"INNOVATIVE APPLICATION OF GEO-GRID CONFINEMENT IN RC COLUMN UNDER AXIAL LOADING"

A thesis report submitted

In the partial fulfillment of the requirement for the award of the degree of

MASTERS OF ENGINEERING

IN

STRUCTURAL ENGINEERING

Submitted by

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2017

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PUNJAB, INDIA

DECLARATION

I, Gaurav Ghangas, hereby declare that the dissertation entitled **"INNOVATIVE APPLICATION OF GEO-GRID CONFINEMENT IN RC COLUMN UNDER AXIAL LOADING"**, in fulfillment of the requirement for the award of degree of Masters of Engineering in Structural Engineering under the Department of Civil Engineering, Thapar University, Patiala is an authentic record of my work carried out during a period from January 2017 to July 2017 under the supervision of **Dr. A.B. Danie Roy**, (**Assistant Professor**, Civil Engineering Department). The content presented in this dissertation has not been submitted by me for the award of any other degree of this or any other University.

Dated: 31|8|17

Gaurav Ghangas

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CERTIFICATE

This is to certify that the above statement made by the student concerned is correct and true to the best of my knowledge and belief.

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ACKNOWLEDGEMENT

I would like to express my deep and sincere gratitude to my research supervisor, ***Dr. A.B. Danie Roy***, Assistant Professor, Civil Engineering Department, Thapar University, Patiala, for giving me the opportunity to do research and providing invaluable guidance throughout this research. His dynamism, vision, sincerity and motivation have deeply inspired me. It was a great privilege and honor to work and study under his guidance. I am extremely grateful for what he has offered me.

A sincere gratitude to **Dr. Naveen Kwatra,** Professor and Head, Civil Engineering Department, for having made available the requisite facilities during the course of study.

I also like to thanks to all faculty members, teaching and non- teaching staff of civil engineering department and staff of central library, Thapar University, Patiala for their assistance.

I am extremely grateful to my parents for their love, prayers, caring and sacrifices for educating and preparing me for my future.

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ABSTRACT

An experimental study has been carried out to check the feasibility of geo-grid as a confining member in columns. The parameters that were varied in the tests are spacing of ties (50mm, 100mm, 200mm, and 400mm), and cross-sectional shape of the column (circular & square). The confining effect of geo-grid was studied by wrapping layers of geo-grid of 90mm width to the control specimens having horizontal tie spacing of 200mm and 400mm respectively. All the specimens were tested under load controlled loading in an ACTM (Automatic Compression Testing Machine) to evaluate the strength parameters. Load-deflection graphs were plotted and strength parameters (peak load, peak displacement, secant stiffness, ductility and energy dissipation) were precisely calculated and tabulated. The geo-grid was found to significantly improve the strength parameters of the columns. The results of the investigation indicate that the geo-grid can be effectively used as a partial replacement for conventional steel ties in the RC column.

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LIST OF ABBREVIATIONS USED

Abbreviation	Full form
CC 50	Circular column with spacing in lateral ties as 50 mm
CC 100	Circular column with spacing in lateral ties as 100 mm
CC 200	Circular column with spacing in lateral ties as 200 mm
CC 400	Circular column with spacing in lateral ties as 400 mm
CC 200G	Circular column with spacing in lateral ties as 200 mm with Geo-grid
CC 400G	Circular column with spacing in lateral ties as 100 mm with Geo-grid
SC 50	Square column with spacing in lateral ties as 400 mm
SC 100	Square column with spacing in lateral ties as 400 mm
SC 200	Square column with spacing in lateral ties as 400 mm
SC 400	Square column with spacing in lateral ties as 400 mm
SC 200G	Square column with spacing in lateral ties as 400 mm with Geo-grid
SC 400G	Square column with spacing in lateral ties as 400 mm with Geo-grid

CHAPTER 1
INTRODUCTION

1.1. General

It is well known that columns are the most important structural elements in any building frame that transmit vertical loads of the superstructure to the foundation below. So, strength and durability of this element becomes a matter of prime significance. Lateral ties in RC columns provide an aid in this regard. They strengthen the column by providing confinement to the core concrete and the longitudinal reinforcement. These lateral ties also increase the durability of the RC column by providing adequate ductility to it so as to tackle moments and shear forces by various loads and during the time of seismic movements. And the degree of improvement in the functional properties of the column largely depends upon the quality of confinement.

1.2. Definition of confinement

Confinement in RC column essentially means to bind the main reinforcement and the concrete core, and to constrain them from moving out. But its function is not limited to its definition, it actually performs a more diverse function and its role is very significant in RC column.

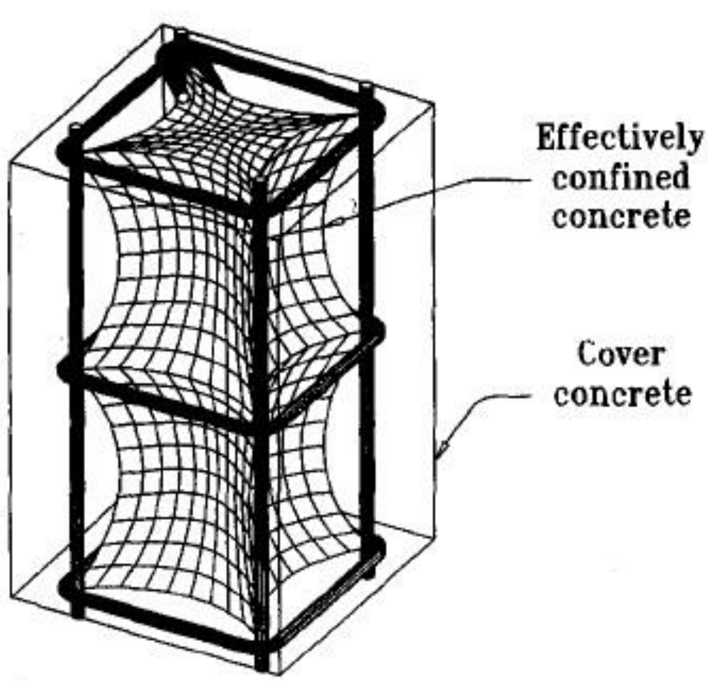


Fig.1.1 (a): Confinement action on concrete in 3D

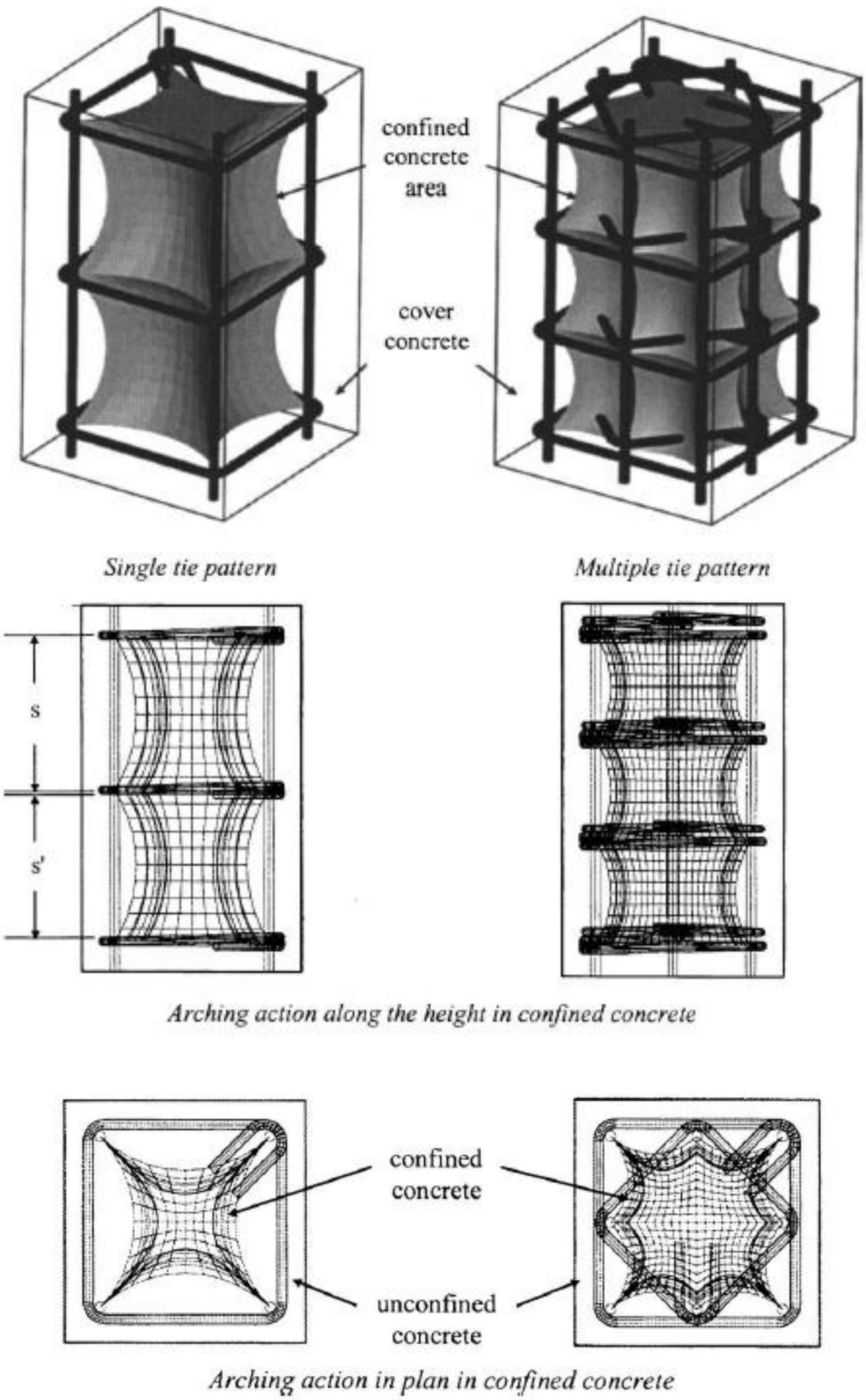


Fig.1.1 (b): Confinement action on concrete

1.3. Role of confinement in RC column

When a column is axially loaded, it undergoes strain in both the directions i.e. longitudinal and lateral directions. The compression caused in vertical direction due to loading causes bulging of column in lateral direction. This bulging after a certain limit causes core concrete to spall and longitudinal reinforcement to buckle outwards. Here comes the role of confinement. Lateral ties tied to main reinforcement during lateral strain restrain the core concrete against bulging and longitudinal reinforcement against buckling. Experimental studies also reveal that the confinement, on the action of lateral forces due to bulging and buckling, gives a lateral reaction which increases the axial load carrying capacity of the column. This concept is similar to pre-stressing in concrete.

1.4. Effect of spacing on confinement

Spacing between the lateral ties has a significant effect on the confinement behavior and axial load carrying capacity of the RC column. The effect of spacing in confinement can be understood by the discussion below.

1.4.1. Large spacing in confinement

Lateral ties tied to longitudinal reinforcement with large spacing results in poor confinement of both core concrete and main reinforcement. On application of load, this results in spalling of concrete from core and buckling in main reinforcement almost at 70% of the ultimate strength of column.

1.4.2. Small spacing in confinement

Lateral ties tied to longitudinal reinforcement with less spacing will prevent buckling of main reinforcement but its close compact frame structure leads to the formation of a weak zone between core concrete and cover concrete. Due to the stress transfer behavior in column (as shown in Fig. 1.1 and Fig.1.2), irregular strain occurs in different vertical layers of RC column. Formation of weak zone at the interface results in spalling of cover from core concrete. Once the spalling of cover concrete occurs, the entire load is transferred to core concrete at once. This sudden increase in stress in column can be fatal. Thus, while designing the columns, the engineers keep a due consideration in mind that the columns are designed for the core concrete only and the cover is provided only to provide protection against corrosion and abrasion. This automatically imparts a certain factor of safety to the column design.

1.4.3. Effective spacing

Knowing the effects of large and small spacing in confinement, it becomes a matter of wisdom to provide an adequate spacing that is effective enough to fulfill its functions and help meet both the ends i.e. able to minimize the ill effects of large and small spacing in confinement.

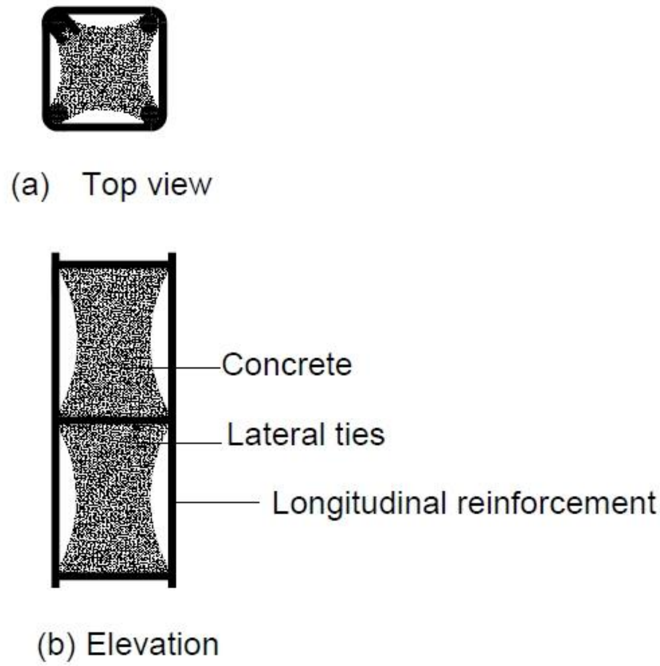


Fig.1.2: Confinement behavior in RC column

1.5. Possible confining materials

In today's world confinement is not restricted to merely steel. Researchers are trying hard to replace steel with a better material that can serve the purpose more efficiently. Some researchers like Ahmed M. and Hany A. have investigated that Expanded Metal Mesh (EMM), Welded Wire Mesh (WMM), Fibre Reinforced Polymer (FRP), etc. are some materials that can replace steel in confinement. Geo-grid is not yet examined for it but its properties advocate its possibilities to replace steel in confinement. Confinement is of two types viz. Active and Passive. In "active confinement" provided generally by hydrostatic pressure or by mechanical devices, the full lateral confining pressure is applied and held constant at the beginning of test. In engineering practice, "passive confinement" has been traditionally provided in compression members through transverse reinforcement in the form of spirals, circular hoops and rectangular ties or encasing the concrete column in a steel tube or using FRP wraps.

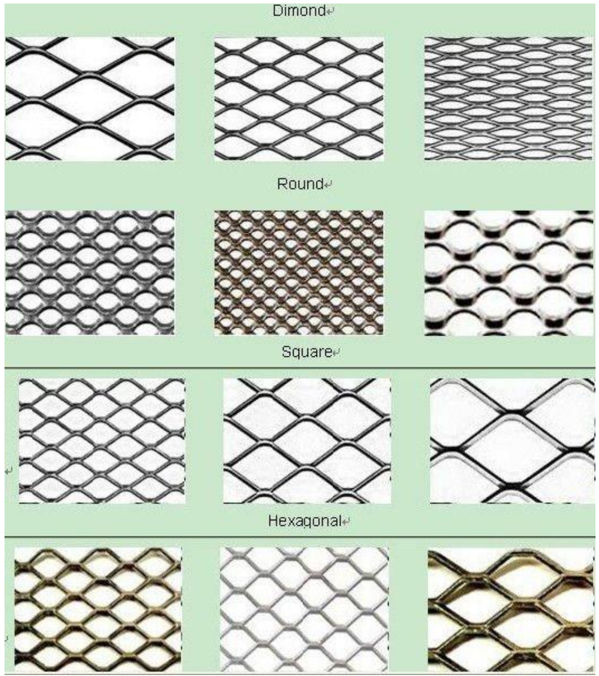


Fig.1.3 (a): Expanded Metal Mesh

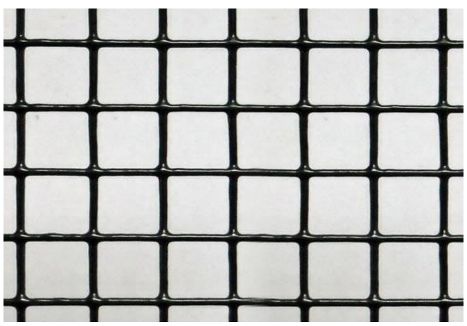


Fig.1.3 (b): Welded Wire Mesh

Fig.1.3 (c): Welded Wire Mesh

Fig.1.3 (d): Fiber Reinforced Polymer

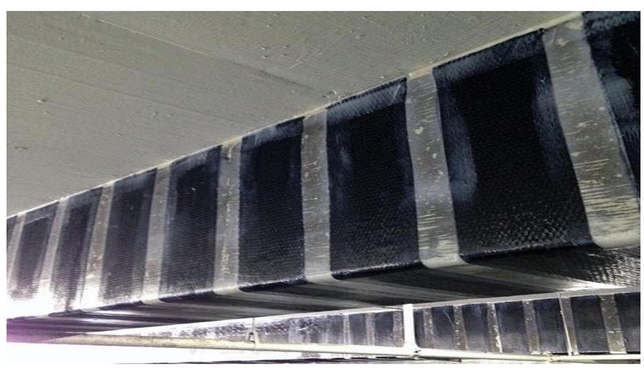


Fig.1.3 (e): Fiber Reinforced Polymer

1.6. Geo-grid

Geo-grid is a polymeric material. It is actually one of the constituent materials classified under geo-synthetics and is manufactured from polymers such as polypropylene, polyethylene and polyester. A geo-grid is geo-synthetic material which is used to reinforce soils and other similar materials. Geo-grids are mostly used for reinforcing retaining walls, as well as sub-bases or sub-soils below roads or structures, when loaded, soils pull apart under tension. Geo-grids are much stronger in tension than soils. This property of geo-grids allows them to transfer loads to a larger area of soil.

Geo-grids are commonly manufactured from polymeric materials, such as polyesters, polyvinyl alcohol, poly-ethylene or polypropylene. They may be woven or knitted from yarns, heat-welded from strips of materials, or manufactured by punching regular patterns of holes in sheets of polymeric material, then stretched into a grid.

The development of the methods of preparation of relatively stiff polymeric materials by tensile drawing, in a sense "cold working," raised the opportunity that such materials could be used in the reinforcement of soils in walls, steep slopes, roadway bases and foundation soils. Used as such, the main function of the obtained geo-grids is in the area of reinforcement. This area, as with many other geo-synthetics, is very active, with a number of diverse products, materials, configurations, etc., making up today's geo-grid market. The fundamental feature of all geo-grids is that the openings between the adjacent sets of longitudinal and transverse ribs, called “apertures,” are large enough to allow for soil strike-through from one side of the geo-grid to the other. The ribs of some geo-grids are often quite stiff compared to the fibers of geotextiles. As conferred later, not only is rib strength important, but junction strength is also important. The reason behind it is that in anchorage situations the soil strike-through within the apertures bears against the transverse ribs, which transmits the load to the longitudinal ribs via the junctions. The junctions are, of course, where the longitudinal and transverse ribs meet and are connected. They are sometimes called “nodes”.

Currently there are three classifications of geo-grids. The first classification, and the original, of geo-grids (called unitized or homogeneous types, or more commonly referred to as 'punched and drawn geo-grids') were discovered by Dr. Frank Brian Mercer in Netlon, United Kingdom, Ltd., and were brought in 1982 to North America by the Tensar Corporation. A conference in 1984 was helpful in bringing geo-grids to the engineering design community. A similar classification of drawn geo-grid, originated in Italy by Tenax, is also available, as are products by new manufacturers in Asia. The second category of geo-grid that is known for its fine knitting is referred to as 'coated yarn geo-grids'. These are fine sets of threads knitted across each other with accurate precision and coated with a layer of adhesive to hold it from spreading. And the third category of geo-grid includes 'grid welded by straps or rods of polyesters'. These are nothing but layers of polyesters stacked together by welding giving any polygonal shape to the aperture.

1.6.1. Classification of geo-grid

There are two basis of classification of geo-grids:

a) On the basis of manufacturing process
b) On the basis of geometry

The geo-grids can be further sub divided based on the above mentioned classifications as follows:

a) On the basis of manufacturing process of geo-grids:
   i. Punched and drawn geo-grids
   ii. Coated yarn geo-grids
   iii. Grid welded by straps or rods of polyester
b) On the basis of geometry of geo-grids:
   i. Uniaxial geo-grids
   ii. Bi-axial geo-grids
   iii. Triangular geo-grids

The uniaxial, biaxial, and triangular geo-grids can be better understood by the figures given below.

Fig.1.4 (a)

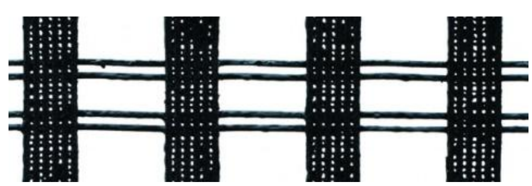


Fig.1.4 (b)

Fig.1.4: Uniaxial geo-grid

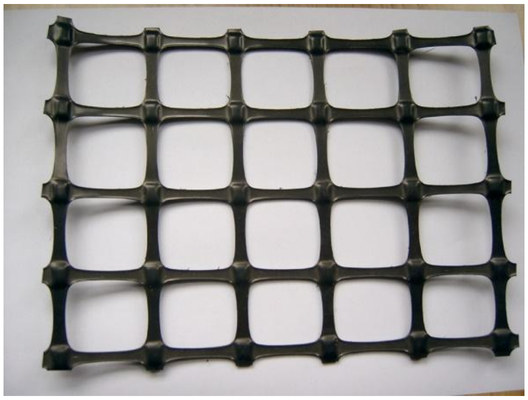


Fig.1.5 (a)

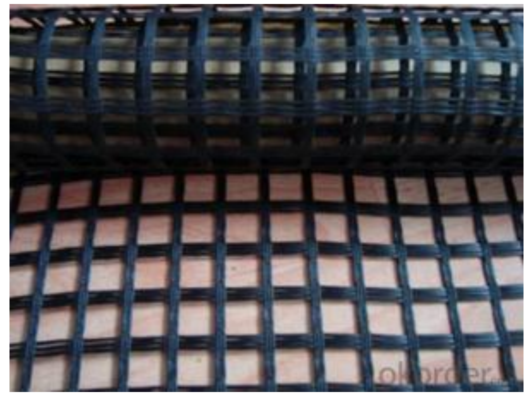


Fig.1.5 (b)

Fig.1.5 (b): Biaxial geo-grid

Fig.1.6 (a)

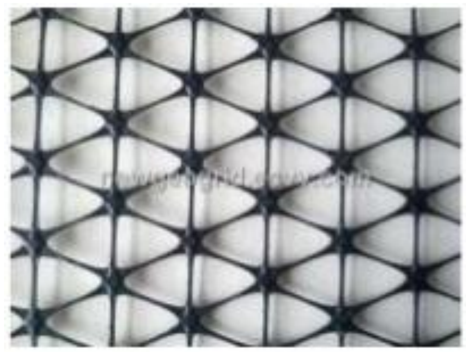


Fig.1.6 (b)

Fig.1.6 (b): Triangular geo-grids

1.6.2. Conventional uses of geo-grid

In today's world, geo-grids have a limited zone of application till now. The uniaxial geo-grids are mainly used in construction of retaining walls and steep slopes as a supporting agent while the bi-axial and triangular geo-grids are used mainly in the construction of highways to help spread and bear the load above the pavement.

Fig.1.7 (a): Biaxial geo-grid in highway construction

Fig.1.7 (b): Geo-grid in retaining wall construction

1.7. Geo-grid use in RC column

Until now geo-grid is not used in RC columns. It possesses an adequate tensile strength to act as a confining element and can perform far better in corrosion than conventional steel. Its physical and chemical properties advocate its use as a potential confining element and, therefore, compel to do research in this direction.

1.8. Advantages of geo-grid

Geo-grid use as confining material provides us many advantages as mentioned below.

i. The use of geo-grid as confinement in the RC columns is easier and less laborious.
ii. It is not as rigid as conventional steel reinforcement but partial replacement of steel with geo-grid will provide adequate tensile strength and serve the purpose effectively.
iii. Being a non-metallic material, it will perform better in corrosive environment.
iv. Also, its reduced self weight, cheap cost and easy availability advocates its use as ties with main reinforcement under compression loading.

1.9. Need of study

A constant research is being done to improve the quality of construction. Column being the most important structural member in any building frame, researchers are trying hard to alter the constituents of its construction to improve its strength parameters. Geo-grid possesses the required essential properties and is not yet explored completely. All these facts made us look onto geo-grid as a constituent in column construction that can improve the strength of the column.

1.10. Objectives of study

The objectives of this study are twofold:

- To study the feasibility of geo-grid confinement in RC column as a partial replacement of conventionally used steel ties.
- To examine the confinement effect of geo-grid in RC columns with adequate spacing of ties.

1.11. Methodology of study

Twenty eight column specimens were prepared using M25 concrete. The parameters that were varied in the tests are:

(i) Spacing of ties (50mm, 100mm, 200mm, and 400mm), and

(ii) Cross-sectional shape of the column (circular & square).

The confining effect of geo-grid was studied by wrapping layers of geo-grid of 90mm width to the control specimens having horizontal tie spacing of 200mm and 400mm respectively, by giving an overlap length of 75mm. All the specimens were tested under load controlled loading in an ACTM (Automatic Compression Testing Machine) to evaluate the strength parameters. Load-deflection graphs were plotted and strength parameters (peak load, peak displacement, secant stiffness, ductility and energy dissipation) were precisely calculated and tabulated.

1.12. Organization of the thesis work

Chapter 1- Describes the role of confinement in column and an introduction to geo-grid. This chapter also specifies the objectives of the study.

Chapter 2- Discusses the literature review on geo-grid behavior in concrete and confinement effect on columns.

Chapter 3- Describes the experimental program, wherein the materials used, specimen preparation and the procedure of work are explained in detail.

Chapter 4- Describes the results obtained from the experimental study and discusses the research output with relevant comparisons.

Chapter 5- Deals with the conclusions and future scope of the study. This chapter is followed by a list of references used in the present study.

CHAPTER 2
LITERATURE REVIEW

2.1. General

When concrete is subjected to a compressive load it undergoes volumetric changes with a lateral increase in dimensions due to the Poisson's effect. If a restraining material is provided to control the lateral dilation of concrete, it resists this tendency of lateral expansion of concrete by developing tensile forces and consequently exerting a compressive reaction force on the concrete. This state of multi-axial compression, where both the deformation capacity and strength of the concrete are enhanced, results into confined concrete. Confinement is of two types viz. Active and Passive. In "active confinement" provided generally by hydrostatic pressure or by mechanical devices, the full lateral confining pressure is applied and held constant at the beginning of test. In engineering practice, "passive confinement" has been traditionally provided in compression members through transverse reinforcement in the form of spirals, circular hoops and rectangular ties or encasing the concrete column in a steel tube or using FRP wraps. In "passive confinement" the confining effect is initiated by the lateral expansion of the concrete and the confining pressure gradually increases as the concrete continues to expand. As the passive confinement is of interest in the design and detailing of the structures, the work reported here deals in confinement provided by transverse reinforcement only.

The effect of confinement on the strength and deformation capacity of concrete under ambient conditions has been extensively studied in the past from both the experimental and theoretical standpoints. Such studies have considered the concrete to be confined by spirals and hoops (Mander et al., 1988, Sheikh and Toklucu, 1993) and rectilinear ties (Kent and Park, 1971, Sheikh and Uzumeri, 1980). Chidambaram and Agarwal, 2014, worked on 'Confining effect of geo-grid on the mechanical properties of concrete beam specimens with steel fibers under 'Compression, flexure and shear behavior of geo-grid confined RC beams with steel fiber reinforced concrete'. Khaleek et al., 2012, worked on 'Effect of lateral confinement on strength of concrete'. Shafqat and Ali, 2012, worked on 'Lateral confinement of RC short columns'. Zhang et al., 2011, studied 'The Experimental research of low strength concrete considering strain rate under uniaxial compression'.

These studies, which were carried out on normal strength concrete columns, have demonstrated the beneficial effects of confinement and gave much insight about the confinement of concrete by transverse reinforcement. At low levels of axial concrete stress the transverse steel is hardly stressed and thus the concrete is unconfined. The concrete becomes confined when, at stresses approaching the uniaxial strength, it commences to increase in volume due to progressive internal fracturing and bears out against the transverse reinforcement, which then applies a confining reaction to the concrete. Therefore, effectiveness of confinement would depend upon the lateral passive confining pressure generated by transverse steel. The early research on confined concrete has suggested that confinement effectiveness is improved if,

(1) The transverse reinforcement is placed at relatively close spacing;

(2) Additional supplementary overlapping hoops or cross ties with several legs crossing the section are included;

(3) The longitudinal bars are well distributed around the perimeter;

(4) The ratio of the volume of transverse reinforcement to the volume of the concrete core or the yield strength of the transverse reinforcement is increased; and

(5) Spirals or circular hoops are used instead of rectangular hoops and supplementary cross ties.

Sheikh and Uzumeri, 1982, proposed a method to determine the capacity of the confined core based on a conceptual model in which it was hypothesized that the area of the effectively confined concrete in a column is less than the core area. This concept was further refined by Mander et al., 1988, and Saatcioglu and Razvi, 1992. It was shown that the maximum transverse pressure from the confining steel could only be exerted effectively on that part of the concrete core where the confining stress had fully developed due to the arching action. While the reduction of the core area to an effectively confined area takes place only along the longitudinal axis of the column in the case of circular spiral or tie, in rectilinear confinement the area of the effectively confined core is less than the core area even at the tie level. The confining pressure on the concrete core dissipates between the ties and away from the longitudinal bars with the full confining pressure acting over a reduced or effective core area. A confinement effectiveness coefficient (K_e) was therefore, defined as that takes into account the effective core area (Sheikh and Uzumeri, 1982, Mander et al., 1988).

2.2. Geo-grid as confining member

On a small note, it can be quoted that the geo-grid possesses the required physical and chemical properties to be used as a confining member, yet its application is restricted to highways and retaining walls. Although, some researchers have observed its behavior as a confinement member in beams and obtained fruitful results but its application in columns as a confinement member is not yet examined. Based on its physical and chemical properties and the results of confinement in beam, the proposed study was given direction.

2.3. Review of literature of various researchers

Saadatmanesh et al. (1994) researched on strengthening of columns by wrapping thin , flexible, high strength fiber-composite straps around the columns to improve the confinement, and thereby its ductility and strength. The fiber straps can be wrapped in discontinuous rings or continuous spirals. Circular and rectangular columns were prepared with fiber straps wrapped around it. The prepared columns were studied using the stress strain models for confined concrete, developed by Mander, Priestley and Park, based on equations proposed by Popovics. The models were put in a computer program developed to predict the ultimate moment and curvature at failure of the columns from pure compression to pure bending, and suitable assumptions were applied. This analytical study proved that the strength and ductility of a seismically deficient column can be increased by wrapping composite straps around the column.

The results of the study showed significant increase in compressive strength and strain at failure, as compared to unconfined concrete column. Also, the ductility factor increases linearly with increase in strap thickness, however, the rate of increase in ductility factor decreases as the strap spacing increases. As per the paper discussed, a number of circular and rectangular columns were studied and tested under reversed inelastic cyclic loading and the results will be incorporated with experimental data to ascertain the viability of the results.

Mander et al. (1988) studied a theoretical stress-strain model for confined concrete. They developed a stress-strain model for concrete subjected to uniaxial compressive loading, and containing confining reinforcement in any form, circular hoops, or spiral, or rectangular hoops with or without supplementary cross ties, which may or may not be having equal confining stresses along each of the transverse axes. The effect of various types of confinement is taken into account by defining an effective lateral confining stress, which depends upon the configuration of lateral and longitudinal reinforcement. The model gave the following conclusions.

Reinforced concrete members with axial compressive forces may be confined in lateral direction by steel to improve strength and ductility. A 'five parameter' maximum strength criterion uses the confining stresses to determine the confined concrete strength on the ultimate strength surface.

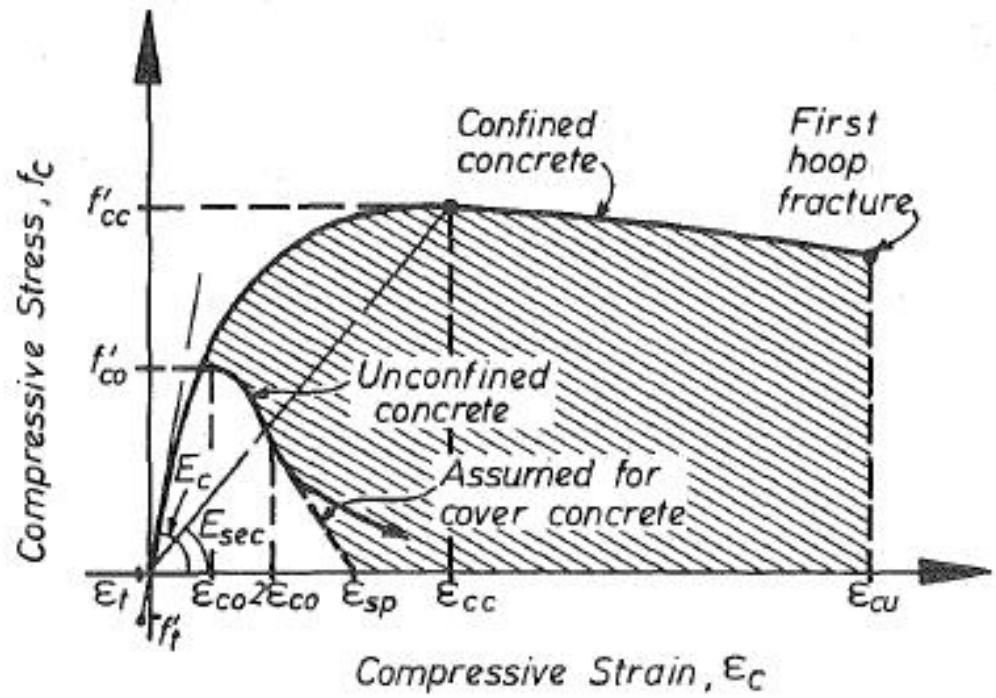


Fig.2.1: Stress-strain model proposed for monotonic loading of confined and unconfined concrete [J.B. Mander et al. (1988)]

The increase in the strain at ultimate stress is assumed to be about five times the strength increase. The stress-strain curve for confined concrete can be expressed in terms of simple uniaxial relations, suggested by Popovics and only requires three control parameters. Also, unloading and reloading curves can be obtained from cyclic loading curves. An allowance for the dynamic response in stress-strain modeling can be incorporated by modifying the quasi-static concrete parameters by dynamic magnification factors, which are subsequently used in the stress-strain models.

Nicolo et al. (1997) studied the increase in peak strength and peak strain in confined concrete for a wide range of strengths and degrees of confinement. Stress-strain models were prepared and compared with experimentally obtained data. It was concluded that the peak strength of the specimen was increased on increasing the confinement. Also, and there was a lesser strain at corresponding stresses.

There was an increase in the peak strain when the confinement was increased. The other parameters like ductility, energy absorption, etc. also showed significant improvement in behavior.

Candappa et al. (1999) studied the stress-strain relationship of high strength concrete under high lateral confinement. They prepared M60 and M100 mix to be casted in cylinders of 100mm Φ and 200 mm height.

The confining pressures applied were 4, 8, and 12 Mpa to each of the specimens in tri-axial test. It was concluded that the lateral strain at peak stress was similar for 60 MPa and 100 MPa concrete at low confinements. However, at large confinements, the lateral strain in 100 MPa specimen was only 80% as compared to 60 MPa specimen, therefore, it was concluded that the effective confinement by lateral reinforcement in high strength concrete under high confinement will be less. Thus the behavior of confinement in high strength concrete was concluded.

Assa et al. (2001) studied a new approach for modeling confined concrete circular columns. They developed an analytical stress-strain model based on concrete spiral steel interaction. The behavior of concrete in deformation under axial and lateral loading was studied experimentally and the response characteristics from spiral to lateral expansion were determined theoretically. They prepared 24 cylinders, with dimensions 145 x 300 mm, and applied monotonic compressive load to failure. Then, the maximum axial strength and a set of constitutive relations were derived for estimating the characteristic points on the stress-strain curve of confined concrete. Observations from researchers working on similar cylinders and columns were also collected and a comparative study was also done to verify the results. The model proposed in this study gave positive results, when compared.

They gave spiral confinements in 20 cylinders and circular confinements in 4 cylinders, to be casted with a mix varying from M20 to M90, and applied compressive loading to them. Experimental results revealed that when the concrete core reached its peak strength, the steel in lateral confinement does not necessarily reach its yield point. However, the confinement model is based on the approach that the lateral steel yields at the maximum stress, and therefore largely overestimates the effect of confinement, particularly when high strength concrete is reinforced with high strength steel.

Ros et al. (2003) studied the influence of confinement on high strength concrete behavior. Keeping the confining values from 0% - 4%, an experimental program was designed to study the behavior of confined concrete when its strength increases from conventional values to high strength values. Experimentally obtained data was used to approximate the equations to compute stress-strain curves. The strength parameter such as, peak stress, peak strain, ductility, etc. were derived and compared with the experimentally obtained results.

The peak stress values were found to be higher for specimens with large confinements, and these specimens were able to take more strain. Also it was concluded that the spacing between the lateral ties must not be more than the specimen cross-sectional dimension, otherwise, the confinement will be ineffective. The ductility and energy absorption of largely confined specimens were found to be more than those of moderately confined specimens.

Husem and Pul (2006) investigated stress-strain models for confined high strength concrete by preparing prismatic specimens for the experiment.

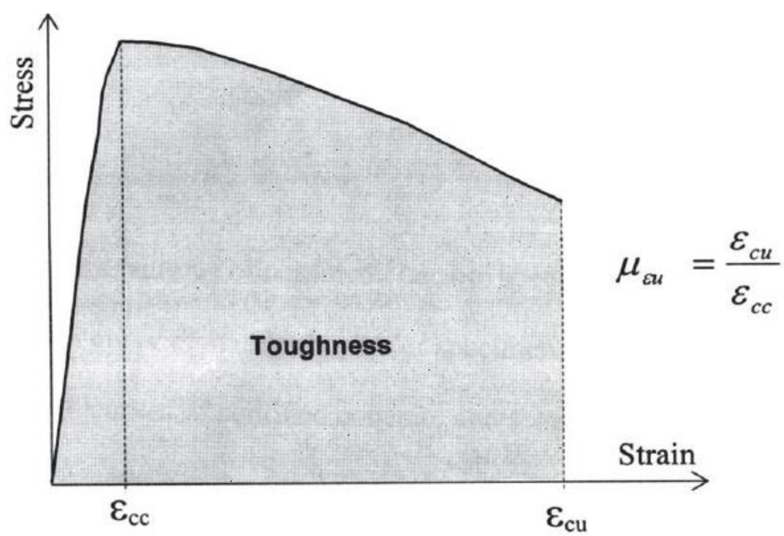


Fig.2.2: Typical stress-strain curve to compute toughness and toughness [Metin Husem and Selim Pul (2006)]

Longitudinal reinforcement (4 in no.) was provided and lateral steel ties were provided. Stress-strain models were prepared and compared with the experimental study. The results showed improvement in ductility of column specimens with large steel confinement in high strength concrete. It was observed that by reducing the spacing of lateral steel ties by half, the ductility of the specimen increased almost twice. And, the maximum increase in ductility obtained reached as much as 19 %.

Bousalem and Chikh (2006) worked on development of a confined model for rectangular ordinary reinforced concrete columns with an objective to develop an analytical model for confinement mechanism in rectangular reinforced concrete columns. Literature review of various relevant researchers was observed to derive the equations correctly and observed the volumetric ratio of lateral reinforcement, characteristics of steel and concrete, and the effectiveness of confinement coefficient.

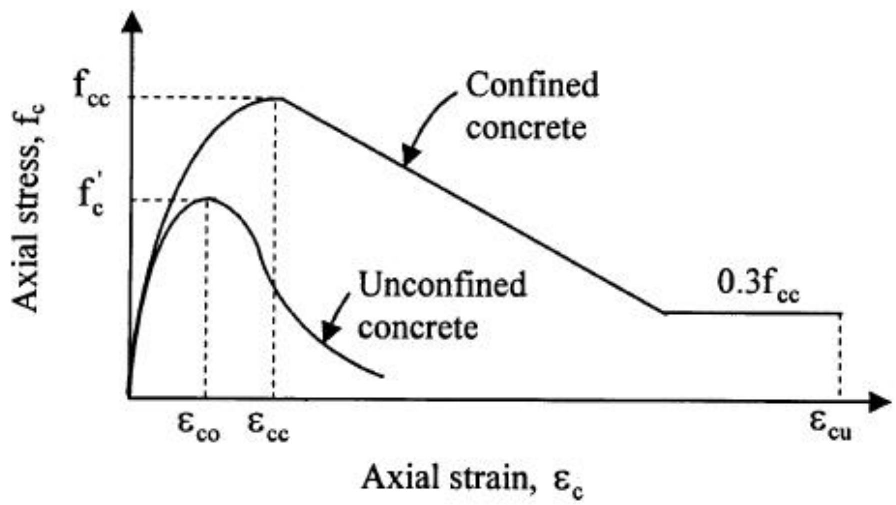


Fig.2.3: Proposed stress-strain curve for confined normal strength concrete [B. Bousalem and N. Chikh (2006)]

It was concluded that the peak strength of the specimen was increased on increasing the confinement. Also, and there was a lesser strain at corresponding stresses. There was an increase in the peak strain when the confinement was increased. The other parameters like ductility, energy absorption, etc. also showed significant improvement in behavior.

Konstantinidis et al. (2007) studied analytical stress-strain models for high strength concrete members under cyclic loading. They performed uniaxial loading, monotonic loading and compression loading on 108 specimens and derived a hysteresis curve for them and analyzed the compressive strength, volumetric ratio of transverse reinforcement, yield strength of ties, tie spacing and tie pattern. The same model was also analyzed by finite modeling in ADAPTIC to observe the effect of cyclic loading, to observe the energy dissipation under cyclic loading, hysteresis behavior, stiffness, degradation in the damage process, and the degree of confinement. Comparison was made with the experimentally obtained data which proved the reliability of the results obtained.

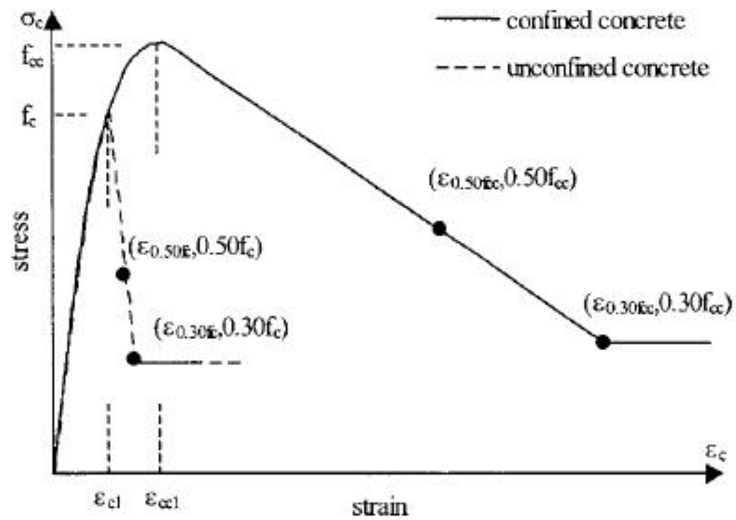


Fig.2.4: Envelope curve for unconfined and confined HSC [Dimitrios K. Konstantinidis et al. (2007)]

Tiecheng and Xiaowei (2010) studied the performance of cross-shaped concrete columns confined by stirrups. They analyzed seven cross-shaped columns under axial load and obtained stress-strain graphs. It was observed that there was an increase of 8 % - 43% in compressive strength, and an increase of 25 % – 195 % in strain corresponding to peak stress of confined concrete.

The effect of stirrups and stirrup spacing on the compressive strength and strain of the concrete column was also analyzed. A linear relationship was observed between stirrup characteristic value and stirrup effective restraint coefficient, and the strain corresponding to the peak stress has a non-linear relationship with the product of stirrup characteristic value and stirrup effective restraint coefficient. The stress-strain equations were derived for the cross-shaped columns confined by stirrups and compared with the results obtained from the experimental work for better understanding.

Khaleek et al. (2012) studied the effect of lateral reinforcement on the compressive strength of the columns. They prepared circular and square columns (having height to diameter ratio as 2), and provided confinement, both seismic and non-seismic, in different quantities. The objective of the study was to observe the peak strength of the column specimens with different volumetric ratios of steel in transverse reinforcement.

The columns were prepared using M20 (1 :1.67 :3.34) mix, with longitudinal reinforcement as 8 mm dia. (4 in no. in each square column) and 6 mm dia. (6 in no. in each circular column), and lateral reinforcement of 5 mm dia. TMT bars of Fe415 steel. The dimensions of the columns were 150 mm x 150 mm (square) and 150Φ (circular), each having a height of 300 mm. The columns were detailed with seismic and non-seismic behavior and axially loaded to obtain the results.

It was concluded that the peak strength of the specimen increased substantially with increase in transverse reinforcement. The circular columns proved to be stronger than the square columns which concluded that the circular hoops are more effective than the square hoops. Columns with non-seismic detailing had lesser confinement action, less strength enactment and limited ductility as compared to those having seismic confinement. Keeping other factors same, the columns with seismic confinement showed more peak strength than columns with non-seismic confinement. The results are summarized in the tables below.

Shafqat and Ali (2012) studied the effect on peak strength, mode of failure and ductility, when the lateral steel ties are replaced with thin steel plates of equivalent area. Three square columns with same cross-sectional area of 150 mm x 150 mm were casted with the following ties configuration.

CSB1 – Concrete column confined with conventional steel ties referred to as control column

CSP1 – Concrete column confined with 2 mm thick steel strips

CSP2 – Concrete column confined with 1.2 mm thick steel strips

Longitudinal reinforcement used was 4 bars of 13 mm dia. in each column specimen and a mix design of M18 was used. The columns were tested under Universal Testing Machine (UTM) and the following results were obtained.

The axial capacity of CSP1 was the maximum (716.13 kN), followed by CSP2 (465 kN), and

CSB1 (402.2 kN) showed the least axial capacity. The axial capacity of CSP1 was approximately 178% of CSB1 (control specimen) and CSP2 was approximately 115.8% of CSB1. CSP2 were not as strong as CSP1 during bulging of columns, that is why they gave lesser axial capacity. CSB1 failed at ε_{cl} =1.15% after peak load while CSP1 failed at ε_{cl} =12.4% after peak load. But it was concluded that the steel ties can be replaced by steel plates of equivalent area in transverse reinforcement.

Chidambaram and Agarwal (2014) worked on 'Confining effect of geo-grid on the mechanical properties of concrete beam specimens with steel fibers under compression and flexure'. They prepared twelve beam specimens and four cylindrical specimens (using the mix ratio as 1 :1.45 :2.25) in OPC of Grade 43, and confined with geo-grid placed axially in lower layers with or without the addition of steel fibers and found that the post-peak stress and strain behaviors of the specimens were significantly improved.

The improvement could be due to confinement of geo-grid or due to the addition of steel fibers. For further introspection, they also compared the test results of specimens confined with geo-grid without steel fibers to the specimens confined with geo-grid with steel fibers. They found out that there was a significant improvement in the axial compressive strength of the specimens, direct split tensile strength of cylindrical specimens and flexure strength of beam specimens as compared to conventional specimens. The stress improvement in the specimens confined with geo-grid was as much 50% and the strain improvement in the specimens was almost 3 times as compared to conventional specimens. The inelastic behavior also showed significant improvements in the results. While the failure strain in conventional specimens occurred at 0.002, the failure strain in specimens confined with geo-grid reached as high as 0.035.

Also, in the geo-grid confined specimens and steel fibers added to it, the failure mechanism was altered. The concrete failure became ductile instead of its natural sudden brittle failure, without any significant loss in strength of the specimen. The confinement of specimens with geo-grid not only increases the tensile strength of the specimen but also helps to hold the deflection for a longer duration, thus increasing its durability. Also, there was a change in crack propagation patterns and the crack widths were also reduced, as observed during the flexure tests.

There was a significant increase in the post peak load deformation capacities, as much as, 5-6 times in case of geo-grid confined specimens as compared to conventional specimens. However, no change was observed in the peak load capacity of the specimen. With increase in the number of layers of geo-grid in the specimen, there was a significant improvement in the load-deformation performance and the energy dissipation of the specimen in addition to increase in strength. They concluded that the behavior of geo-grid placed specimens with steel fibers is similar to the behavior of specimens with conventional reinforcement.

Chidambaram and Agarwal (2015) also worked on 'Flexure and shear behavior of geo-grid confined RC beams with steel fiber reinforced concrete'. They prepared twelve beam specimens (using the mix ratio as 1 :1.45 :2.25) in OPC of Grade 43, and divided them into three categories based on the configuration of longitudinal and lateral reinforcement, amount of geo-grid confinement in hoop tension and volume of steel fibers used in the mix. Single point static loading was then applied to the beam specimens to obtain the load-deflection curve.

Significant improvement was observed in the post peak behavior of beam specimens depending upon the amount of geo-grid confined and volume of steel fibers used. Geo-grid confinement with and without steel fibers was observed in compression and split tensile strength of concrete specimens and it was concluded that geo-grid confinement not only imparted strength to the beam specimens but also retained the strain for a longer duration. The crack pattern was keen fully observed and concluded that the geo-grid confinement plays a significant role in increasing the tension retaining capacity i.e. hoop stress in the lateral direction. The results of load-deflection curve also prove that the geo-grid confinement helps improve the post yield behavior and significant increase in the energy dissipation capacity of the specimens by at least 50 percent. The load-deformation curve shows improvement in load and deformation capacity, as much as 2-2.5 times the capacities of the control specimen and also showed a remarkable increase in the energy dissipation capacity. It was also inferred from the results that the flexure and shear capacity of the deficient beam specimens were effectively increased when confined with geo-grid and added with steel fibers. It was also observed that the strength of the conventionally confined beam specimen decreased as the amount of transverse reinforcement increased, whereas in case of geo-grid confined specimens, with or without steel fibers, the decrease in strength and stiffness was more gradual and stable. The results showed about 20% degradation in stiffness over a post elastic ratio of 0.005 and an over-strength ratio of about 1.2. They also observed increase in the strength characteristics of the beam specimens and alteration in the mode of failure. The crack patterns of the beam specimens showed drastic change when confined with geo-grid. The conventionally confined beam specimens showed brittle shear failure mechanism whereas beam specimens confined with geo- grid showed flexural failure mechanism because the strength of the specimens largely depends upon the strength of the geo-grid and percentage of steel fibers used. Thus the use of geo-grid and SFRC increases the shear capacity of the beam specimens particularly in the plastic hinge region. They concluded that the geo-grid will prove an effective structural component in reinforced concrete but its versatility and reliability needs to be examined with more diverse load applications.

CHAPTER 3

METHODOLOGY AND MATERIALS USED

3.1. Overview

Twenty eight short RC columns, each of length 450 mm were divided into two categories according to their cross-sectional shape- *Group-1:* 14 Square columns (150mm x 150mm), and *Group-2:* 14 Circular columns (150mm Φ), tied in lateral direction with steel or geo-grid or a combination of both at different spacing and tested under axial compression at a temperature of 28°C in the structures laboratory in the department of civil engineering at Thapar University, Patiala, Punjab, India. The complete details of the experimental program along with the details of the specimens and material properties are described below.

3.2. Material Properties

A standard concrete of grade M25 (1: 1.60: 2.69) with W/C ratio as 0.45 was prepared using ordinary Portland cement of grade-43, fine aggregates, coarse aggregates and tap water. The specimens were then casted using prepared M25 concrete, steel reinforcing bars and geo-grid material. Due considerations were given to ascertain that the materials used conformed to the requirements laid down by the relevant Indian Standard Codes. The detail characteristics of the materials used are presented below.

3.2.1. Water

The water to be used for mixing and curing of concrete should be free from deleterious materials as per IS 456. Thus potable tap water is generally considered for both the processes. In the present research, the tap water available in the laboratory was found to be of appropriate potable quality. Thus, it was used for mixing and curing of concrete.

3.2.2. Steel reinforcing bars

Tata steel reinforcement bars of Fe500 of 12 mm in diameter and 10 mm in diameter were used as main longitudinal reinforcement, and that of 6 mm in diameter were used as lateral ties to counter hoop tension.

3.2.3. Cement

Ordinary Portland cement of grade-43 from a single lot was used to prepare mixes throughout the research. The cement bags were kept at dry place within the laboratory, above the ground surface as soon as they were received, to prevent cement hardening. The received samples were thoroughly tested in the laboratory to ascertain their feasibility as per the relevant IS Codes (IS 4031:1988 and IS 4032:1985) as shown in Fig.3.1 and Fig.3.2. The physical and chemical properties of the cement used are derived in comparison to the requirements as per IS 8112 (1989) and tabulated in Table 3.1 and Table 3.2 below.

Fig.3.1: Cement consistency test

Fig.3.2: Determining initial & final setting time of cement

Table 3.1: Physical properties of cement

CHARACTERISTICS	RESULTS OBTAINED	RECOMMENDED VALUES AS PER IS 8112:1989 (BIS 1989)
Grade of cement	OPC 43	-
Specific gravity	3.15	-
Standard consistency of cement (%)	26	30
Setting Time		
i. Initial setting time (Min.)	160 min	30 min (Min.)
ii. Final setting time (Max.)	225 min	600 min (Max.)
Compressive Strength		
i. 3 days strength of cement (N/mm^2)	32.5	23 (Min.)

ii. 7 days strength of cement (N/mm^2) iii. 28 days strength of cement (N/mm^2)	42.9 57.5	33 (Min.) 43 (Min.) 58 (Max.)
Soundness Le-Chat Expansion (mm)	 0.5	 10 (Max.)
Fineness of cement (m^2/kg)	254	225 (Min.)

Table 3.2: Chemical composition of OPC 43 cement

OXIDES	TEST RESULTS (%)	LIMITING % VALUES AS PER IS 8112:1989 (BIS 1989)
Silicon dioxide (SiO_2)	23.35	17-25
Sulphur trioxide (SO_3)	2.39	1.3-3.0
Ferric oxide (Fe_2O_3)	1.3	0.5-6.0
Alumina (Al_2O_3)	1.3	3.0-8.0
Calcium oxide (CaO)	63.4	60-67
Magnesia (MgO)	0.96	0.1-4.0
Sodium oxide (Na_2O)	0.97	0.4-1.3
Potassium oxide (K_2O)	1.11	0.4-1.3
LOI	2.94	≤ 5
IR	1.6	≤ 2

3.2.4. Fine aggregates

River sand from a nearby area of zone III as per IS 383 (BIS 2002) was used as fine aggregates. The particle size distribution was derived from sieve analysis and other physical properties were ascertained by testing in the laboratory as shown in Fig.3.3. These properties are tabulated in Table 3.3 and Table 3.4 below.

Total weight taken = 1 kg

Table 3.3: Sieve analysis of fine aggregates

Sieve Size	Weight retained (g)	% Weight retained	Cumulative % retained	% Passing	IS:383 Limits for ZONE III
4.75 mm	13	13	1.3	98.7	90-100
2.36 mm	1	4	1.4	98.6	85-100
1.18 mm	180	194	19.9	80.1	75-100
600 µ	164	358	36.8	63.2	60-79

300 µ	262	820	83.5	16.5	12-40
150 µ	115	935	95.5	4.5	0-10

Table 3.4: Physical properties of fine aggregates

CHARACTERISTICS	RESULTS OBTAINED	REQUIREMENTS AS PER IS 383: 1970
Grading	Conforming to grading zone III	-
Fineness modulus	2.11	2.2-2.6
Specific gravity	2.61 (Dry basis) 2.64 (SSD basis)	2.6-2.7
Water absorption (%)	1.21	-
Moisture content (%)	1.20	-

Fig.3.3: Sieving of fine aggregates

3.2.5. Coarse aggregates

Locally available crushed stone angular aggregates with a nominal size of 12.5 mm were used as coarse aggregates. The particle size distribution was derived from sieve analysis and other physical properties were ascertained by testing in the laboratory as shown in Fig.3.4. These properties are tabulated in Table 3.5 and Table 3.6 below.

Fig.3.4: Sieving of coarse aggregates

Total weight taken = 5 kg

Table 3.5: Sieve analysis of coarse aggregates

Sieve Size	Weight retained (g)	% Weight retained	Cumulative % retained	% Passing	IS:383 Limits for aggregate of nominal size of 20 mm
40 mm	0	0	0	100	100
20 mm	26	0.52	0.52	99.48	95-100
16 mm	789	15.78	16.3	83.70	-
12.5 mm	1259	25.18	41.48	58.52	-
10 mm	602	12.00	53.52	46.48	25-55
4.75 mm	2045	40.90	94.42	5.58	0-10
2.36 mm	218	4.36	98.78	1.22	-
Residue	50	1	99.78	0.22	-
Total	4989	99.74	404.80	-	-

Table 3.6: Physical properties of coarse aggregates

CHARACTERISTICS	**RESULTS OBTAINED**	**REQUIREMENTS AS PER IS 383: 1970**
Grading	Conforming to grading zone III	-
Fineness modulus	4.048	5.5-8.0

Specific gravity	2.65	2.6-2.7
Water absorption (%)	0.56	-
Moisture content (%)	Nil	-

3.2.6. Geo-grid

Uniaxial geo-grid, manufactured by using knitted polyester yarns having high molecular weight and tenacity with a proprietary coating were employed in the present study as lateral tie to replace steel bars in hoop tension (shown in Fig.3.5). The average axial tensile strength of geo-grid is 200 kN/m, as obtained from the universal testing machine (UTM) in the laboratory.

Fig.3.5: Geo-grid used in the study

3.3. Preparation of specimens

Twenty eight specimens were prepared in 2 groups viz. Group 1 and Group 2, each containing 14 specimens of length 450 mm. The Group 1 specimens were casted as square columns of cross-section dimensions as 150 mm x 150 mm, and the Group 2 specimens were casted as circular columns with cross-section diameter as 150 mm.

3.3.1. Specimen designation

The column specimens were prepared and each specimen was given a unique identity as its designation. The Table 3.7 represents the designations allotted to the specimens.

Table 3.7: Specimen designation

Specimen Identity	Description
CC 50	Circular column with spacing in lateral ties as 50 mm
CC 100	Circular column with spacing in lateral ties as 100 mm
CC 200	Circular column with spacing in lateral ties as 200 mm
CC 400	Circular column with spacing in lateral ties as 400 mm
CC 200G	Circular column with spacing in lateral ties as 200 mm with Geo-grid
CC 400G	Circular column with spacing in lateral ties as 100 mm with Geo-grid
SC 50	Square column with spacing in lateral ties as 400 mm
SC 100	Square column with spacing in lateral ties as 400 mm
SC 200	Square column with spacing in lateral ties as 400 mm
SC 400	Square column with spacing in lateral ties as 400 mm
SC 200G	Square column with spacing in lateral ties as 400 mm with Geo-grid
SC 400G	Square column with spacing in lateral ties as 400 mm with Geo-grid

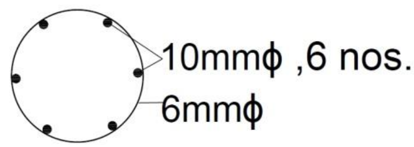
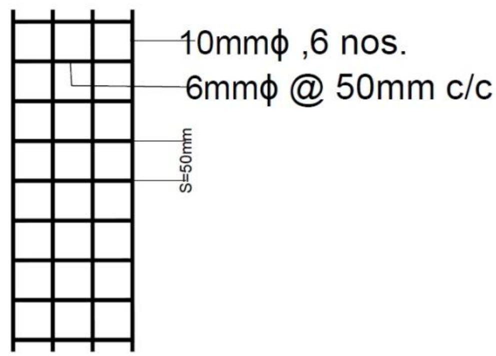
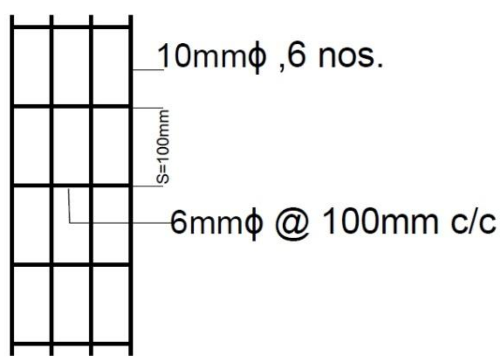
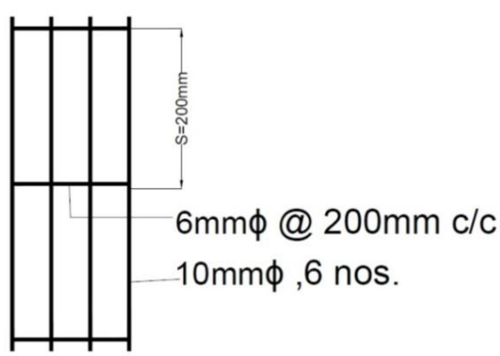
3.3.2. Reinforcement arrangement

For longitudinal reinforcement, 4 bars of 12 mm Φ were used in each Group 1 (square) specimens, and 6 bars of 10 mm Φ were used in each Group 2 (circular) specimens. The column specimens were provided with lateral reinforcing steel ties of 6 mm Φ at a distinguished spacing of 50 mm, 100 mm, 200mm and 400mm, with and without geo-grid. The longitudinal and lateral reinforcement details of specimens are shown in Table 3.7 and Table 3.8 tabulated below.

Table 3.8: Lateral reinforcement details

Lateral reinforcement spacing	No. of specimens (without geo-grid)	No. of specimens (with geo-grid)
50mm	2	-
100mm	2	-
200mm	2	3
400mm	2	3

Table 3.9 (a): Detailing of circular column specimens

Sr. No.	Designation	Detailing
1	Top view	
2	CC 50	
3	CC 100	
4	CC 200	

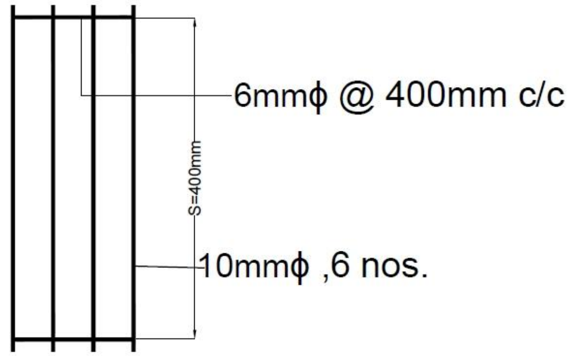
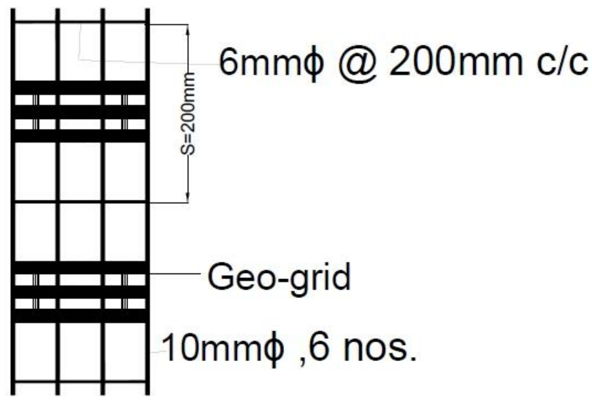
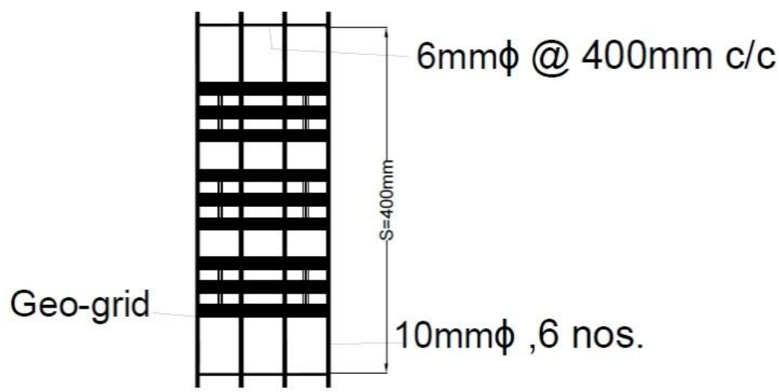
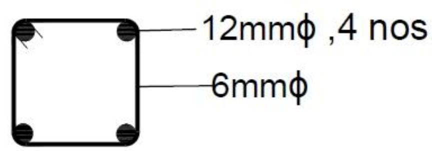
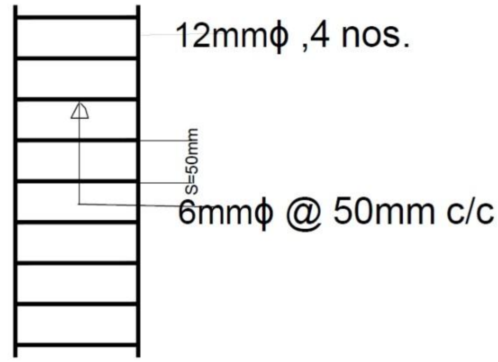
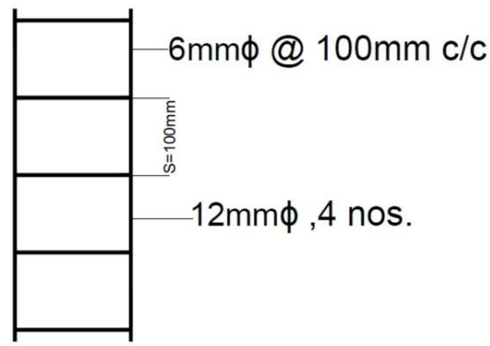
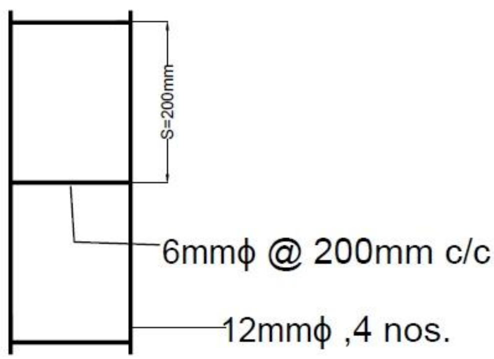
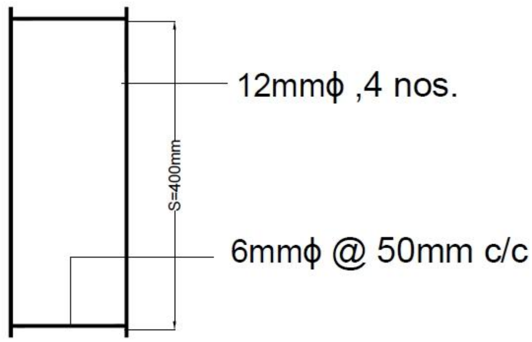
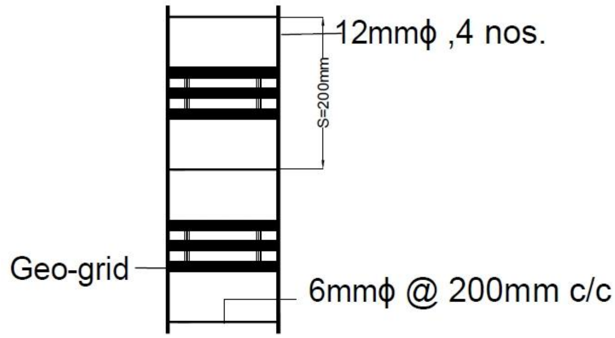
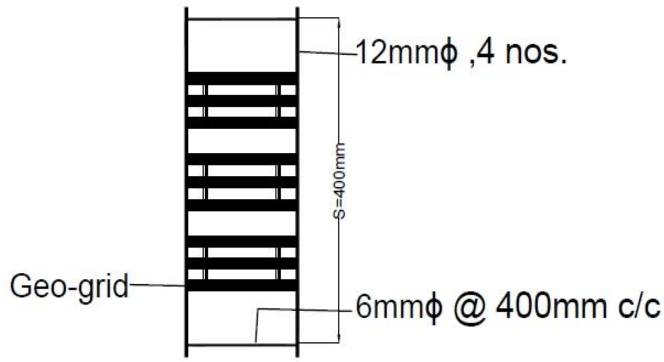
5	CC 400	
6	CC 200G	
7	CC 400G	

Table 3.9 (b): Detailing of square column specimens

Sr. No.	Designation	Detailing
1	Top view	

2	SC 50	
3	SC 100	
4	SC 200	
5	SC 400	

6	SC 200G	
7	SC 400G	

3.3.3. Geo-grid application

Uniaxial geo-grid was tied to the 3 of the specimens, each with a lateral steel spacing of 200 mm and 400 mm respectively, in both the groups. The specimens were casted and painted in white colour before being tested, for better crack monitoring.

Fig.3.6: Geo-grid tied column specimens

3.3.4. Concrete Mix

A standard concrete mix was prepared for M25 using the ratios mentioned in Table 3.10 below. Due considerations were given while designing and proportioning of the mix that the guidelines of IS: 10262 (BIS 2009) are followed. The design mix so prepared was used to cast all the specimens. The details of concrete mix proportions are described in Table 3.10 and the compressive strength of cubes and the split tensile strength of cylinders after 28 days and 56 days are described in Table 3.11 below.

Table 3.10: Concrete mix proportions

Cement (kg/m^3)	Water (kg/m^3)	Fine aggregates (kg/m^3)	Coarse aggregates (kg/m^3)
430	186	690	1156

Table 3.11: Strength of specimens

Strength of specimen	28 days (MPa)	56 days (MPa)
Compressive strength of cube	31.8	33.4
Split tensile strength of cylinder	2.597	2.85

3.3.5. Mixing and Casting

Hand mixing was adopted to mix the constituents in required proportions. The quantities of each constituent viz. cement, water, fine aggregates and coarse aggregates, were kept ready for each batch of casting, before being mixed. Initially, the cement and fine aggregates were mixed in a dry state till uniformity is appeared. The uniformity was observed by the absence of concentration of one material at a place i.e. absence of lumps. Then, the coarse aggregates were added to the mix and mixed thoroughly to get a uniform mix in dry state. Water was then added skillfully to the mix and mixed thoroughly till a uniform concrete paste is prepared. Before placing the concrete in the molds, the workability of the concrete was ascertained by slump test. An appropriate value for workability was established for mix of all batches. An average value of results of slump for five batches is shown in Table 3.12 below.

Table 3.12: Results of slump test

Date	Slump (mm)
28/04/2017	76
01/04/2017	74
02/04/2017	79
03/04/2017	82
04/04/2017	78

Fig.3.7: Preparation of circular column specimen

The molds for specimens were already prepared, cleaned, and brushed with oil before the casting process. After verifying the workability of the prepared concrete mix, the molds were put on a vibrating table with a speed range of 12000 ± 400 revolutions per minute and an amplitude range of 0.055 mm. The concrete was put in the molds in three layers and then vibrated properly to remove the air voids and ensure proper compaction. The molds used were plastic molds (for circular column specimens) and steel molds (for square column specimens) available in the laboratory. After 24 hours, the specimens were de-molded, marked, and enwrapped with wet burlap in the laboratory as shown in Fig.3.8 below. These burlaps were cured from time to time to remain wet. The curing period lasted 28 days after which the specimens were uncovered to dry and ready for testing. The test cubes and test cylinders were also casted, marked and kept immersed in water for a period of 28 days.

(a)

(b)

Fig.3.8: Curing of specimens using wet burlap

3.3.6. Surface preparation

The end surfaces of the column specimens were thoroughly rubbed with a grinder so as to obtain a smooth and leveled surface. The leveled surface helps the specimen in obtaining true load upon itself when subjected to compression loading in ACTM (Automatic Compression Testing Machine).

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1. General

This chapter presents the results obtained from the compression tests performed on the specimen columns and discusses the effect on various parameters of compressive strength of the specimens with varying amount of steel and geo-grid in lateral confinement. The test specimens had been casted for a mix proportion of M25 (1: 1.60 :2.69), properly cured for 28 days and precisely tested in Automatic Compression Testing Machine (ACTM) to compute the load-deflection values. Three test cubes were also casted from the same mix, each time the mix was prepared, and subjected to compressive loading in ACTM to ascertain the strength of the specimens prepared. The test cubes in ACTM provided the following compressive strengths as mentioned in Table 4.1 below.

Table 4.1: Compressive strength of cubes

Date	Average compressive strength of cubes (MPa)
28/04/2017	36.2
01/04/2017	34.8
02/04/2017	35.4
03/04/2017	37.8
04/04/2017	35.1

(a)

(b)

Fig.4.1: Specimens painted in white colour for crack monitoring

The column specimens were painted in white colour for better crack monitoring (as shown in Fig.4.1) also subjected to axial compression loading in ACTM (as shown in Fig.4.2) and the output was thoroughly analyzed to obtain the peak load, ductility, stiffness and energy absorption of the prepared specimens. Corresponding graphs were plotted and a comparison was done of the above mentioned properties.

Fig.4.2: Test setup

4.2. Load-deflection behavior

The general load-deflection behavior of the columns can be assessed from the graphs obtained for the control specimens, both in circular and square columns. The average load-deflection behavior of the circular column specimens can be seen in Fig.4.3 (a) and for square column specimens can be seen in Fig.4.3 (b) below. From both the figures, it can be concluded that, in case of columns (both circular and square), the strength of the column increases with increase in the lateral reinforcement, for the reason being that the confinement helps to increase the axial load carrying capacity of the column by providing lateral reaction against bulging and buckling. Thus, more the confinement, greater will be the load carrying capacity of the compression member. It can also be observed that as the amount of lateral reinforcement decreases, the ductility of the column decreases, and the column behavior becomes more and more brittle. It was also observed that the energy absorption of the columns decreases with decrease in lateral reinforcement.

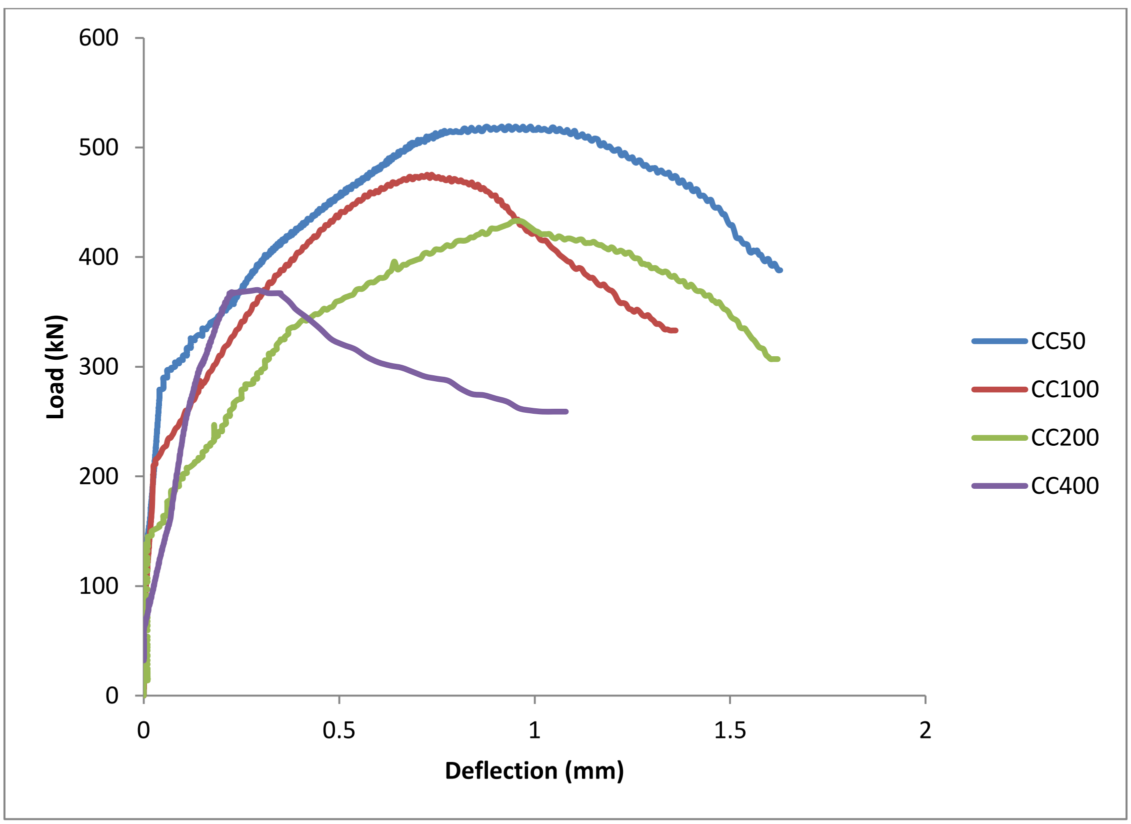


Fig.4.3 (a): Average load-deflection behavior of circular column specimens

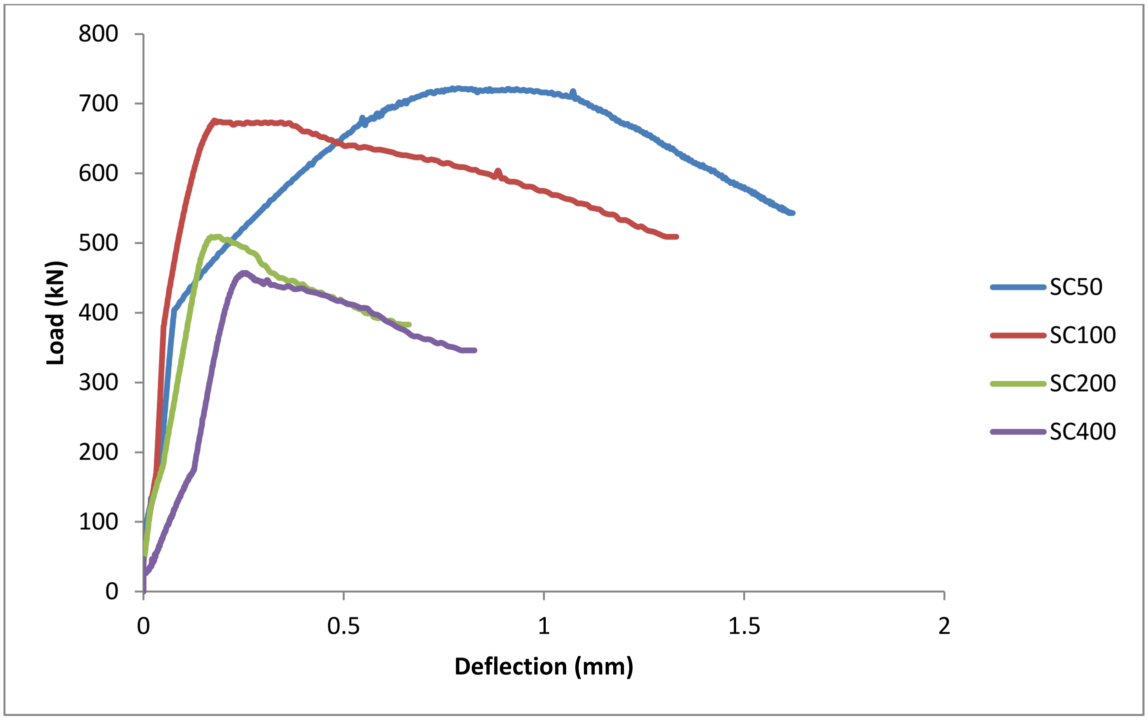


Fig.4.3 (b): Average load-deflection behavior of square column specimens

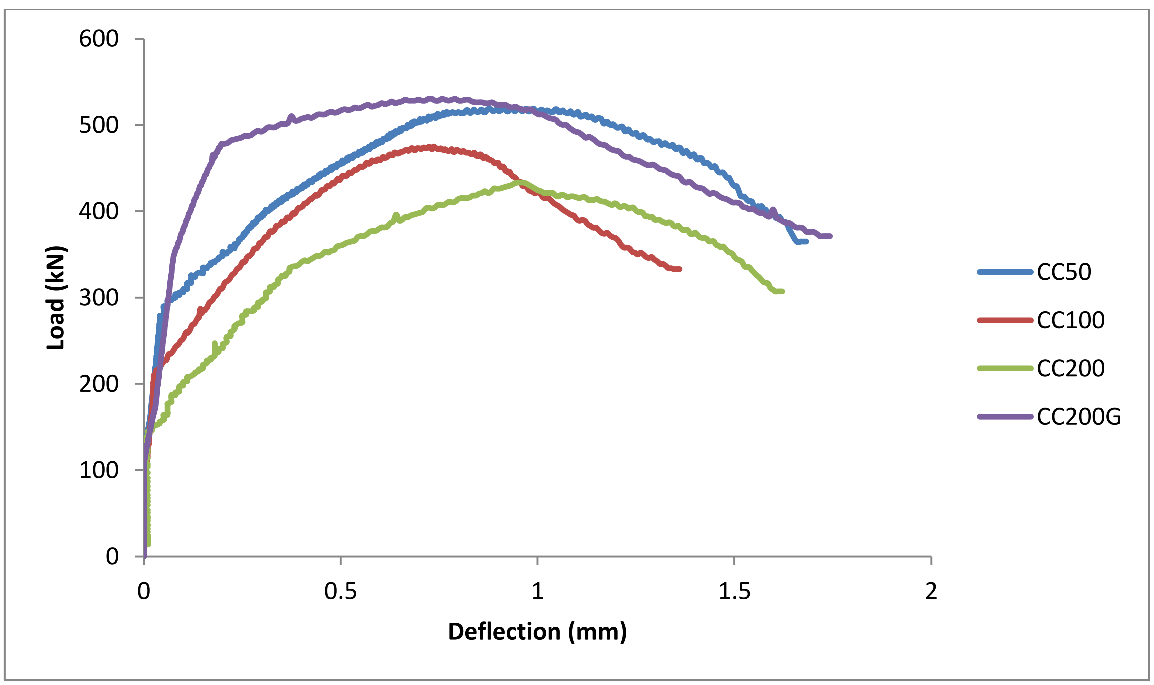


Fig.4.4 (a): Comparison of load-deflection behavior of CC 200G with control specimen

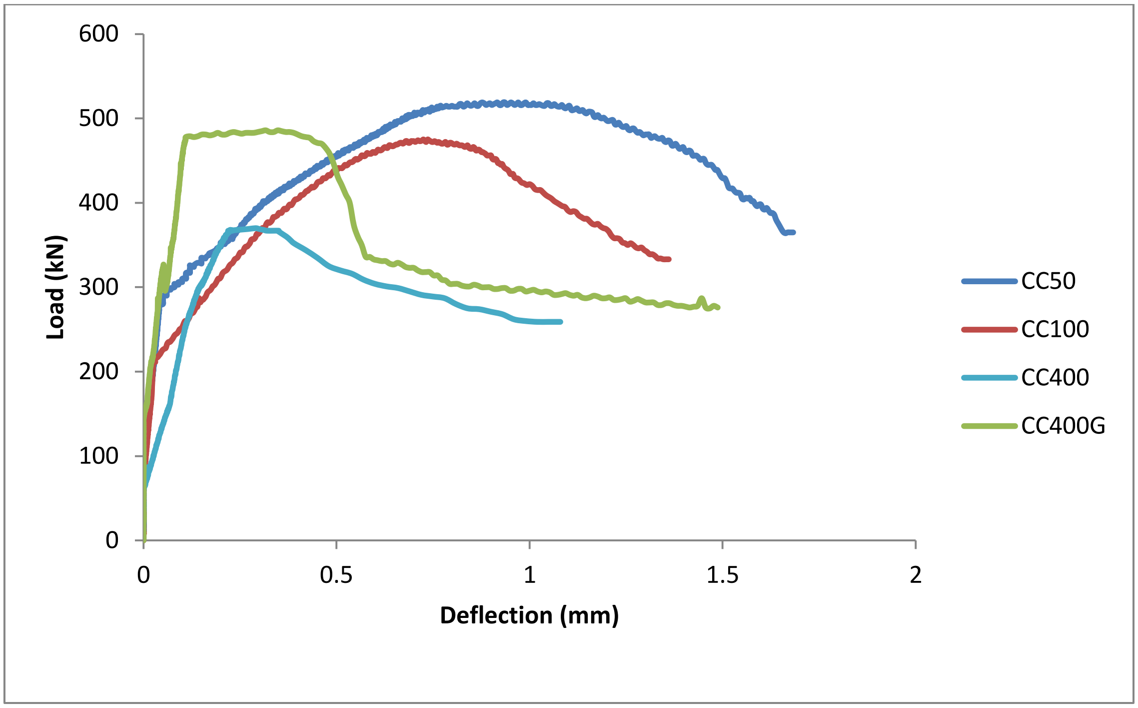


Fig.4.4 (b): Comparison of load-deflection behavior of CC 400G with control specimen

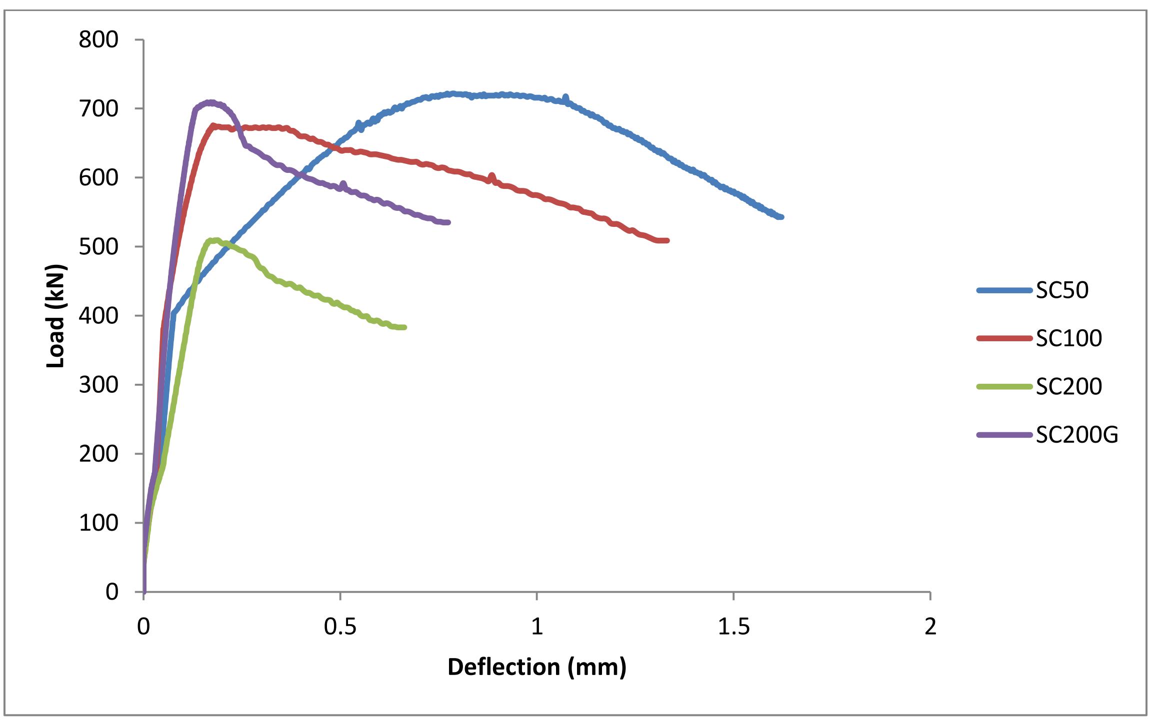


Fig.4.5 (a): Comparison of load-deflection behavior of SC 200G with control specimen

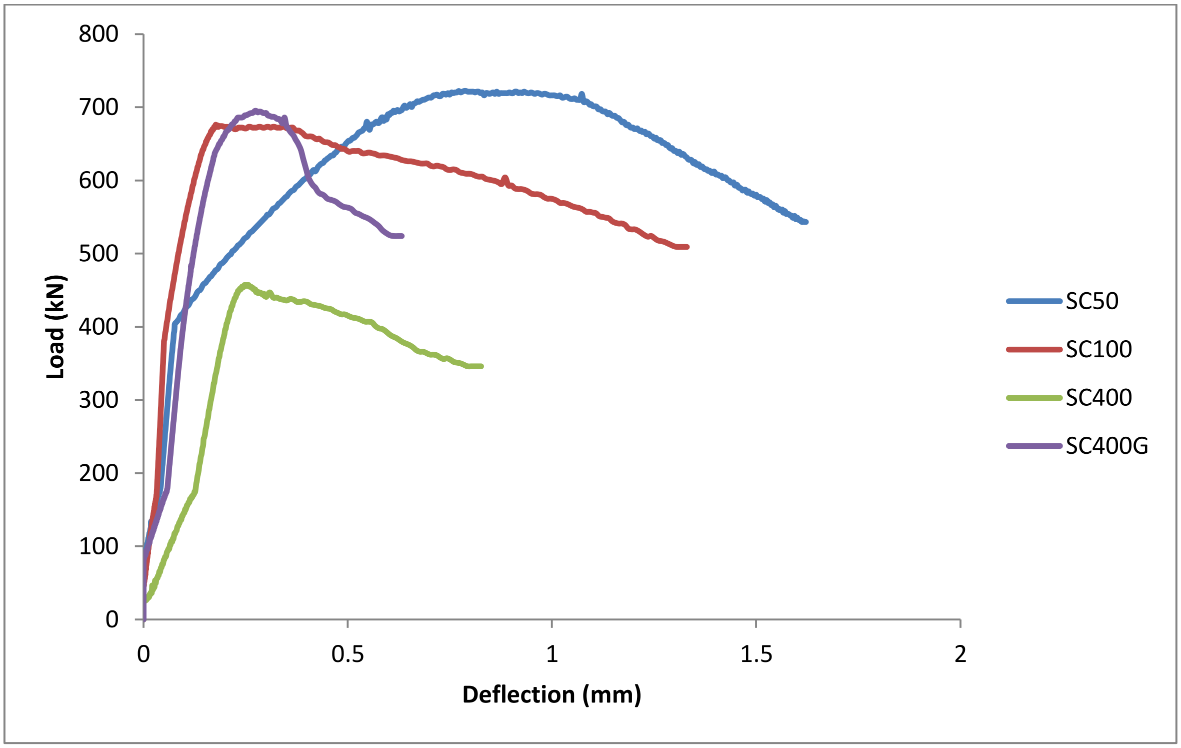


Fig.4.5 (b): Comparison of load-deflection behavior of SC 400G with control specimen

Table 4.2: Test results

Specimen Designation	Ultimate load (kN)		0.8 Ultimate load		Secant Stiffness P_u/Δ_u	Energy dissipation (kN-mm)
	P_u (kN)	Δ_u (mm)	P_f (kN)	Δ_f (mm)		
CC 50	519	0.88	415.2	1.53	589.77	534.6
CC 100	475	0.74	380	1.16	641.89	224
CC 200	433	0.96	346.4	0.43	451.04	270
CC 400	370	0.29	296	0.69	1275.86	74.9
CC 200G	530	0.72	424	1.43	736.11	212
CC 400G	486	0.35	388.8	0.54	1388.57	89.15
SC 50	722	0.77	577.6	1.51	937.66	494
SC 100	676	0.18	540.8	1.72	3755.56	171
SC 200	509	0.17	407.2	0.53	2994.12	74.98
SC 400	457	0.25	365.6	0.68	1828	116
SC 200G	709	0.18	567.2	0.59	3938.89	98
SC 400G	695	0.27	556	0.52	2574.07	124

4.3. Effect on Peak Strength

The effect of confinement on peak strength of the column can be understood from the Table 4.2 and Table 4.3. The table represents the results obtained from the experiment.

Table 4.3 (a): Peak strength in circular column specimens

R/f Spacing (mm)	Peak Strength			
	Control specimen	**Circular Columns, CC**	**CC 200G Peak Strength comparison**	**CC 400G Peak Strength comparison**
50	100%	-	+2.1%	-6.4%
100	-	-8.5 %	+11.6%	+2.3%
200	-	-16.6 %	+22.4%	+12.2%
400	-	-28.7 %	+43.2%	+31.4%
200G	-	+2.1 %	-	-
400G	-	-6.4 %	-	-

Table 4.3 (b): Peak strength in square column specimens

R/f Spacing (mm)	Peak Strength			
	Control specimen	**Square Columns, SC**	**SC 200G Peak Strength comparison**	**SC 400G Peak Strength comparison**
50	100%	-	-1.8%	-3.7%
100	-	-6.4 %	+4.9%	+2.8%
200	-	-29.5 %	+39.3%	+36.5%
400	-	-36.7 %	+55.1%	+52.1%
200G	-	-1.8 %	-	-
400G	-	-3.7 %	-	-

As seen from the Table 4.2 and Table 4.3 above, it is evident that, as we reduce the confinement the load carrying capacity of the column decreases. In circular columns, when the confinement spacing in steel is increased from 50mm to 100 mm, there is a fall of 8.5% in peak strength of the column. Reducing it further to 200mm, gives a total fall of 16.6%, which on further reduction to 400mm leaves us with 28.7% downfall from the initial. However, when geo-grid is confined to column with 200mm confinement spacing, this trend is altered. In CC200G, the geo-grid confinement increased the peak strength of the column by 2.1%, whereas, the CC400G showed a downfall of only 6.4%, which is significantly lesser than the control specimens. Also, the CC200G and CC400G specimen showed strength higher than the control specimens as depicted from table 4.2. The CC200G showed increase in strength by 2.1% than CC50 specimen, 11.6% more than CC100 specimen, 22.4% more than CC200 specimen, and 43.2% more than CC400 specimen. The CC400G showed decrease in strength by 6.4% than CC50 specimen, but showed increase in peak strength in all other specimens. It showed peak strength 2.3% more than CC100 specimen, 12.2% more than CC200 specimen, and 31.4% more than CC400 specimen. This shows that geo-grid confinement was able to maintain substantial confinement standards in specimens.

Similarly, in square columns, as we increased the confinement spacing, the peak strength of the column showed a significant downfall of 6.4%, 29.5% and 36.7%. However, specimens with geo-grid confinement were able to maintain the peak strength. SC200G showed a downfall of only 1.8%, and SC400G showed a loss of 3.7% in peak strength, which are significantly lesser than the control specimens. The SC200G showed decrease in strength by 1.8% than SC50 specimen, but increase in peak strength in all other specimens. It showed peak strength 4.9% more than SC100 specimen, 39.3% more than SC200 specimen, and 55.1% more than SC400 specimen. The SC400G showed decrease in strength by 3.7% than SC50mm specimen, but increase in peak strength in all other specimens. It showed peak strength 2.8% more than SC100 specimen, 36.5% more than SC200 specimen, and 52.1% more than SC400 specimen. This also shows that geo-grid confinement was able to maintain substantial confinement standards in specimens.

Now, this clearly explains the role of confinement in columns. The confinement gives lateral reaction against bulging and buckling on application of load, which helps to increase the axial load carrying capacity of the column, which can also be seen in the trend of the results of the control specimens. When geo-grid is confined to specimens, it increases the confinement action and therefore prevents loss in peak strength. Thus, from the experiments it is evident that geo-grid confinement can serve as the lateral confinement along with steel ties, to increase the axial load carrying capacity of the column

4.4. Effect on Secant Stiffness

In the present study, the secant stiffness has been calculated by dividing the measured ultimate load by the measured ultimate displacement at the mid-height of the column specimen, as shown in the Fig.4.6 below. The results were collected and secant stiffness was computed using the relevant data and tabulated in Table 4.4 below.

It can be seen from the table that as the spacing in confinement increases, the secant stiffness increases for the simple reason that, as the amount of steel in the column specimen decreases, integrity of the material increases, and therefore, its stiffness increases.

In circular column specimens, it was observed that the secant stiffness increased by 8.84%, 23.52% and 116.33% in control specimens CC 50, CC 100 and CC 200. The geo-grid confined specimens, however, showed a higher stiffness as compared to control specimens (+24.81% and +135.44%), which proves their compatible integrity with the concrete matrix.

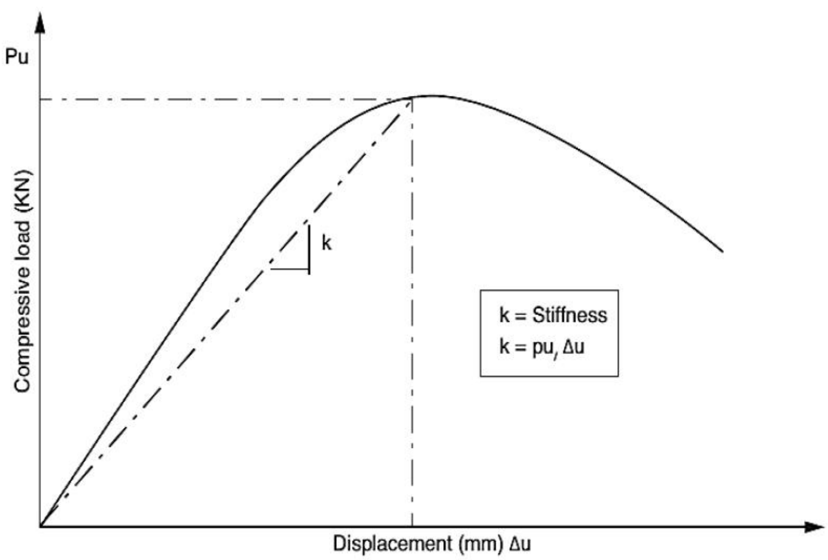


Fig.4.6: Secant stiffness [Danie et. al. (2014)]

Table 4.4 (a): Secant stiffness in circular column specimens

R/f Spacing (mm)	**Secant Stiffness**			
	Control specimen	**Circular Columns, CC**	**CC 200G Secant stiffness comparison**	**CC 400G Secant stiffness comparison**
50	100%	-	+24.8%	+135.4%
100	-	+8.84%	+14.7%	+116.3%
200	-	+23.52%	+63.2%	+207.9%
400	-	+116.33%	-42.3%	+8.8%
200G	-	+24.81%	-	-
400G	-	+135.44%	-	-

Table 4.4 (b): Secant stiffness in square column specimens

R/f Spacing (mm)	Secant Stiffness			
	Control specimen	**Square Columns, SC**	**SC 200G Secant stiffness comparison**	**SC 400G Secant stiffness comparison**
50	100%	-	+320.1%	+174.5%
100	-	+300.52%	+4.9%	-31.5%
200	-	+219.32%	+31.6%	-14.1%
400	-	+94.95%	+115.5%	+40.8%
200G	-	+320.08%	-	-
400G	-	+174.52%	-	-

The square column specimens, on the other hand, showed a much higher stiffness and a relatively large increment in stiffness, as compared to circular specimens. This is due to the reason that the area of cross-section of square specimens is more than that of circular specimens. The geo-grid in square column specimens also proved to be integral with concrete, by showing larger stiffness than the control specimens. The behavior of column specimens in terms of secant stiffness is depicted in Fig.4.7 below.

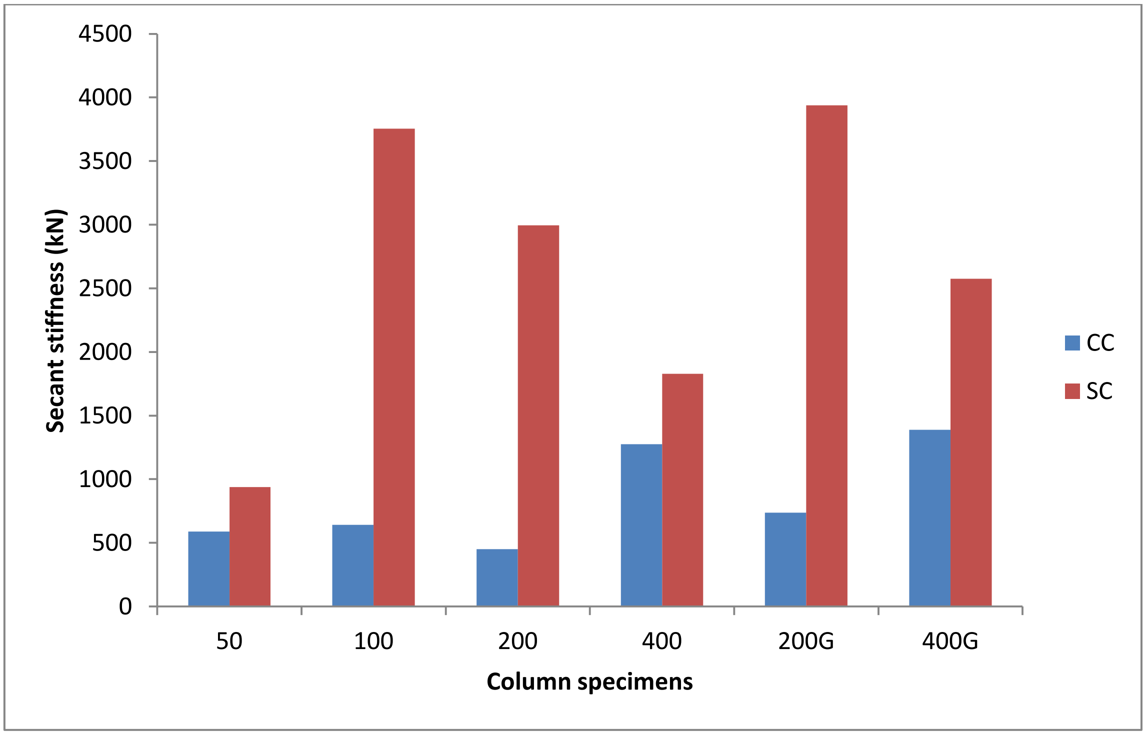


Fig.4.7: Secant stiffness behavior of column specimens

4.5. Effect on Energy dissipation

Energy dissipation is defined as the amount of energy a material can absorb before failure. It can also be defined as the area under the load-deflection curve of the material. The energy absorption capacity values were calculated up to 80% of P_u on the descending portion of the curve as shown in the Fig.4.8 below. Energy dissipation values are calculated from the results obtained and tabulated in the Table 4.5 below.

It can be observed that energy dissipation values decreases with reduction in amount of lateral steel ties. This can be understood by the fact that, with the reduction in ductility of a specimen, the stiffness of the specimen increases, which decreases the energy dissipation capacity of the column.

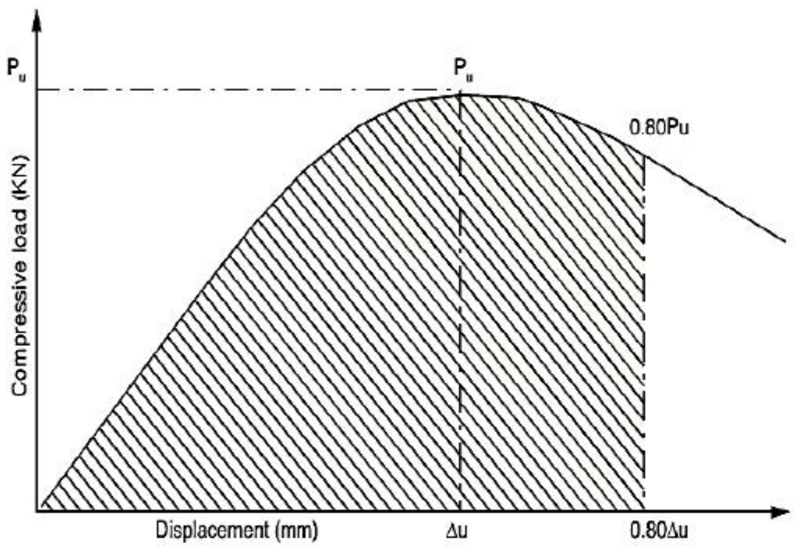


Fig.4.8: Energy dissipation calculation [Danie et. al. (2014)]

Table 4.5 (a): Energy dissipation in circular column specimens

R/f Spacing (mm)	Energy Dissipation			
	Control Specimen	Circular Columns, CC	CC 200G Energy dissipation comparison	CC 400G Energy dissipation comparison
50	100%	-	-60.3%	-83.3%
100	-	-33.77%	-5.3%	-60.2%
200	-	-20.28%	-21.5%	-66.9%
400	-	-73.30%	+183.1%	+19.1%
200G	-	-10.03%	-	-
400G	-	-55.98%	-	-

Table 4.5 (b): Energy dissipation in square column specimens

R/f Spacing (mm)	Energy Dissipation			
	Control Specimen	**Square Columns, SC**	**SC 200G Energy dissipation comparison**	**SC 400G Energy dissipation comparison**
50	100%	-	-80.2%	-74.9%
100	-	-42.27%	-42.7%	-27.5%
200	-	-80.05%	30.7%	+65.4%
400	-	-60.94%	-15.5%	+6.9%
200G	-	-74.75%	-	-
400G	-	-61.81%	-	-

The geo-grid confined specimens, however, showed some higher values of energy dissipation, when compared to control specimens. Although, CC200G showed a downfall, as compared to CC400 specimen but it can be generalized that the geo-grid confined specimens improved the energy dissipation capacities of the specimens. The relevant comparison of energy dissipation is presented in Table 4.5 above. The energy dissipation of the column specimens is also depicted in Fig.4.9 below.

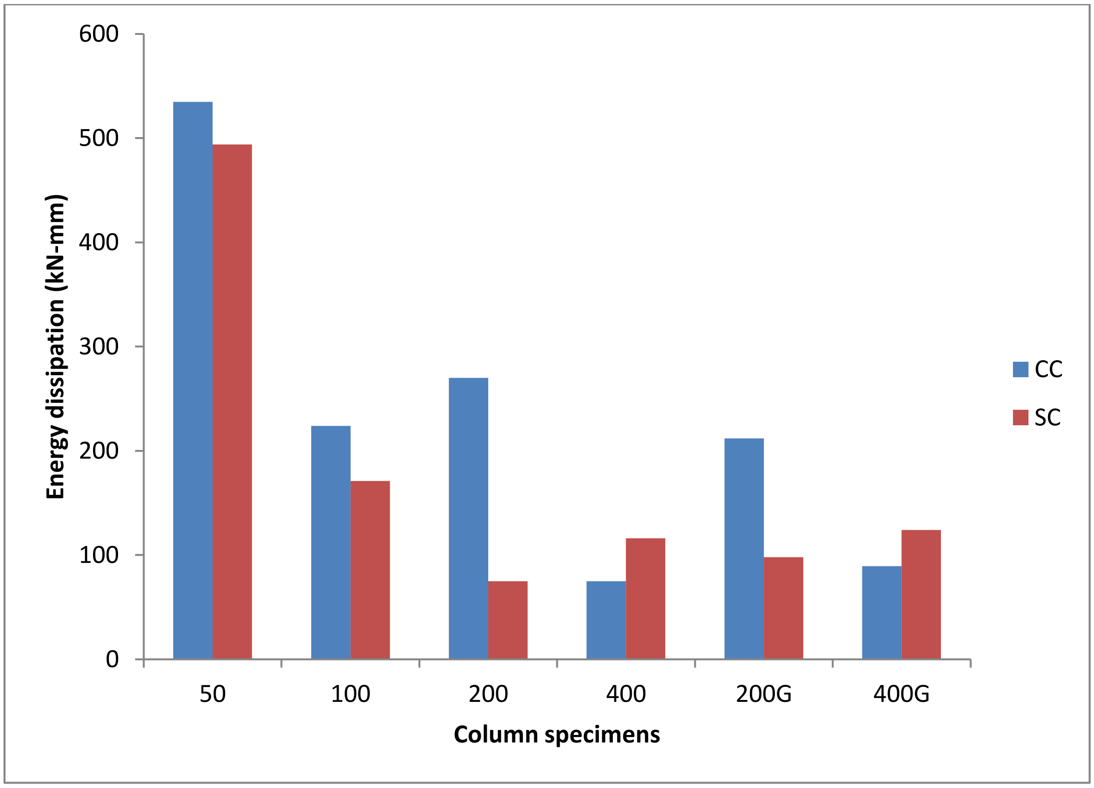


Fig.4.9: Energy dissipation behavior of column specimens

The characteristic data for deformability and ductility was also observed from the obtained results. It was observed that with decrease in lateral steel confinement, both in circular and square column specimens, the specimen showed gradual decrease in ductility behavior. It can be accounted for the simple reason that the reduction of ductile component (steel) and increase in the brittle component (concrete) in the specimen reduced the ductility of the specimen. However, specimens with geo-grid confinement did not lost ductility as much as control specimens. In fact, from the data computed, it can be inferred that they possess significant ductile behavior.

CHAPTER 5
CONCLUSION AND FUTURE SCOPE

5.1. Conclusion

We have seen various applications of geo-grid and inspected whether it can serve as a confining member along with conventional steel. Twenty eight column specimens were prepared in total, with different proportions of conventional steel and geo-grid, and tested in Automatic Compression Testing Machine (ACTM) to find the strength parameters of the column specimens and the following conclusions were drawn:

- The peak strength of the geo-grid confined specimen increased as much as 43.2% in case of circular column specimens and up to 55.1% in case of square column specimens, as compared to control specimens.
- The secant stiffness values showed an increment. For the circular column specimens, the value increased up to 115.5% more than the control specimen, and for square column specimens, the value increased up to 207.9% as compared to column specimen.
- The energy dissipation values of the geo-grid confined specimens came out to be more than the control specimens. For circular column specimens, the values reached as much as 30.7% more than the control specimens, and in square column specimens, the values reached up to 65.4% more than the control specimens.

It was seen that the geo-grid as a confining member proved to improve the strength characteristics of the column specimens. Thus, it can be used as a confining member in the columns along with the conventional steel ties. After observing the physical and chemical properties of the geo-grid, and performing the relevant tests, it can be firmly said that the geo-grid as the only member in confinement may not fulfill the purpose, but as a partial replacement with steel confinement will serve the purpose efficiently.

5.2. Future scope

In the present study, the column specimens prepared and tested were merely prototypes. An extensive study needs to be carried out on full scale columns to increase the reliability of the data obtained and to arrive at more precise conclusions. Although, the study revealed positive characteristics of the geo-grid yet more tests need to be conducted on the material to unfold its many other properties and ascertain its scope to be used as a construction material.

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