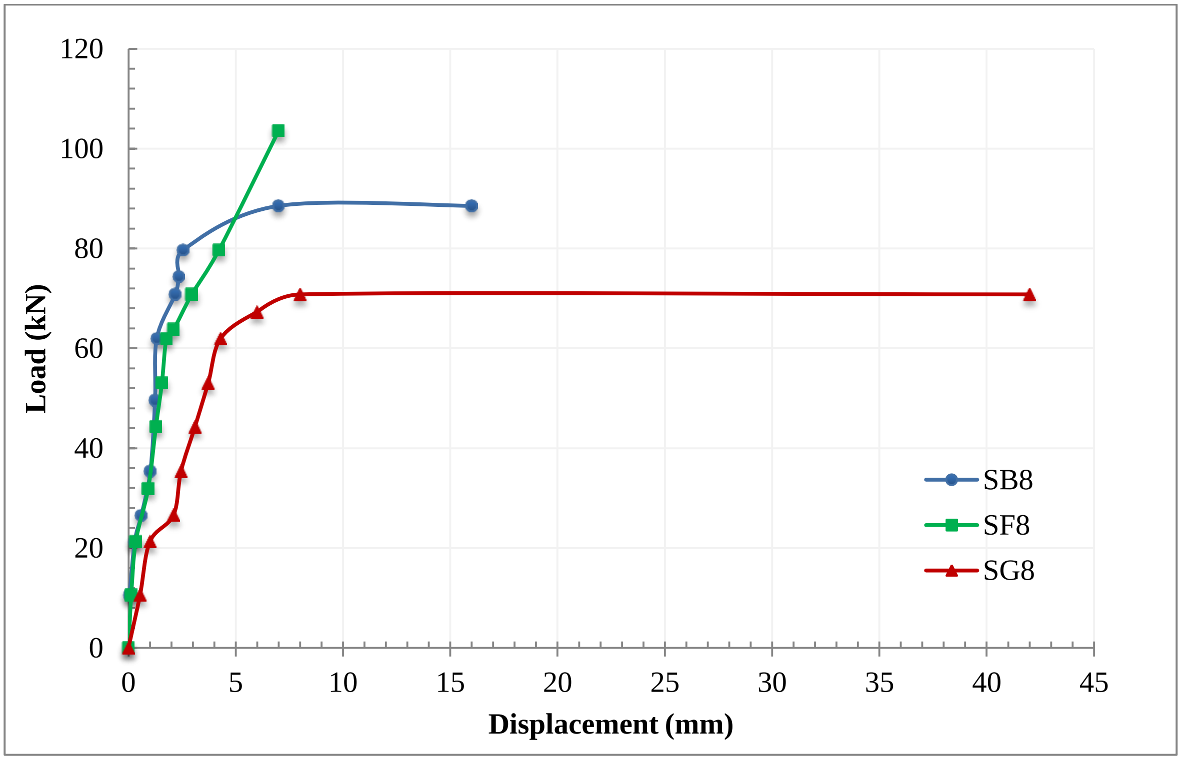


Figure (4.39) Load – lateral deformation of confined specimens various L / r

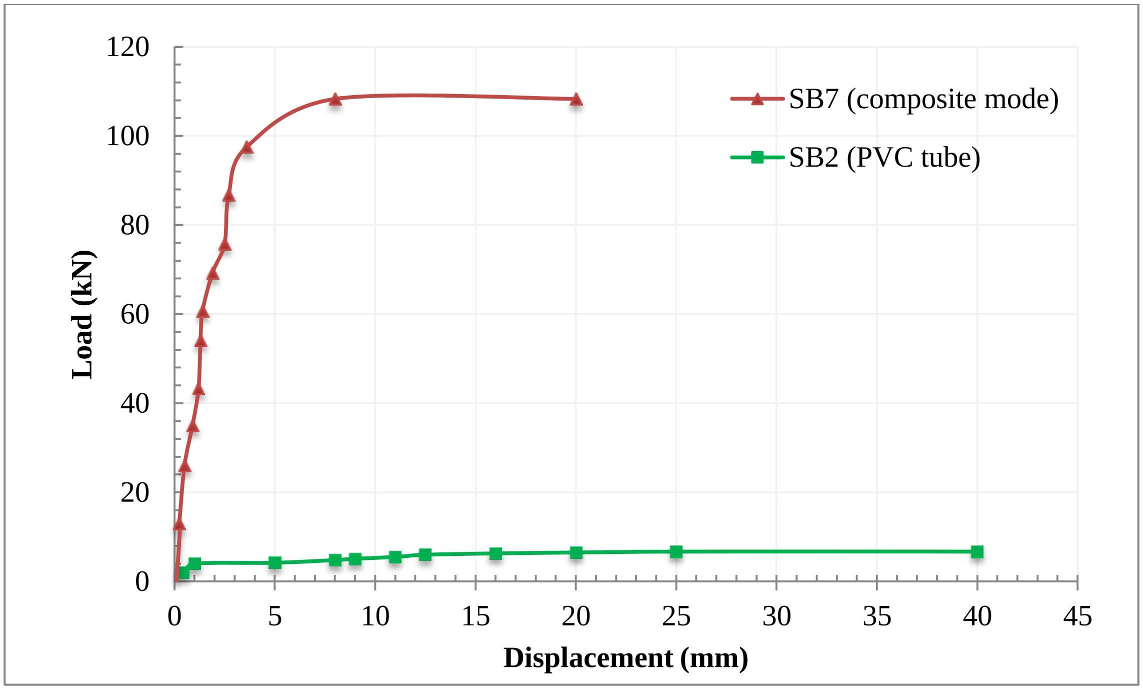


Figure (4.40) Load – lateral deformation of composite and PVC tube

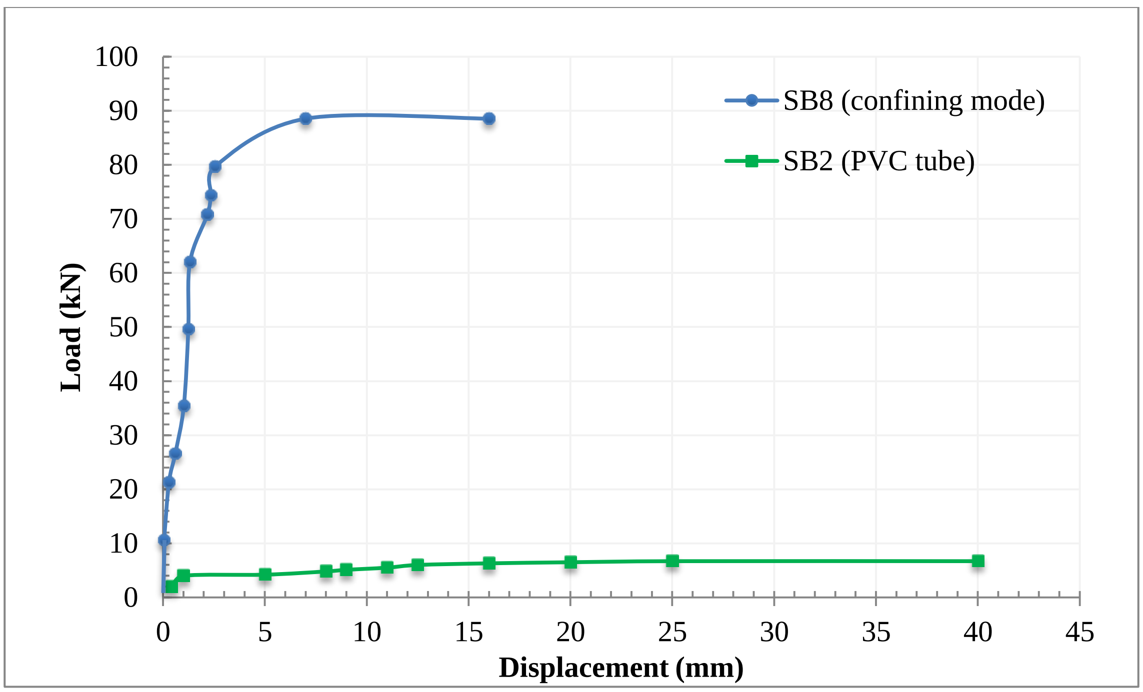


Figure (4.41) Load – lateral deformation comparison of confined column to PVC tube

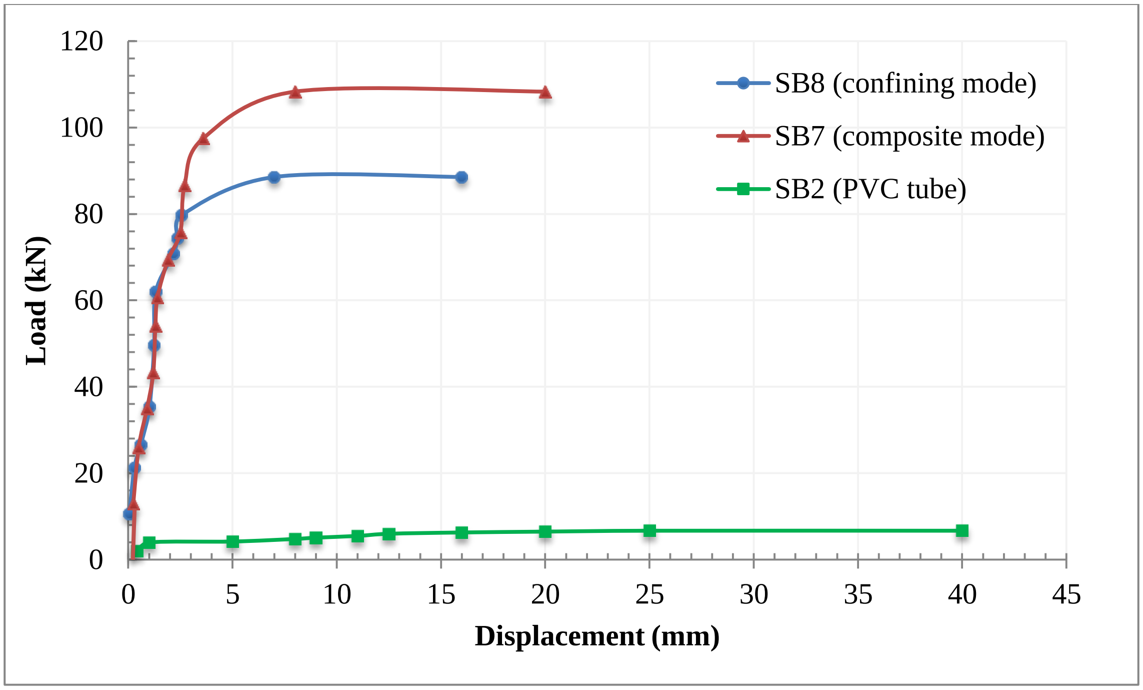


Figure (4.42) Load – lateral deformation comparison of SB8, SB7 and SB2 constant L/r and D/tp

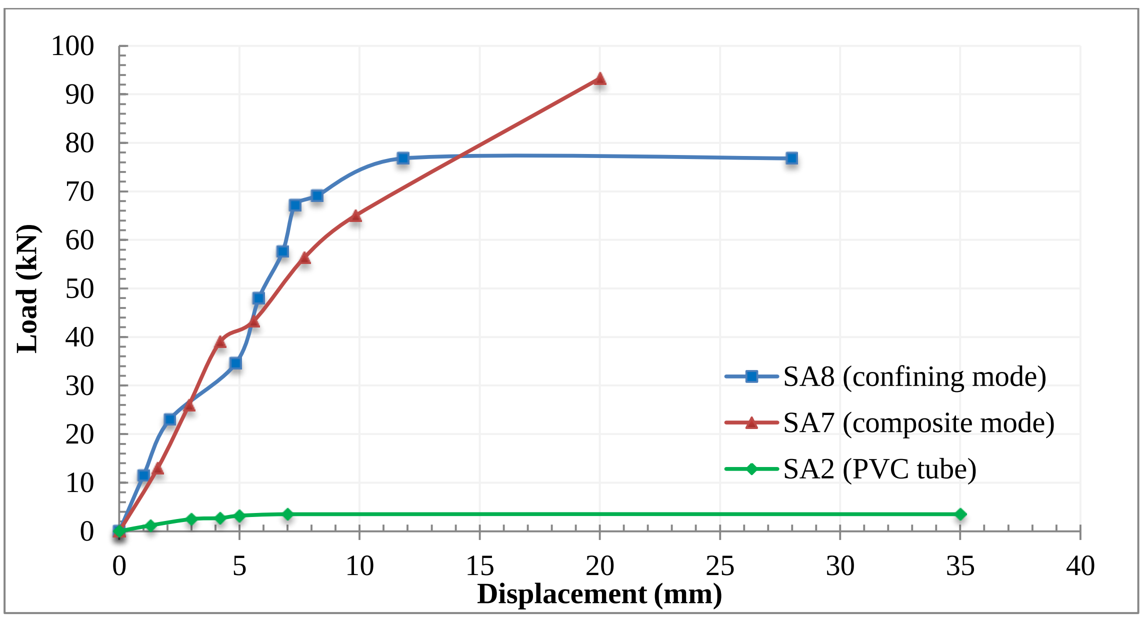


Figure (4.43) Load – lateral deformation comparison of SA8, SA7 and SA2 constant L/r and D/tp

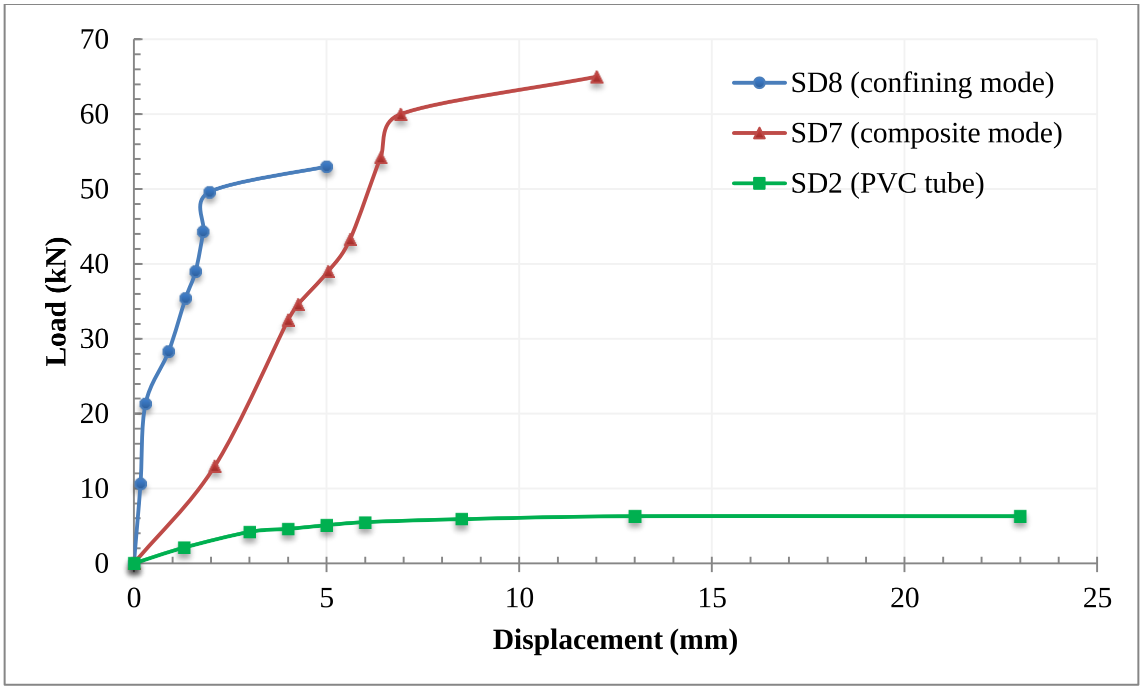


Figure (4.44) Load – lateral deformation comparison of SD8, SD7 and SD2 constant L/r and D/tp

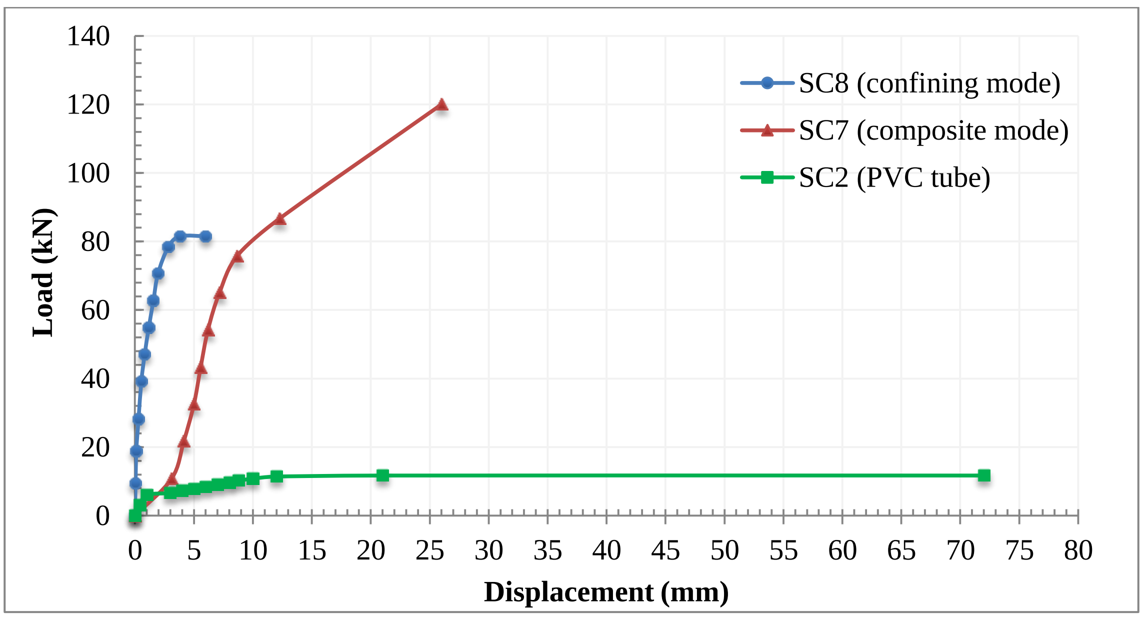


Figure (4.45) Load – lateral deformation comparison of SC8, SC7 and SC2 constant L/r and D/tp

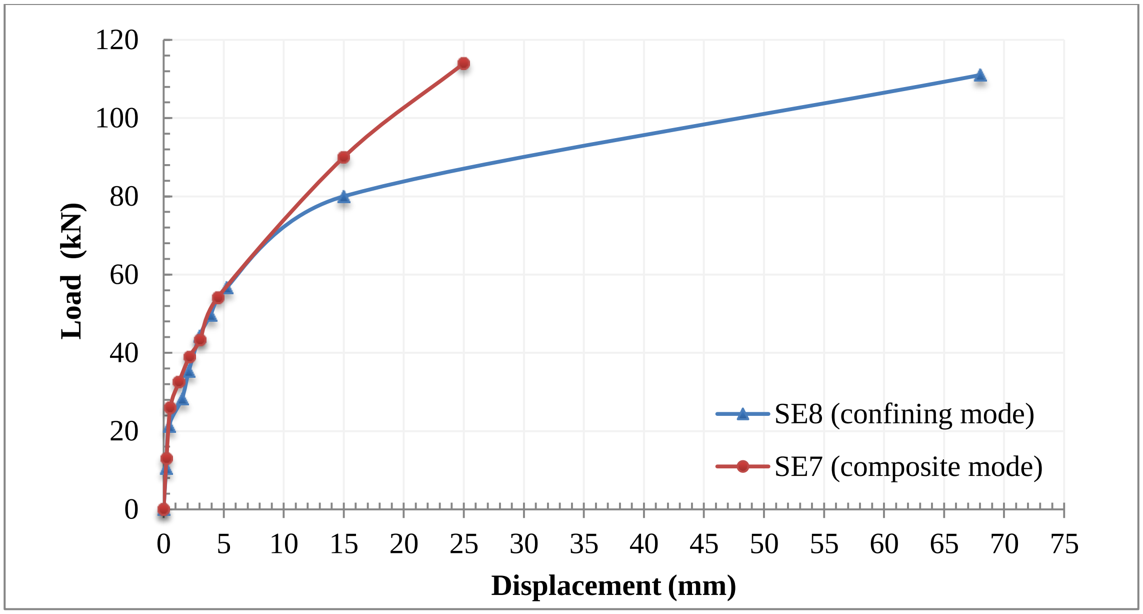


Figure (4.46) Load – lateral deformation comparison of composite and confined columns SE7 and SE8

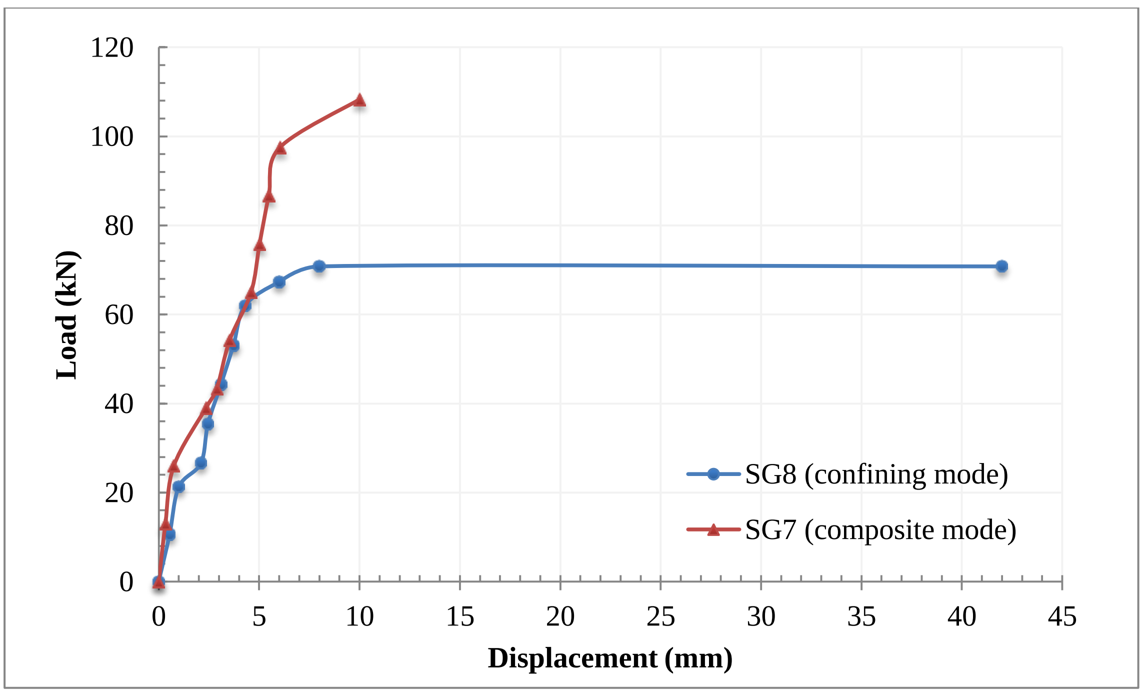


Figure (4.47) Load – lateral deformation comparison of composite and confined columns SG7 and SG8

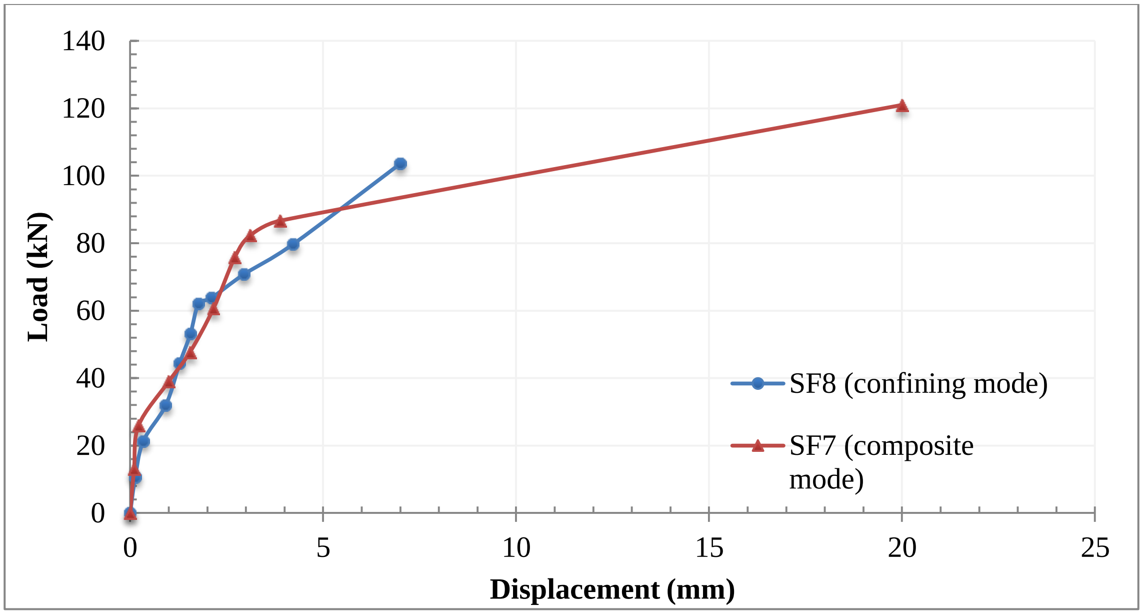


Figure (4.48) Load – lateral deformation comparison of composite and confined columns SF7 and SF8

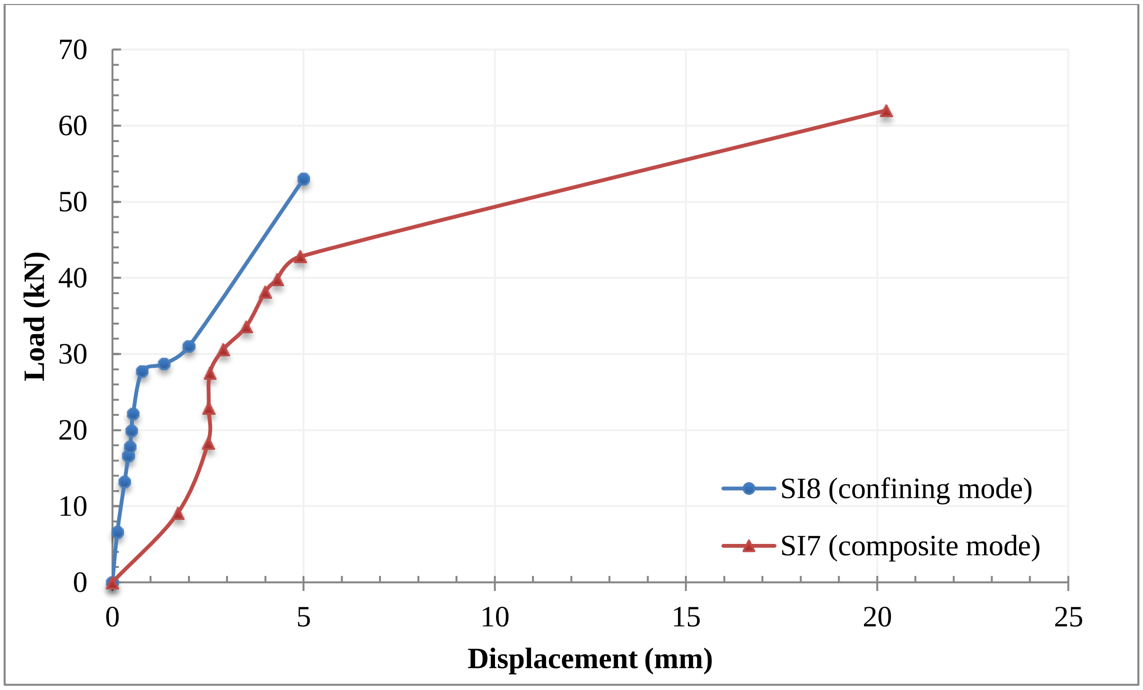


Figure (4.49) Load – lateral deformation comparison of composite and confined columns SI7and SI8

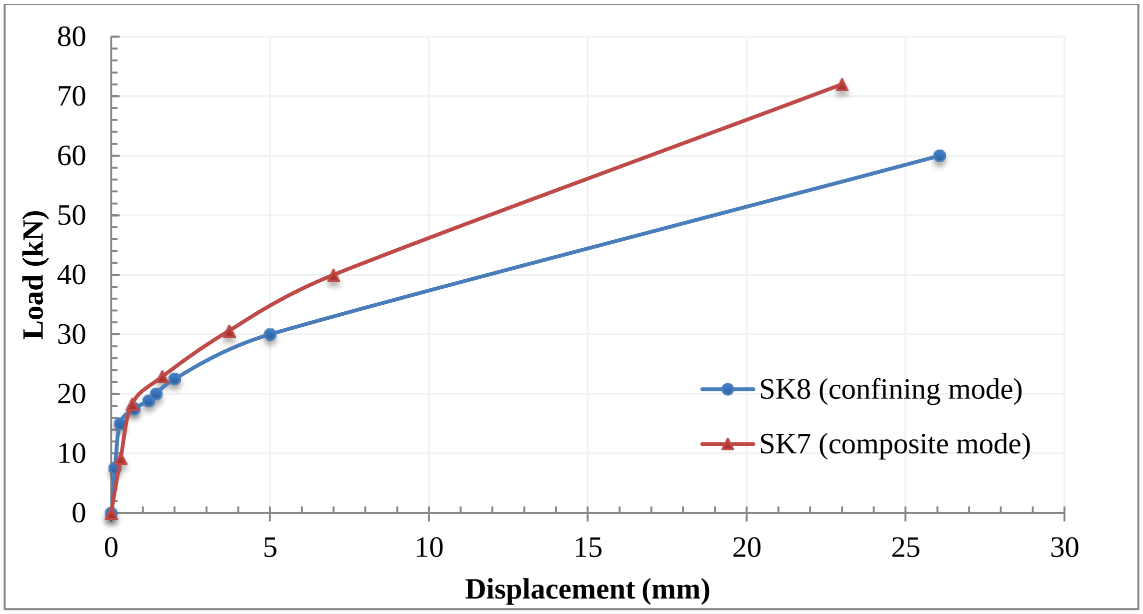


Figure (4.50) Load – lateral deformation comparison of composite and confined columns SK7 and SK8

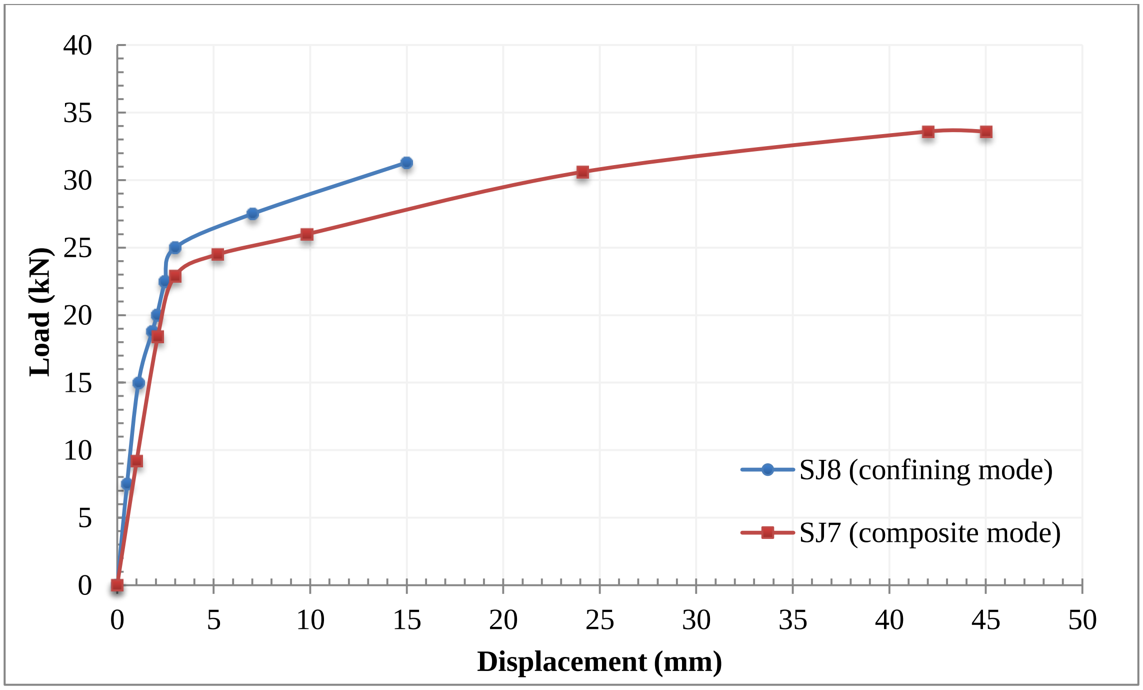


Figure (4.51) Load – lateral deformation comparison of composite and confined columns SJ7and SJ8

4.5.2.3 Stress – Strain Response

The strain is determined using three electrical strain gauges for each column distributed at specimens mid span equally around tube circumference.

Figs. (4.52) to (4.56) exhibited longitudinal stress strain response of composite columns while Figs. (4.57) to (4.60) exhibited transvers stress strain response of confining columns. The contribution of PVC tube as reinforcement is confirmed as strain is distinguished by plastic stage. While for confining columns, the transvers plastic strains slightly developed prior to sudden lateral buckling. for composite mode, strain gauge installed vertically and supposed to axial shortening, thus the results in data logger with negative sign. And for confined mode strain gauge installed horizontally and supposed to extension, thus the results in data logger with positive sign.

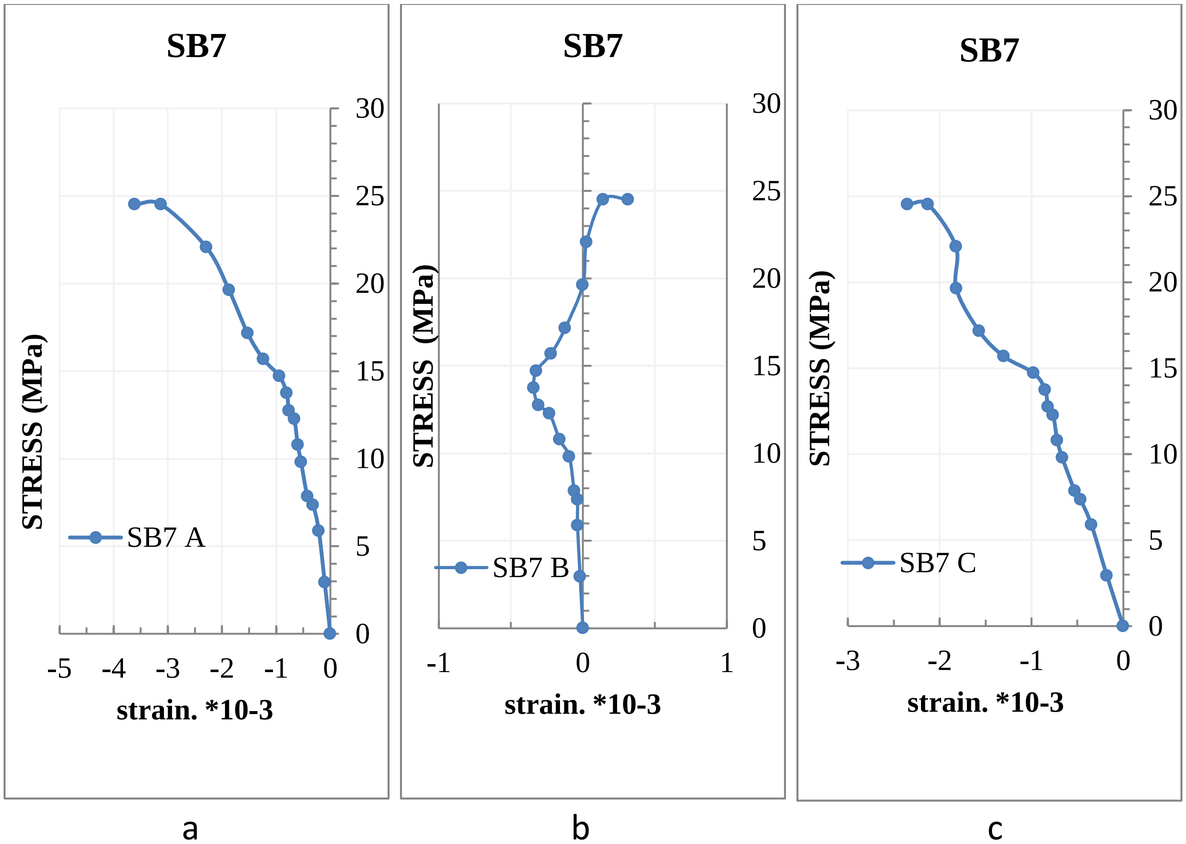


Figure (4.52) Stress – strain behavior of composite column SB7

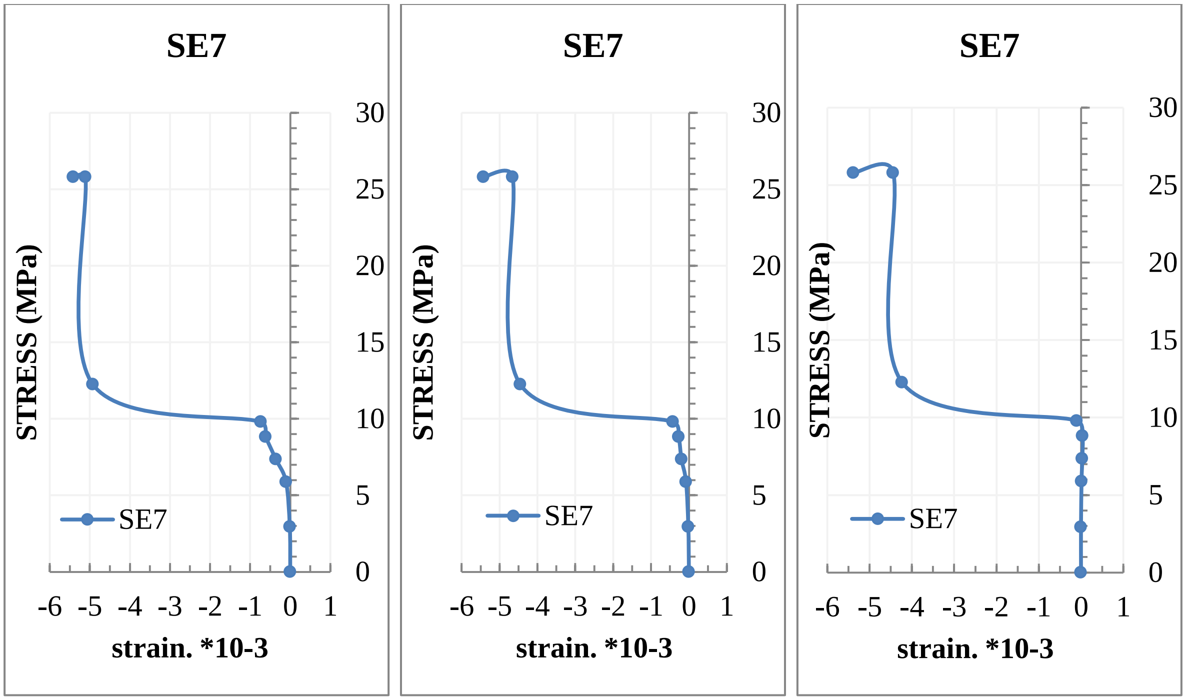


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Figure (4.53) Stress – strain behavior of composite column SE7

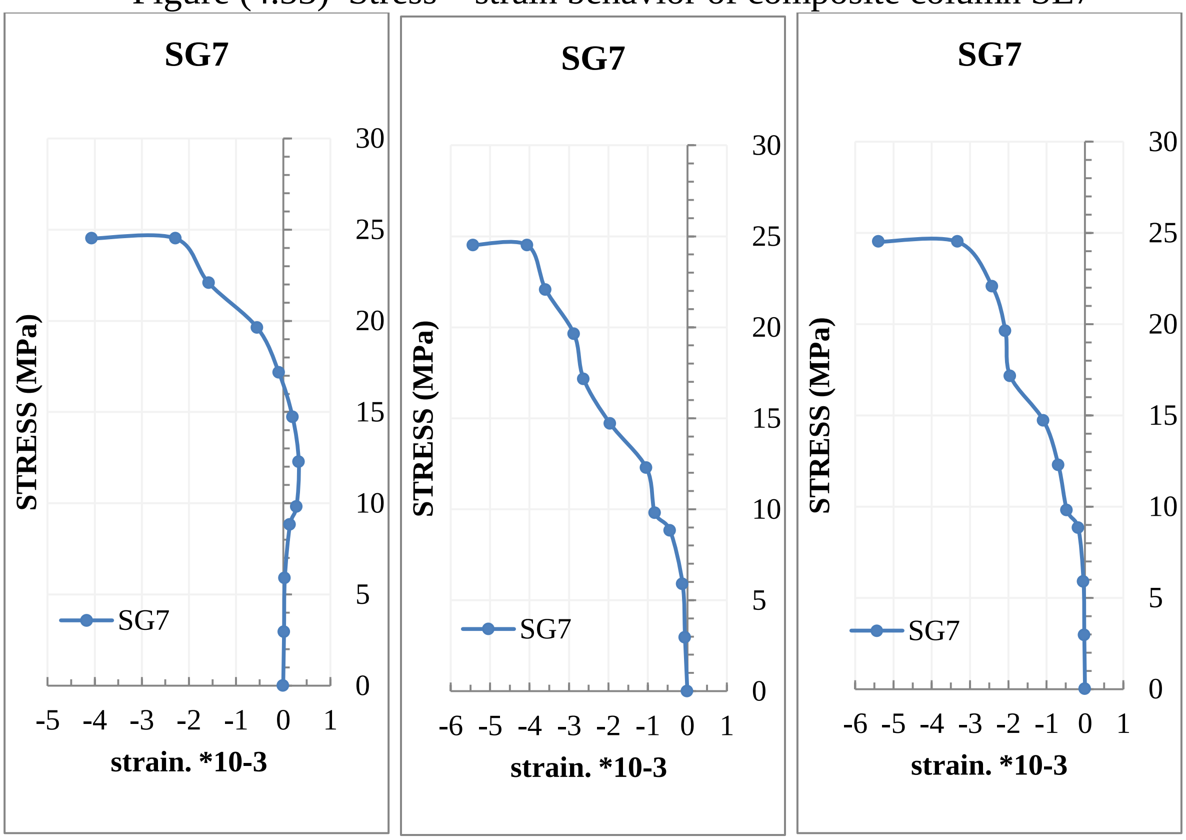

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Figure (4.54) Stress – strain behavior of composite column SG7

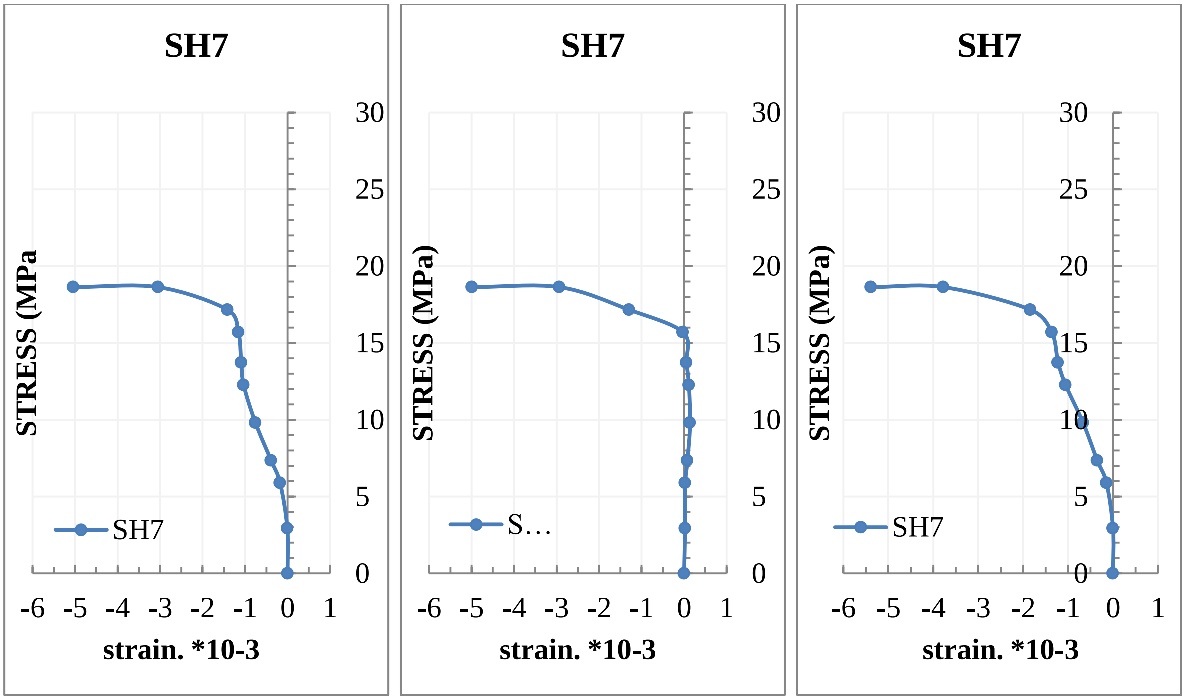

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Figure (4.55) Stress – strain behavior of composite column SH7

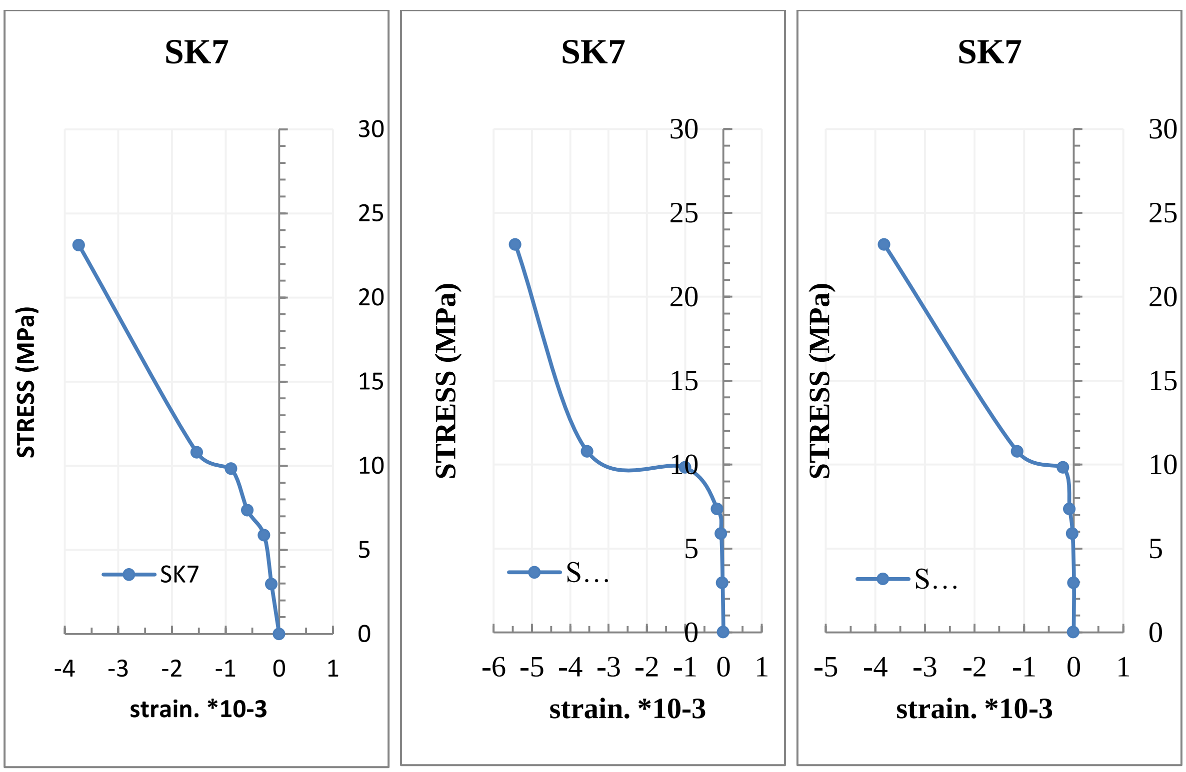

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Figure (4.56) Stress – strain behavior of composite column SK7

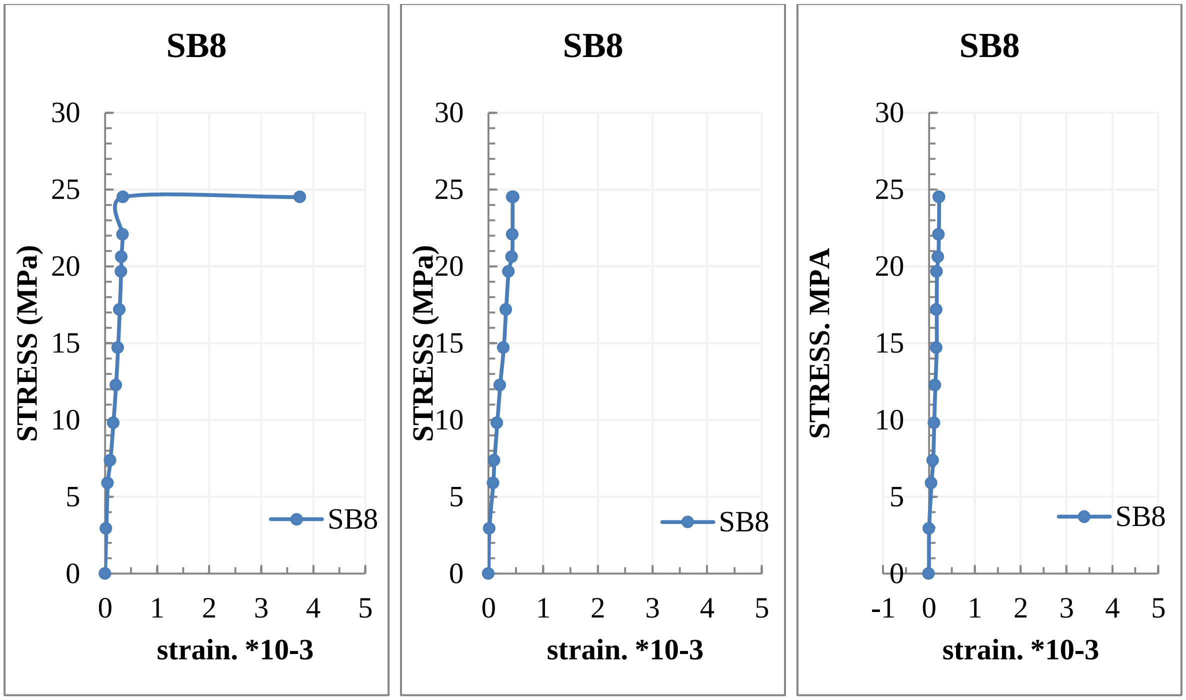

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Figure (4.57) Stress – strain behavior of confined column SB8

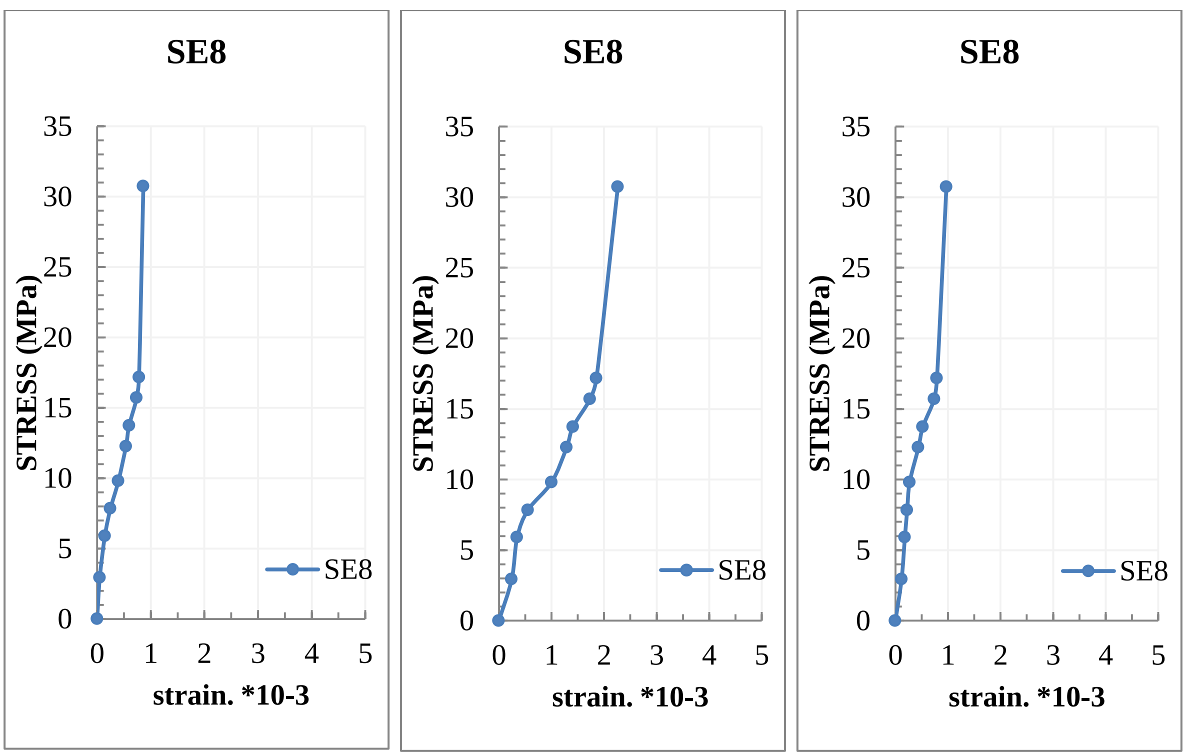

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Figure (4.58) Stress – strain behavior of confined column SE8

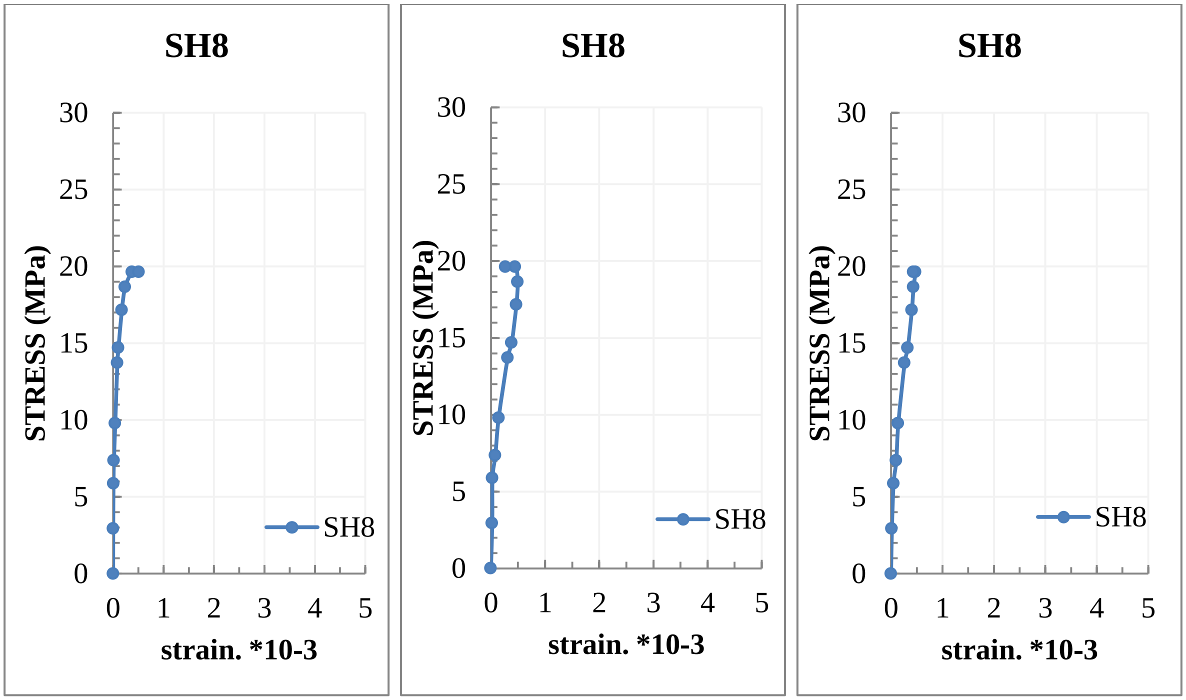

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Figure (4.59) Stress – strain behavior of confined column SH8

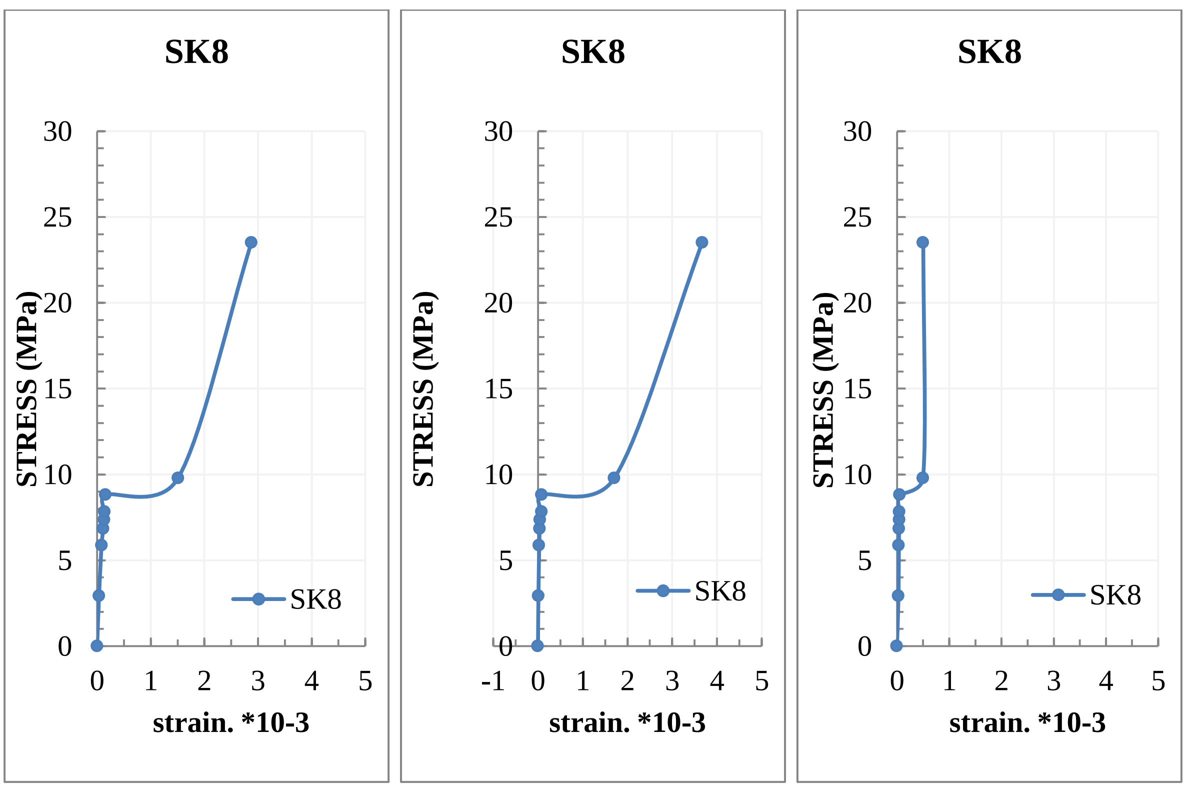

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Figure (4.60) Stress – strain behavior of confined column SK8

4.6 Failure Modes

The short concrete cores, suffers from excessive lateral expansion due to unstable propagation of the internal micro-cracks, which causes the strain softening behavior and eventually the concrete mass loses its integrity and fails in splitting manner. while slender specimens suffers from slightly lateral expansion and exhibited sudden explosion failure without any visible cracks.

Local buckling occurs in short PVC specimens, as compression strength of the material is not attainted, the column compressed longitudinally until section developed an expansion as hoop deformations within length. The deformations frequently were large and more than tube thickness. In the other side, slender PVC tubes suffer from global elastic buckling followed by significant local buckling deformation, led to sudden loading capacity reduction.

For compacted PVC concrete columns, material failure is dominated in all tested specimens, the assigned failure is shear failure where concrete filling typically initiated failing in a classical shear mode. It was observed, when the PVC tube is cut, interface bonding didn't develop between concrete cores and PVC tube and the confinement exerted by the PVC tube could not fully turn off customary shear failure.

For slender PVC concrete columns, stability failure is dominated in all tested specimens where they are suffered from global elastic buckling followed by significant concrete failure and local buckling deformation, led to sudden loading capacity reduction with highly lateral deformation.

Plates (4.1) to (4.11) depicts assigned typical failure modes of various specimens.

Plate (4.1) Typical failure modes of concrete short specimens SA3 and SB3


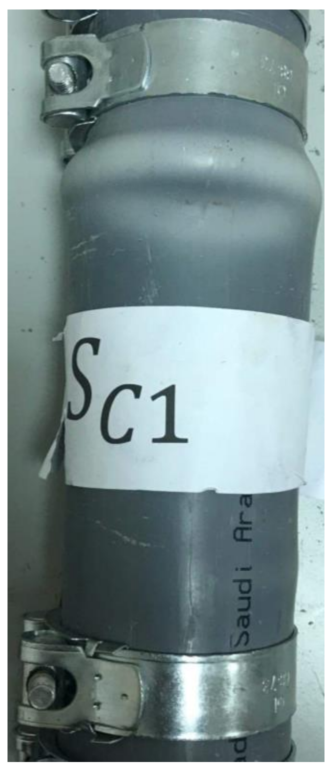

Plate (4.2) Typical failure modes of short plastic specimens SE1 and SC1

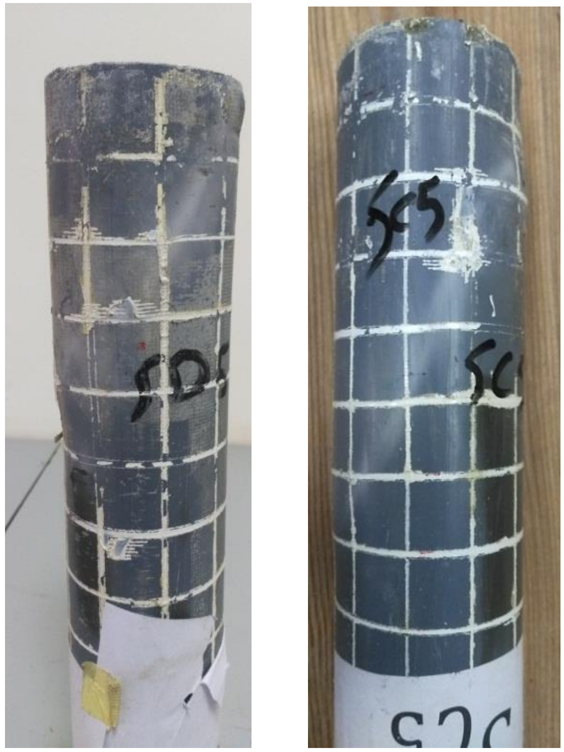

Plate (4.3) Typical failure modes of short composite specimens SD5 and SC5

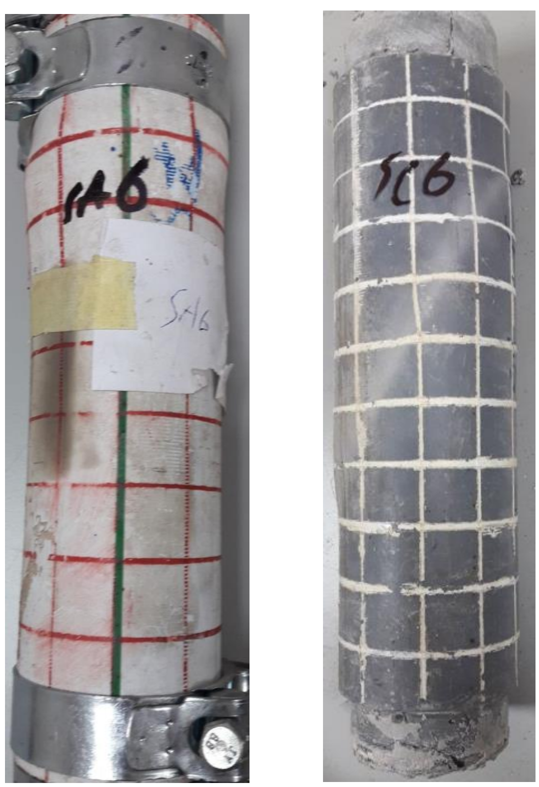

Plate (4.4) Typical failure modes of short confined specimens SA6 and SC6

Plate (4.5) Failure mode of slender concrete column SA4

Plate (4.6) Typical failure mode of slender column SC7

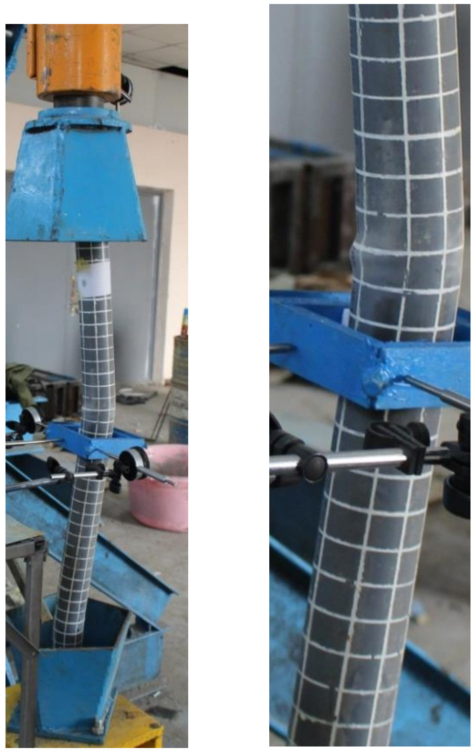

Plate (4.7) Typical failure modes of slender column SE7

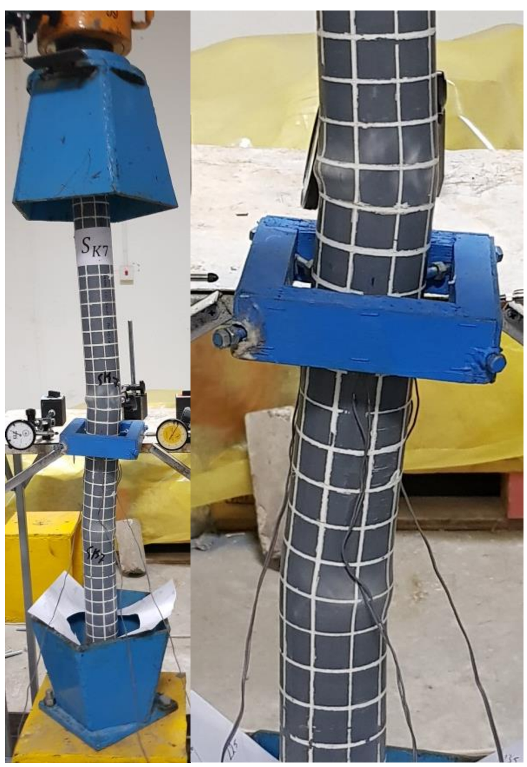

Plate (4.8) Typical failure modes of slender column SK7

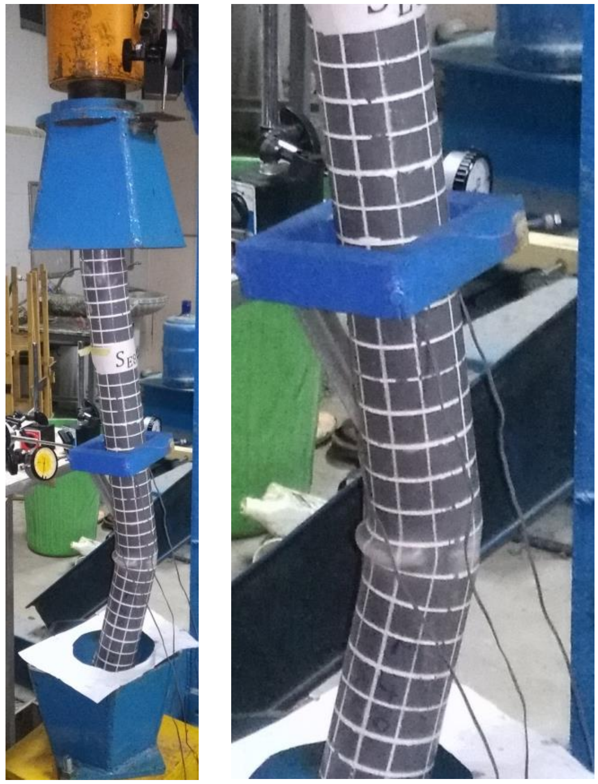

Plate (4.9) Failure modes of slender column SE8

Plate (4.10) Typical failure modes of slender column SK8

4.7 Effective Flexural Stiffness, EI_e

Inelastic flexural buckling is the significant failure mode as confirmed by indicated strains as shown in Figs. (4.52) to (4.60) which is depicted that determined strains are within elastic range.

Euler buckling mode occurred in tested slender columns and distinguished by a sudden lateral deflection followed by deformation of the cross-section where filling concrete undergoes shear failure.

The Euler buckling equation;

$$P_e = \frac{\pi^2 EI_e}{(kl)^2} \quad \text{...(4.1)}$$

Thus,

$$EI_e = \frac{P_e\,(kl)^2}{\pi^2} \quad \text{...(4.2)}$$

where;

P_e = Euler critical load

EI_e = Effectiveness stiffness

L = unsupported length of column

K = column effective length factor

Which is accurately predicts critical elastic buckling load for columns of slender section in terms of slenderness ratio and flexural stiffness *(EI)*. Therefore, the Euler buckling load can be used as failure criteria for a slender column. Effectiveness stiffness (EI_e) of PVC-concrete composite slender columns of different modes is assigned according to ACI 318-14[40] using Euler formula where elastic buckling is attainted for all tested slender specimens. Tables (4.5) and (4.6) illustrates the results of EI effective for confined and composite modes.

As mention, interface bonding not developed between concrete cores and PVC tube and the confinement exerted by the PVC tube not fully turn off customary shear failure so the reduction of buckling load due to shear deformation must be considered in designing purposes.

Table (4.5) Results of effective stiffness of composite columns

No	Specimens	L/r	fc'	fyp/fc'	D	Ap	Ac	Ap/Ac	P (KN)	EI eff x106, N.mm2
1	SA7	58.67	42.3	1.006	75	503	3913	0.12853	93.27	11.45
2	SB7	58.67	42.3	1.006	75	807	3609	0.223667	108.30	13.29
3	SC7	58.67	42.3	1.006	75	1220	3195	0.381914	120.00	14.73
4	SD7	58.67	34.7	0.826	75	807	3609	0.223667	65.01	7.98
5	SE7	58.67	58.8	1.400	75	807	3609	0.223667	114.00	13.99
6	SF7	50.67	42.3	1.006	75	807	3609	0.223667	121.00	11.08
7	SG7	66.67	42.3	1.006	75	807	3609	0.223667	108.30	17.16
8	SH7	69.84	42.3	1.006	63	565	2550	0.221607	58.10	7.13
9	SI7	69.84	42.3	1.006	63	860	2255	0.381502	62.00	7.61
10	SJ7	69.84	34.7	0.826	63	565	2550	0.221607	33.64	4.13
11	SK7	69.84	58.8	1.400	63	565	2550	0.221607	72.00	8.84

Table (4.6) Results of effective stiffness of confined columns.

No	Specimens	L/r	fc'	fyp/fc'	D	Ap	Ac	Ap/Ac	P (KN)	EI eff x106, N.mm2
21	SA8	58.67	42.3	1.006	75	503	3913	0.12853	76.80	9.43
22	SB8	58.67	42.3	1.006	75	807	3609	0.223667	88.50	10.86
23	SC8	58.67	42.3	1.006	75	1220	3195	0.381914	101.50	12.46
24	SD8	58.67	34.7	0.826	75	807	3609	0.223667	53.13	6.52
25	SE8	58.67	58.8	1.400	75	807	3609	0.223667	92.98	11.41

Continuous to table (4.6) Results of effective stiffness of confined columns.

No	Specimens	L/r	fc'	fyp/fc'	D	Ap	Ac	Ap/Ac	P (KN)	EI eff x106, N.mm2
26	SF8	50.67	42.3	1.006	75	807	3609	0.223667	103.61	9.48
27	SG8	66.67	42.3	1.006	75	807	3609	0.223667	70.80	11.22
28	SH8	69.84	42.3	1.006	63	565	2550	0.221607	50.07	6.14
29	SI8	69.84	42.3	1.006	63	860	2255	0.381502	53.20	6.53
30	SJ8	69.84	34.7	0.826	63	565	2550	0.221607	33.79	4.15
31	SK8	69.84	58.8	1.400	63	565	2550	0.221607	60.05	7.37

Using experimental results, determined effective stiffness of is normalized in term of filling concrete stiffness and PVC tube stiffness as indicated in equation

$EI_{eff} = (\gamma 1 EcIg + \gamma 2 EpIp)$ ……………………………………………....... (4.3)

Where γ1, γ2 constant would be depending on considered mode (confining or composite), PVC and filling concrete strength as well as column slender ratio as shown in Figures (4.61) and (4.62) were Ec and Ep are modulus of elasticity for concrete and plastic respectively. While Ig and Ip are moment of inertia of concrete and plastic, respectively.

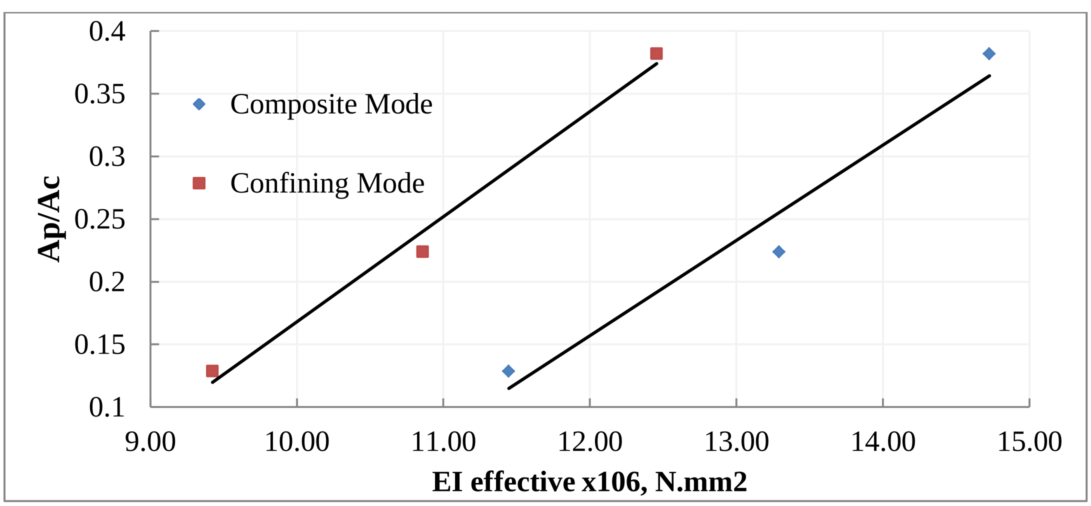

Figure (4.61) effective stiffness normalization L/r =58.67

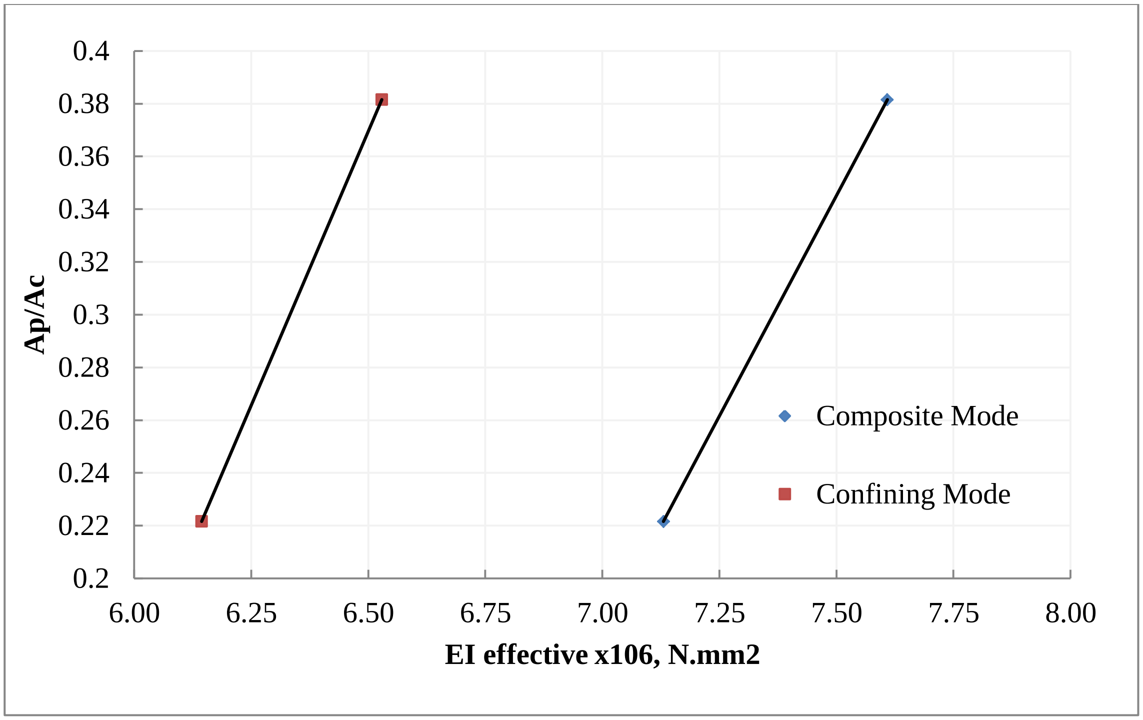

Figure (4.62) Effective stiffness normalization, L/r = 69.84.

4.8 Enhanced Compressive Strength, f'_{ce}

Filling concrete compressive strength affected by casing, Table (4.7) exhibits the efficiency of PVC as casing confining materials which it is strongly contributed to enhance concrete compressive strengths. The assigned improving compressive strength decreased as slenderness ratio increased. The increase in strength capacity due to confinement mechanism depends on the tube's D/t ratio, thicker tubes introduce a high increase. Table (4.7) clearly shows that the confinement mechanism of confining mode columns introduces a confinement effectiveness ranged from 1.55 to 2.17 versus a confinement effectiveness ranged from 1.26 to 1.81 for composite mode columns. Figure (4.63) depicts the enhancement in compressive strength of composite and confining mode columns. Enhanced confined concrete strength (f'_{ce}) is experimentally predicated as;

For composite mechanism,

As;

$p_{cm}=f_{ce}A_c+f_{yp}A_p$ ……………………………………………………….…………(4.4)

So; $f'_{ce} = (P_{cm}-f_{yp}\, A_p)/A_c$ ………………………………………………….…(4.5)

For confining mechanism,

$f'_{ce} = P_{cn}/A_c$ ……………………………………….…………………………..…(4.6)

Table (4.7) Results of confinement effectiveness

No	Specimen code	λ= *L/r*	Ultimate strength, kN	Unconfined concrete compressive strength, *f'c* MPa	Experimental enhanced concrete compressive strength, *f'ce* MPa	Confinement effectiveness *f'ce/f'c*
Concrete columns						
1	SA3	16.99	125.18	32		
2	SB3	17.69	118.90	32.95		
3	SC3	18.80	115.50	36.15		
4	SD3	21.05	89.20	34.98		
5	SE3	22.38	70.00	31		
PVC-Concrete Columns, (Composite mode)						
6	SA5	16.00	208.70		47.29	1.48
7	SB5	16.00	253.20		59.64	1.81
8	SC5	16.00	259.90		63.36	1.75
9	SD5	19.04	139.00		44.07	1.26
10	SE6	19.04	153.60		50.15	1.62
PVC-Concrete Columns, (Confining mode)						
11	SA6	16.00	197.00		50.35	1.57
12	SB6	16.00	232.30		64.38	1.95
13	SC6	16.00	238.70		74.70	2.07
14	SD6	19.04	138.40		54.26	1.55
15	SE6	19.04	151.50		67.18	2.17

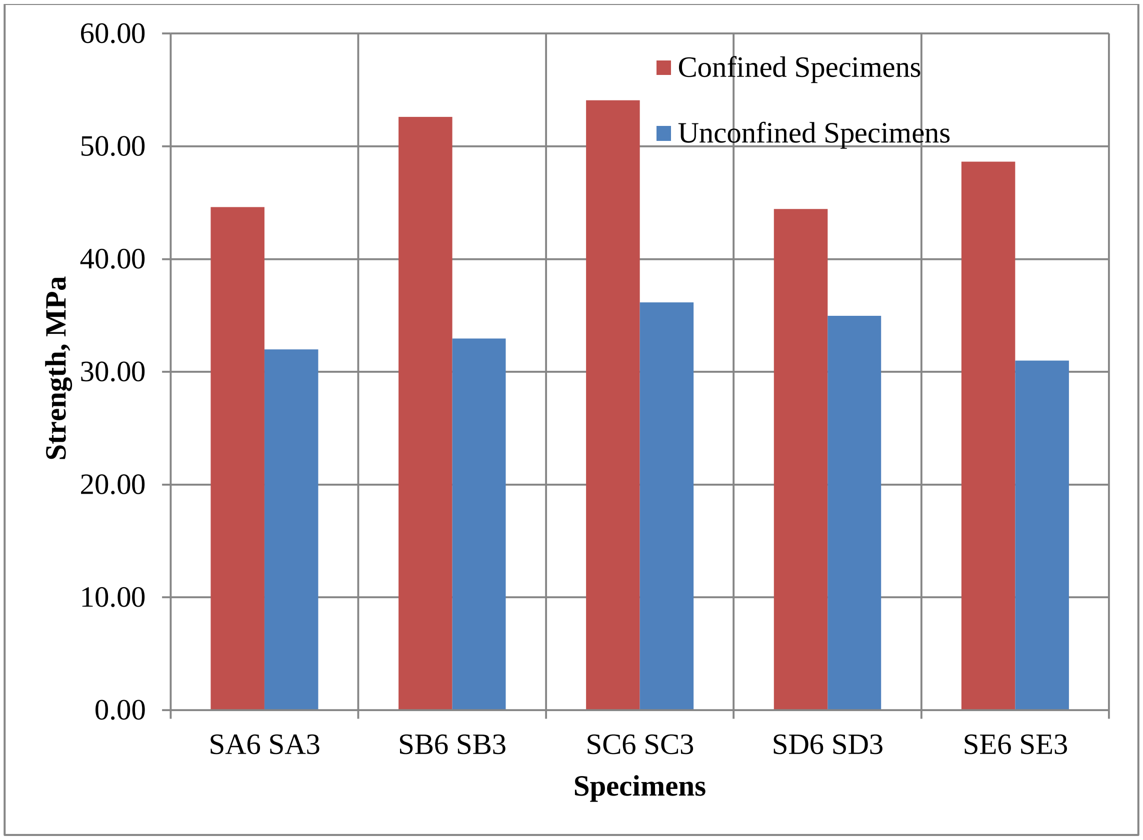

Figure (4.63) Confined and unconfined compressive strength

4. 9 Confinement Normalization

Figure (4.64) shows the normalized confinement effectiveness, the trend of confining approach highlights best enhancing in comparing with composite approach, this difference explains ductility improving of confining mode, while strength improving of composite mode columns are mainly related to the presence of PVC tube as an external reinforcement attribute with concrete to resist applied loading. The results are normalized in terms of radial stress (f_r) and concrete compressive strength (f'_c). The enhanced confined concrete strength (f'_{ce}) could be determined as:

$$f'_{ce}=\alpha 1\, f'_c+ \alpha 2\, f_r \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.7)$$

Referring to Figure (4.56) ;

$\alpha 1=0.905$, $\alpha 2= 10.35$ For confining mechanism

$\alpha 1=0.94$, $\alpha 2= 8.02$ For composite mechanism;

where f_r is determined according to Barlow's[41] formula;

$f_r=2\ f_{yp}\ t_p / D$ …………………………………. …………………………..….(4.8)

So, plastic capacity of compact PVC- concrete columns could be predicted as;

For composite mechanism

$q_{cm} = f'_{ce}\, Ac + f_{yp}\, A_p$ ……………………….…………….………………….(4.9)

For confined mechanism

$q_{cn} = f'_{ce}\, A_c$ ………………………………………...…………………(4.10)

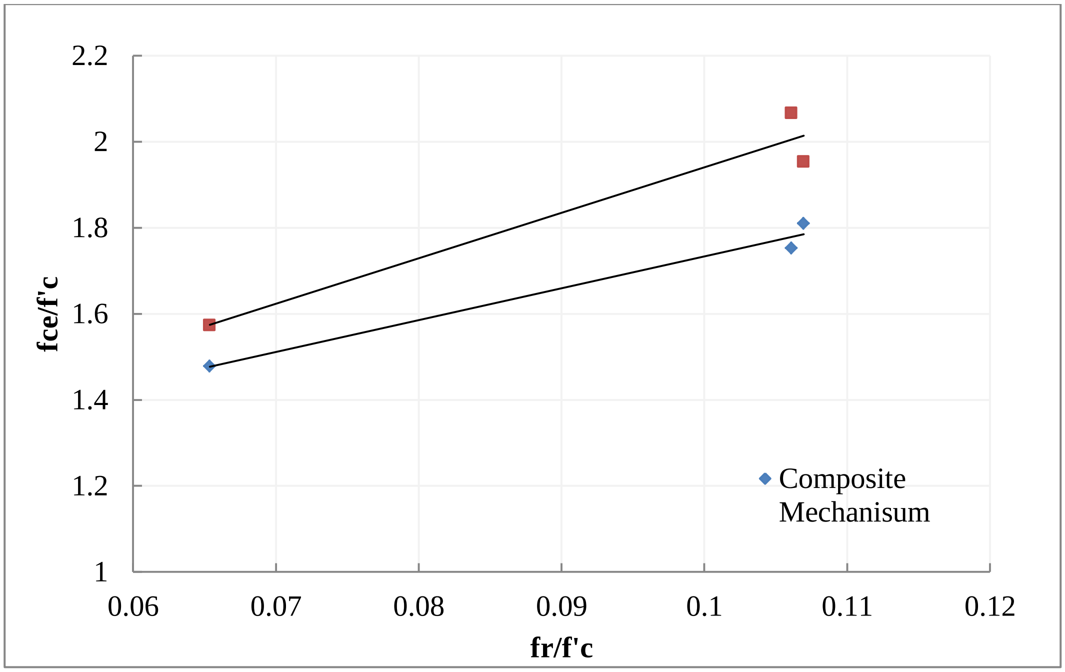

Figure (4.64) Normalized confined concrete strength for different sections of L/r =16

CHAPTER FIVE

Conclusion

and

Recommendations

CHAPTER FIVE

Conclusion and Recommendations

5.1 introduction

This study investigate the behavior of slender Plastic-concrete composite columns under axial compression loading conditions consisting of PVC tubes filled with concrete. Two modes of loading, composite and confining mode, with different PVC tube thickness, slenderness ratios, diameter of PVC tubes and concrete compressive strengths are used to assess the effect of these variables on the strength and ductility of column. The following conclusions are assigned while some recommendations related to this field are indicated.

5.2 Conclusion

5.2.1 Long Column

1. Sustained loading resistance of PVC composite with concrete exhibited more strength improving (in respect to their constitutes) than these of PVC confined concrete where upgrading rates varied from 2.42 to1.645 for composite mode verse varying from 2.047 to 1.345 for confining mode. The same comparison is observed for ductility where specimens of PVC composite concrete exhibited more axial and lateral deformations than corresponding samples of confined mode.
2. The variation of loading mode effect on load-deformation response is significantly indicated as strength upgrading for composite mode relate to attaint of PVC as reinforcement while assigned enhancing in confining mode relates to confining efficiency to upgrading filling concrete strength.

3. Strength, stiffness and ductility of introduced PVC-concrete columns of various loading mode significantly affected by column slenderness ratio (L/r), PVC section compactness as well as filling concrete strength.
4. Stability failure is dominated in all tested slender PVC concrete columns, where they are suffered from global elastic buckling followed by significant concrete failure and local buckling deformation, led to sudden loading capacity reduction with assigned sustainable lateral deformation.
5. Interface bonding not developed between concrete cores and PVC tube and the confinement exerted by the PVC tube not fully turn off customary shear failure so the reduction of buckling load due to shear deformation must be considered in designing purpose.
6. Effectiveness flexural stiffness (EI_e) of PVC-concrete slender columns of different modes could be assigned according to ACI 318-14[38] using Euler formula where elastic buckling is attainted for all tested slender specimens.
7. Determined effective flexural stiffness normalized in term of filling concrete stiffness and PVC tube stiffness, the normalization results indicate that effective flexural stiffness depends on considered mode (confining or composite), PVC and filling concrete strength as well as column slender ratio.

5.2.2 Short Columns

1- The test results confirmed that the PVC-concrete columns of composite mode exhibited more strength improving than those of confining mode.
2- The upgrading rate in sustained loading resistance of composite mode columns varied from 2.25 to 1.56, while it was 2.07 to 1.55 for confining mode columns.

3- The same comparison is entirely reversed in scope of ductility, where confining mode columns exhibited more axial and lateral deformations than the corresponding composite mode column.

4- For composite columns, PVC tube thickness leads to greater increase in ultimate strength of the PVC-concrete columns. This could be attributed to the effect of PVC tube as an external reinforcement with respect to the overall section area. For confining columns, the PVC tube causes the development of a pure triaxial stress field within confined concrete, constraining it during dilation and thereby increasing plastic deformation.

5- Load-axial deformation responses' comparisons clearly verified the positive enhancement of composite mechanism in scope of strength and stiffness upgrading, as much as verified the positive enhancement of confining mechanism in scope of ductility and energy absorption upgrading.

6- For considered PVC concrete columns, material failure is dominated in all tested specimens, the assigned failure is shear failure where concrete filling typically initiated failing in a classical shear mode.

7- The results are normalized in term of radial stress (f_r)and concrete compressive strength(f'_c), determined enhanced confined concrete strength (f'_{ce}) could be used to predicate plastic capacity of columns of different mechanism.

5.3 Recommendations

The following is a list of problems on which further studies could be recommended:

1- It is recommended that future researchers work on finding ways for enhance bonding between PVC and concrete.
2- Experimental and theoretical studies for investigating the behavior of plastic-concrete composite column with light weight concrete as a replacement to normal concrete to infill PVC tube.
3- Investigate the behavior of plastic-concrete composite column with steel reinforcement is required.
4- It is recommended that future researchers to investigate the behavior of plastic concrete columns under eccentric loading condition.
5- It is recommended to venture into modeling to provide design guide for this type of column.

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الخلاصة

في هذه الدراسة ، تم فحص أداء الأعمدة النحيفة المركبة من البلاستك والخرسانة باستخدام متغيرات مختلفة مثل قوة ضغط الخرسانة ، ونسبة نحافة العمود ، ونسبة نحافة مقطع الانبوب البلاستيكي. تعرضت النماذج لضغط محوري في وضعي تحميل ، في الوضع الأول ، تم استخدام الأنبوب البلاستيكي لتعزيز النواة الخرسانية كمقطع مركب ، وفي الوضع الثاني ، تم استخدام الأنبوب البلاستيكي كمقيد للنواة الخرسانية فقط. معدل الترقية في مقاومة التحميل المستمر لأعمدة الوضع المركب تختلف من(2.25 الى 1.56) ، بينما كانت (2.07 إلى 1.55) لأعمدة الوضع المقيد. اما في نطاق تحمل التشوهات اللدنة فان المقارنة تنعكس، حيث تعرضت الأعمدة المقيدة الى تشوهات محورية وجانبية أكثر من أعمدة الوضع المركب. كانت أطوال الأعمدة متنوعة بحيث تم فحص الانبعاج للأعمدة. أظهرت النتائج أن الأعمدة ذات الوضع المركب تظهر تحسين للقوة والتشوهات أكثر من تلك الموجودة في الوضع المقيد ، تجريبياً تم حساب جسائة الانحناء الفعالة المتوقعة ثم تم تطبيعها بدلالة جسائة الخرسانة المالئة و جسائة الأنبوب البلاستيكي ، تشير نتائج التطبيع إلى أن جسائة الانحناء الفعالة تعتمد على وضع التحميل (المقيد أو المركب) ، قوة الخرسانة المالئة والانبوب بالإضافة إلى نسبة نحافة العمود. تم تطبيع النتائج بدلالة الإجهاد الشعاعي (f_r) وقوة الضغط الخرسانية (f'_c) ، وأخيرا تم بيان امكانية استخدام قوة الخرسانة المقيدة المحسنة (f'_{ce}) التي تم تحديدها لتقدير سعة التحمل للأعمدة بالأنماط المختلفة.

جمهورية العراق

وزارة التعليم العالي والبحث العلمي

جامعة ميسان / كلية الهندسة

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رسالة
مقدمة إلى قسم الهندسة المدنية في جامعة ميسان كجزء من متطلبات نيل شهادة الماجستير في علوم الهندسة المدنية/انشاءات

من قبل

مرتضى علاوي رحيمة
(بكالوريوس هندسة مدنية 2016)

باشراف

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رمضان 1440 **ايار 2019**