EFFECT OF PARTIAL GEO-GRID CONFINEMENT ON CIRCULAR COLUMNS UNDER AXIAL LOADING

A thesis submitted in fulfillment of the requirement for the award of degree of

MASTER OF ENGINEERING
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Submitted by

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DECLARATION

I, Pavitar Singh hereby declare that the work which is presented in this thesis report entitled **"Effect of Partial Geo-Grid Confinement on Circular Columns Under Axial Loading"** in fulfilment of requirement for the award of degree of **Master of Engineering** in **Structures,** submitted at **Civil Engineering Department, Thapar Institute of Engineering & Technology(Deemed to be University), Patiala,** is an authentic record of the work carried out under the guidance of **Dr. A.B. Danie Roy, Assistant Professor, Department of Civil Engineering, Thapar Institute of Engineering & Technology , Patiala** from January 2018 to June 2018. The matter presented in this has not been submitted either in part or full to any other university or institute for the award of any other degree.

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CERTIFICATE

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

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ABSTRACT

The present research work deals with the application of geogrids in columns, that is partially replacing the conventional way of confining via stirrups with an alternative technique, means using geogrids partially as confining material along with stirrups. The reasons that has inspired for such an experimental research include fact that geogrids are good at tension and encourage flexibility, easy to handle (lighter in weight) and economical compared to steel. Total of sixteen columns (8 types) were casted. The parameters included spacing of stirrups (150 mm and 450 mm), use of type of concrete (NC and SFRC) and use of type of geogrids (average tensile strength of 100 kN/m and 200 kN/m). The columns were subjected to axial load under UTM and their load deflection curves were plotted and parameters such as ultimate load, maximum axial displacement, secant stiffness, ductility and energy dissipation were evaluated and compared. The test results revealed that application of geogrids along with fibres significantly improved the strength parameters of columns, thus paving out new way of reinforcing columns in combination with steel fibres.

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LIST OF ABBREVIATIONS

NC	Normal Concrete
SFRC	Steel Fibre Reinforced Concrete
ACTM	Automatic Compression Testing Machine
ACI	American Concrete Institute
FRP	Fibre Reinforced Polymer
CFST	Concrete Filled Steel Tube
IS	Indian Standard
$\mathbf{G_{100}}$	Geogrids with average tensile strength of 100 kN/m
$\mathbf{G_{200}}$	Geogrids with average tensile strength of 200 kN/m
RC	Reinforced Concrete
HSCFST	High Strength Concrete Filled Steel Tube
NSC	Normal Strength Concrete
OPC	Ordinary Portland cement
SCC	Self Compacting Concrete
GFRP	Glass Fibre Reinforced Polymer
CFRP	Carbon Fibre Reinforced Polymer
HSW	High Strength Steel Wires

CHAPTER 1

INTRODUCTION

1.1 General

Generally confinement can be defined as act of imprisonment, custody, captivity, restraint or arrest. Thus confines mean something (such as walls or borders) that encloses something that obstructs or restrains. In case of civil engineering we deal with structures that are composed of concrete as one of its main constituent materials along with steel as material for reinforcement. Thus talking about confinement in case of concrete, confined concrete can be defined as a concrete which has closely spaced special transverse reinforcement which restrains or disallows the concrete in directions perpendicular to applied stress. So here what we need to notice is that load is perpendicular to the direction of reinforcement and it is this transverse reinforcement which makes the concrete restricted.

Columns (or say compression members) are subjected to axial loads in a structure. According to *ACI Code 2.2,* a structural element with a ratio of height-to-least lateral dimension exceeding three used primarily to support compressive loads is defined as column. IS code 456:2000 vide clause 25.1.1 defines that column or strut is a compression member, the effective length of which exceeds three times the least lateral dimension.

1.2 Role of Confinement in RC Columns

Columns are one of the main supporting components of structure and may be subjected to strong earthquakes or accidental lateral loads. So in such cases it becomes important to safeguard them against such forces which may not only lead to their failure as individual but also indirectly the failure or collapse of structure as whole. In order to tackle such circumstances the need of transverse reinforcement, say in form of hoops, spirals, or cross ties becomes important. Transverse reinforcement tries to hold both main reinforcement as well as concrete in its position when subjected to loads (axial loads) and prevents them from moving out or bulging out, thus providing purpose of confinement as well as enhancing strength and durability of columns. Columns when subjected to axial load may fail (in case load exceeds beyond designed) due to excessive cracking in concrete section followed by buckling of longitudinal reinforcement within failure region as shown in Figure 1.1. Thus effective confinement becomes necessary so as to prevent buckling of longitudinal bars which further prevents column failure as well as structural failure indirectly.

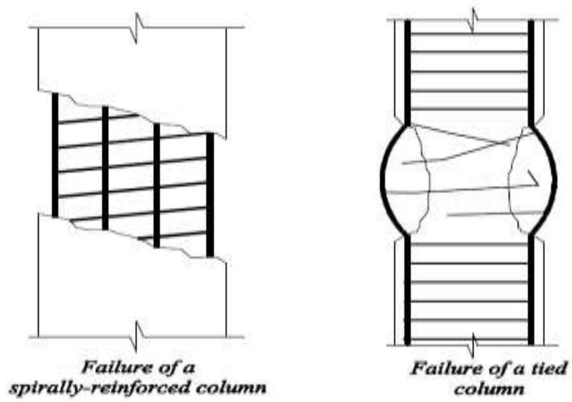


Figure 1.1 Failure of spirally reinforced and tied column

Confinement can be provided both internally or externally. Considering the simple reinforced concrete columns the conventional way of providing confinement internally can be in form of ties (in case of square or rectangular columns) or in form of spirals (in case of circular columns). A minimum of four longitudinal bars are recommended in case of square and rectangular cross sections that are arranged within ties. Spirally-reinforced columns are columns in which the longitudinal bars (minimum of six recommended) are arranged in a circular formation surrounded by a closely spaced continuous spiral.

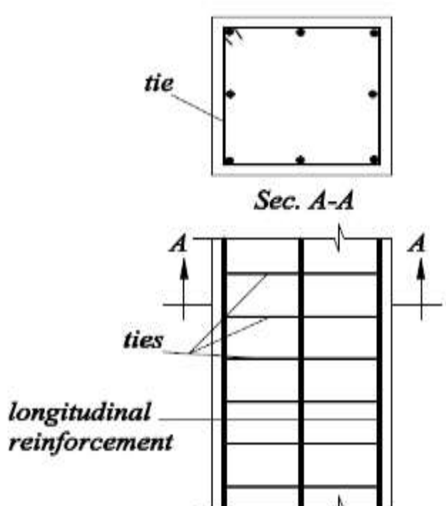


Figure 1.2 Tied columns

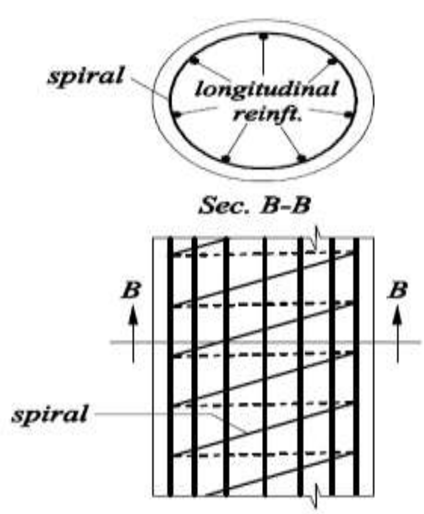


Figure 1.3 Spirally reinforced columns

1.3 Effect of spacing on confinement

Generally the spacing of transverse reinforcement plays an important role in defining the extent up to which its purpose is served effectively. Larger spacing of transverse reinforcement results in poor confinement of both main reinforcement as well as concrete which leads to columns failure often early in form of cover spalling and buckling before it reach design load (ultimate load). And on another side smaller spacing may lead to congested frame which may result in difficulties in casting and formation of weak zone between core concrete and cover concrete which may again lead to early spalling of cover concrete. Thus need for effective spacing becomes important which may compensate the issues related to both larger and smaller spacing.

1.4 Design equations and arrangement of transverse reinforcement for columns as per IS and ACI codes

Various design equations have been suggested by different codes to provide the effective confinement in case of columns. The parameters that were taken into account while producing these design equations for confinement include:

1. effective confining pressure or concrete strength to tie strength ratio
2. level of axial load
3. thickness of unconfined cover concrete
4. longitudinal reinforcement and spacing
5. curvature ductility factor

Following are the final derived equations as suggested by Indian code (IS: 456) and ACI code for ultimate loads and other parameters that column must carry;

1.4.1 As per IS: 456

- $P_u = 0.4 f_{ck} A_c + 0.67 f_y A_{sc}$ (for tied columns)
- $P_u = 1.05(0.4 f_{ck} A_c + 0.67 f_y A_{sc})$ (for spiral columns)

Where;

P_u = factored axial load on the member,

f_{ck} = characteristic compressive strength of the concrete,

A_c = area of concrete,

f_y = characteristic strength of the compression reinforcement

A_{sc} = area of longitudinal reinforcement for columns.

Also considering the one of main parameters for spiral columns that is pitch, the equation given in IS: 456 is as

- $\mathbf{p \le 11.1(D_c - \phi_{sp})\, a_{sp} f_y/(D^2 - D_c^2) f_{ck}}$

Where;

p = pitch of spiral reinforcement

D_c = diameter of the core

ϕ_{sp} = diameter of the spiral reinforcement

a_{sp} = area of cross-section of spiral reinforcement

Clause 26.5.3.2 of IS 456 describes the arrangements for the transverse reinforcement which are shown in Figures below:

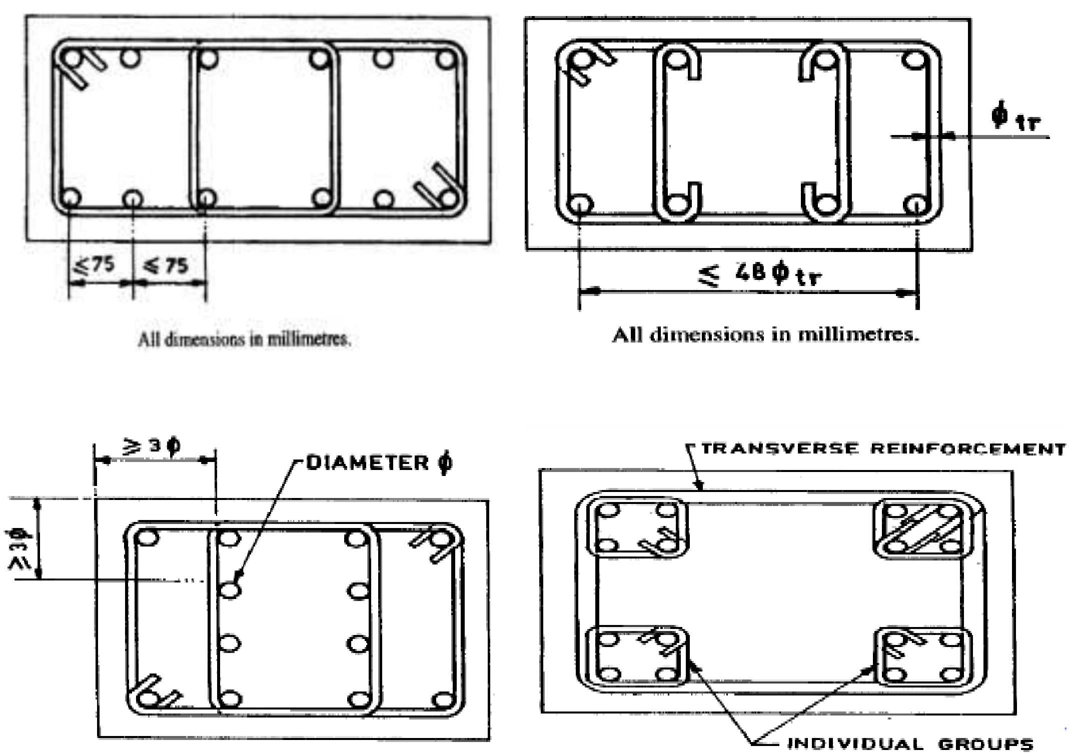


Figure 1.4 Arrangement of ties (IS 456:2000)

1.4.2 As per ACI code

- $P_u = 0.52\, A_g\, [0.85\, f'_c + \rho_g(f_y - 0.85\, f'_c)]$ (for tied columns)
- $P_u = 0.6375\, A_g\, [0.85\, f'_c + \rho_g(f_y - 0.85\, f'_c)]$ (for spirally reinforced columns)

Where;

P_u = factored axial load

A_g = gross sectional area of column

f'_c = concrete compressive strength at 28-days

ρ_g = reinforcement ratio

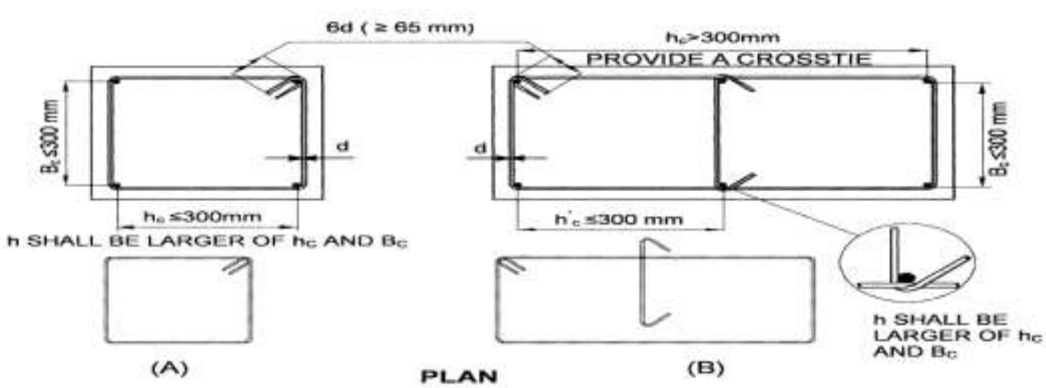
f_y = yield stress of steel

ACI 318-08 vide clause 7.8 gives the Reinforcement details for columns. Clause 7.10.4 gives details regarding arrangement of spirals. Clause 7.10.4.3 specifies that clear spacing between spirals shall not exceed 3 in., nor be less than 1 in. Clause 7.10.5 specifies arrangement for ties. Clause 7.10.5.2 says that Vertical spacing of ties shall not exceed

- 16 times longitudinal bar diameters,
- 48 times tie bar or wire diameters,
- Or least dimension of the compression member.

1.4.3 As per IS 13920:2016

Along with this Indian code IS 13920:2016 specifies some special confining arrangements for earthquake resistant design of structures. Clause 7.4 suggests the transverse reinforcement as shown in Figures below:



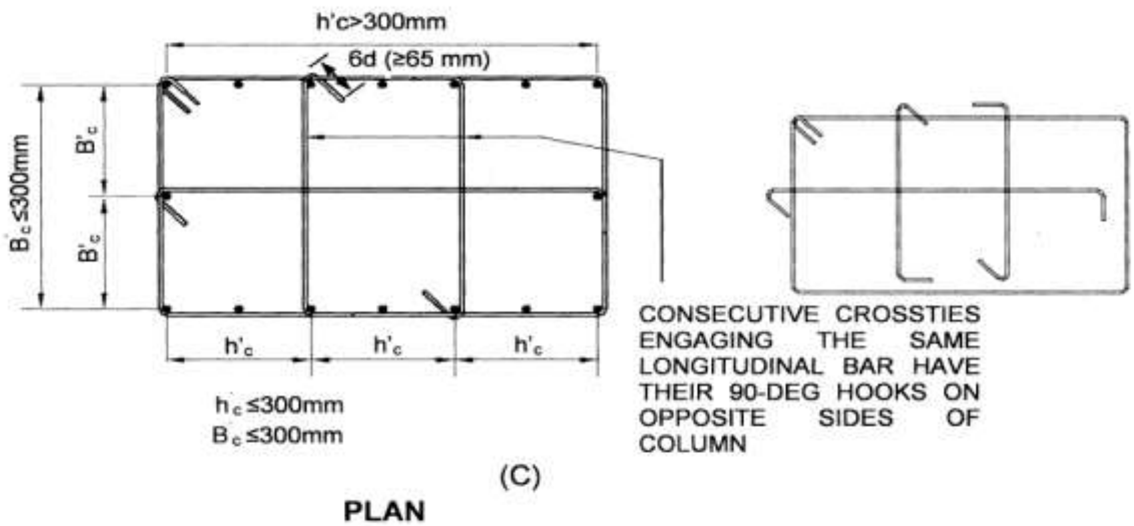


Figure 1.5 Arrangements of Ties (IS 13920:2016)

1.5 Basic concept of confinement in RC circular columns

Number of laboratory tests has been conducted on confined columns. The test results have proven that the compressive strength of concrete confined within the spirals is increased. It is attributed to the fact that spirals exert lateral pressure on concrete core as illustrated in the Figure 1.6.

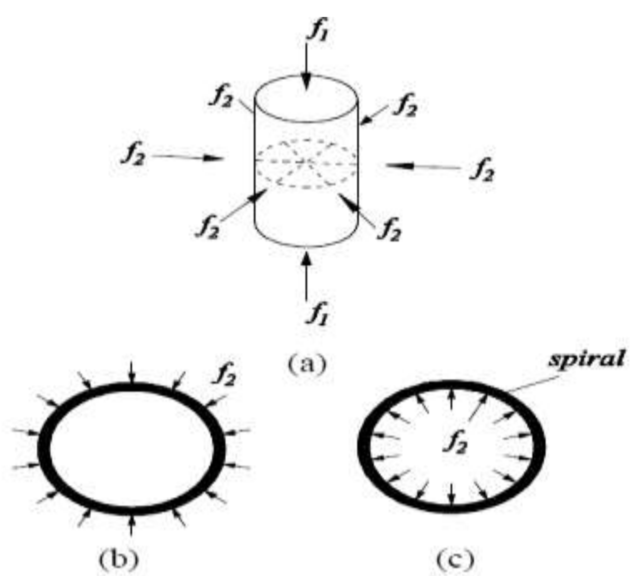


Figure 1.6 (a) Influence of lateral pressure f_2 on the ultimate Compressive strength; (b) lateral pressure on core; (c) lateral pressure on spiral

Again cutting the cylindrical specimen vertically along its diameter as shown in Figure 1.7 below provides us with an equilibrium equation in horizontal direction stated as:

$$\mathbf{2a_s\, f_{sy} = D_cSf_2}$$

Or,

$$\mathbf{f_2 = 2a_sf_{sy}/D_cS}$$

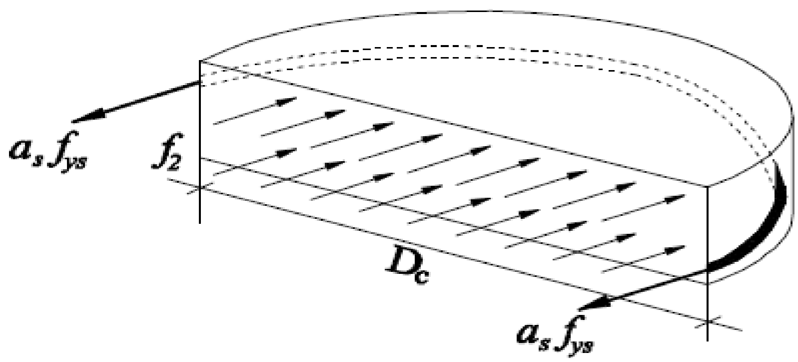
Where;

a = cross-sectional area of spiral

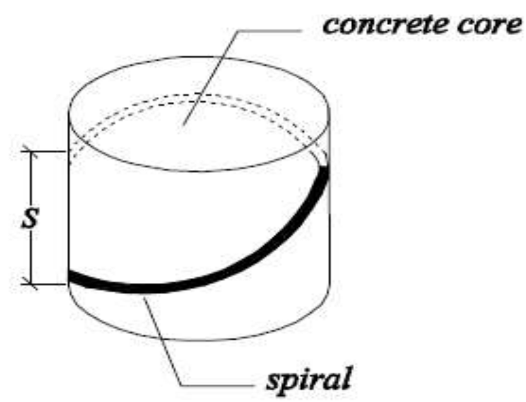
f_{sy}= yield stress of spiral

D_c = core diameter = diameter minus twice the concrete cover

S = spiral's pitch



(a)



(b)

Figure 1.7 (a) Free body diagram of core and spiral cut along diameter; (b) one turn of spiral

Thus concluding confinement provided in columns in form of transverse reinforcement serves the number of purposes or functions. These include:

- preventing buckling of longitudinal reinforcing bars
- providing resistance against shear and torsion, if required

- confining concrete core to provide sufficient ductility and improving strength
- clamping together lap splices wherever provided

1.6 Different Techniques for Confinement in Columns

1.6.1 FRP (Fibre Reinforced Polymers)

With the advancement in technology and need for measures of efficiency (in terms of strength and ductility) and safety in structures the new concept of providing FRP (fibre reinforced plastics or polymers) as confinement have become popular from past two decades. FRP can be provided both internally (in form of tubes) or externally (in form of sheets). A good quality of research has been done all over the world by researchers in past years so as to get improved or enhanced results for confined concrete columns.

Fiber Reinforced Polymers (FRP) composites were developed and came into use during the 1940s, for military and aerospace engineering. Along with this FRPs have been successfully used in many civil engineering applications, including pressure pipes, load bearing and infill panels, tank liners, bridge repair and retrofit, roofs, structural strengthening, etc. FRP can rather be considered as a new class of composite material that is manufactured from fibers and resins. They have proven to be economical and efficient for repair and development of new and deteriorating structures in civil engineering.

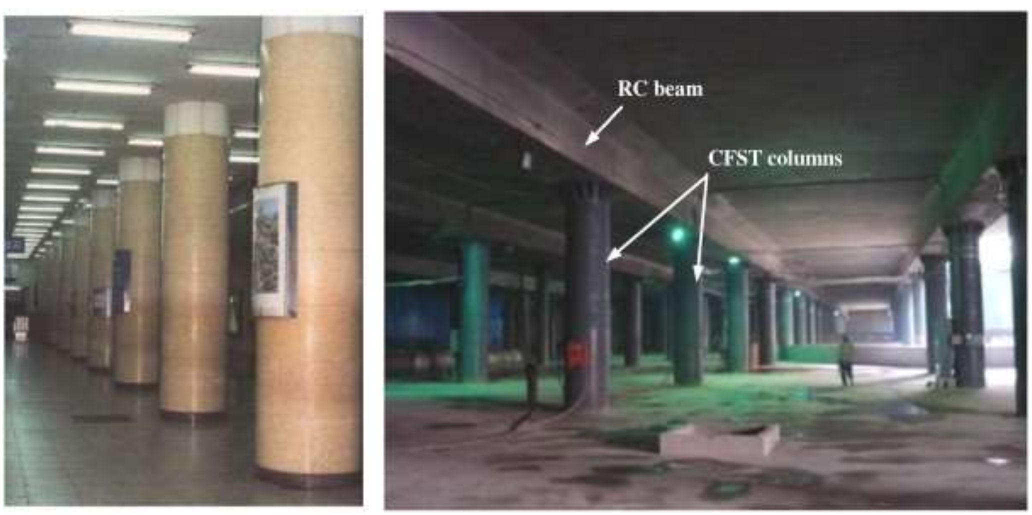
Compared to steel and concrete, FRP composites are about 1.5 to 5 times lighter. As FRP composites provide only a nominal increase in stiffness, they are generally useful for increased structural strength instead of deflection control. In a RC structure, strengthening and increased durability against corrosion of steel can be achieved by wrapping them with FRP.

Figure 1.8 Columns wrapped with FRP externally (http://www.3eservices.net)

1.6.2 CFST (Concrete filled steel tube) columns

Another technique that has become popular in tall buildings is use of concrete filled steel tube (CFST) columns due to the composite action between steel and concrete. As compared to transverse steel bars used in design of traditional reinforced columns, the steel tube can provide more continuous and uniform confining pressure. Other benefits include prevention or at least delayed local buckling of steel tube and improved corrosion as well as the fire resistance of the steel tube. Thus, CFST columns have advantage of having higher strength to weight ratio, higher stiffness and higher ductile behavior compared with the traditional RC columns. From a practical construction point of view, it saves the construction materials; the steel tube acts as formwork such that no external formwork for concreting is needed, the construction cycle time can also be shortened.

However, there is a major disadvantage of adopting CFST columns. Due to the fact that steel dilates more than concrete there is the imperfect interface bonding between concrete and steel tube during initial elastic stage. This imperfect bonding not only reduces the confining pressure provided by the steel tube but also reduces the initial stiffness and elastic strength of columns. This situation is even worse for high strength CFST (HSCFST) columns as high strength concrete (HSC) is more brittle compared to normal-strength concrete (NSC) and can result in premature failure of columns.



(a) (b)

Figure 1.9 CFST columns (Han et al., 2014)

1.7 Geogrids

In our present research work we have tried to opt a new technique for confining purposes. What we have done is, tried to use the geo-synthetic material partially as reinforcing material.

Geogrids is a geo-synthetic material that is made up of polymer materials such as polyethylene, polypropylene, polyester, polyvinyl alcohol. Due to its property of being good at tension it can be used as partial replacement for steel in concrete.

Figure 1.10 Geogrids strips (Wikipedia.com)

1.7.1 Advantages of geo-grid:

- Chemically and microbiologically inert, thus free from problems like corrosion.
- Zero water absorption
- High tensile strength and flexibility
- Light in weight
- Simple handling and installation
- Less coast as compared to equivalent amount of steel, thus economical

1.7.2 Applications of geo- grid:

There have been number of applications for geogrids, some of which are listed below:

- **Embankments and soft soils**: Weak soils are always a concern for any construction site. Geo-grid products interlock with structural fill (say soil) to provide a strong "mattress" foundation that effectively increases the stability over the weakest soil. This turns the weakest subsoil's such as dredge spoil, swamps and saturated clay into a structural base to build over for surcharge embankments, crane pads, haul pads and more.
- **Erosion control**: Geo-grids can minimize the effect of erosion and provide permanent protection. Thus providing ease for further construction or working.
- **Highway Infrastructure**: Geo-grids can be used as reinforcement in both temporary as well as permanent structures. When permanent highway infrastructure is built or improved, the need for temporary structures is required for easy flow of traffic. These

temporary structures if built on loose soils can be risk to both human life and property. Thus again ensuring use of geo-synthetic materials as reinforcement wherever required.

- **Roadway Improvements**: These materials can be used to confine and reinforce the fill and further increase the load bearing capacity of underlying subgrade soil and thus increasing about 50% of structural performance of roadway. The application involve in improved railroads, haul roads, paved and unpaved roads and airport runways.
- **Retaining Walls**: System of geo-grid along with welded wire can provide long term stability to any kind of permanent retaining wall.
- **Lining:** These materials have their application in tunnel lining, canal lining and landfill lining.

1.8 Objectives of Study

There have been number of applications of geogrids being used as reinforcement or stabilizing material, say in pavements, retaining walls etc. But its application as reinforcing material for concrete is yet to be explored as we get least of its research with respect to application in concrete especially in case of columns. Thus the present study aims at:

- To study the confinement effect in columns when partially reinforced with geogrids along with stirrups.
- To evaluate the effect of different tensile strengths of geogrids on strength parameters of columns.
- To study behavior of partially geogrids confined column composed of normal concrete (NC) and steel fibre reinforced concrete (SFRC).

1.9 Organization of Thesis Work

CHAPTER 1-Defines confinement and introduces materials used for confinement, states objectives of present study.

CHAPTER 2-Provides an overview of past studies regarding techniques used for confinement both internally and externally.

CHAPTER 3-Describes material properties along with procedure carried out for casting and testing of specimens.

CHAPTER 4-Results in form of graphs, bar charts and tables are discussed with valid reasons.

CHAPTER 5-Important observations are listed along with future scope for present study. This chapter is followed by the list of references used in this research work.

CHAPTER 2

LITERATURE REVIEW

2.1 General

Good quality of research has been done in past to improve or enhance the strength parameters and durability of columns. Various researchers have opted different techniques for confinement to enhance performance of columns when subjected to axial loads. Confinement can be provided both internally as well as externally about which we will study as we progress in this chapter. Confinement may be in form of Tie bars, Spiral reinforcement (hoops), FRP wrapping (partially or fully wrapped), Shape memory alloy wires, Multiple spirals, Composite jackets, Steel tubes, steel casing, Mesh, Fibre composite sheets, SRP (steel reinforced polymer) jackets etc. Extensive research work has been done using geogrids as reinforcing material for soil stabilizing. Tang et al. (2008) studied the application of geogrids for stabilizing weak pavement subgrade. Raymond et al. (2003) evaluated the effect of geo-grid reinforcement on unbound aggregates. Beside this the application of geogrids in concrete beams to study flexural behavior has been studied by Meski et al. (2013). The application of geogrids as reinforcing material in concrete confinement is discussed further in this chapter.

2.1 Internal Confinement

Chung et al. (2002) developed the stress strain curve for laterally confined concrete. The experimental results were analyzed to investigate the confinement effects of confined concrete according to parameters such as compressive strength of concrete, volumetric ratio, type of arrangement for rectilinear ties, and distribution of longitudinal bars. It was observed that magnitude of increase in strength and ductility of confine concrete decreased with increase in concrete strength because of concretes increased brittleness. Also closely spaced ties lead to improved strength and ductility. It was due to fact that high strength ties yielded after the maximum load. Another reason was that confined area got increased for carrying axial loads and buckling of longitudinal bars was prevented. And volumetric ratio proved to be more important parameter in enhancing strength and improving ductility than tie strength.

Ros et al. (2003) studied the high strength concrete behavior influenced by confinement. The objective of research was to determine the evolution in ductility when compressive strength changes from lower values (25 MPa) to higher ones (100 MPa). It was concluded that the increase in strength reduces strain under a maximum concrete load and causes more fragile post-peak behavior. Also minimum confinement level was needed to make stirrups effective that is spacing among stirrups must be smaller than specimen diameter or width. Also it was found that strength is not influenced by specimen shape or size.

Suzuki et al. (2004) purposed the stress strain model of HSC confined by rectangular ties. The compressive strength of concrete, volumetric ratio and yield strength of ties were the variables that were considered for study. It was observed that increase in volumetric ratio resulted in increased peak stress and increase in corresponding strain. The columns with additional reinforcement exhibited higher ductility. Consistent decrease in ductility was observed in columns with increasing concrete strength. The reason being that HSC exhibit less lateral expansion under axial compression than NSC due to its lower internal micro cracking and higher modulus of elasticity. Also conclusions were made that confinement effect did not increase significantly with increase in ties yield strength.

Umesh K Sharma et al. (2005) studied the axial compression behavior of confined HSC columns. The purpose of study was to examine the effect of variables such as volumetric ratio, longitudinal reinforcement ratio, yield strength and spacing of transverse reinforcement, cross section shape and compressive concrete strength on uni axial behavior of HSC columns. HSC columns suffered premature cover spalling which reduced load carrying capacity of column to even less than unconfined concrete strength, in case sufficient confinement was not provided. And improvement in each of variables (volumetric ratio, reducing spacing of lateral ties, yield strength of lateral steel and longituidinal steel ratio) lead to enhancements in strength and ductility.

Hong et al. (2006) studied the HSC columns confined by lateral ties with low volumetric ratio. The focus of study was to know the effect of test variables that are compressive strength of concrete, tie volumetric ratio and tie yield strength on ductility and strength of columns. Results obtained were that the peak strength and the corresponding strain of the confined concrete increased with increase in volumetric ratio. HSC columns showed less strength enhancement ratio compared to NSC columns when volumetric ratio for two were kept same. The confinement effect did not improve significantly with increase in tie yield strength. It was found that the specimens with lower tie yield strengths and higher volumetric ratios performed better than those with of higher tie yield strengths and lower volumetric ratios.

U K Sharma et al. (2007) studied the HSC fibre-reinforced short columns confined by ties. The process involved effect of test variables such as volume fraction and aspect ratio of crimped steel fibres, configuration, volumetric ratio and yield strength of tie reinforcement used and strength of concrete on the uniaxial behavior of HSC short columns. It was concluded that the ductility and strength of confined HSC columns increased with the addition of steel fibres, strength enhancement being less sensitive than ductility. The introduction of steel fibres prevented the early spalling of cover concrete in HSC column specimens. Increase in the aspect ratio of fibres resulted in slight decrease of strength gain. The percentage improvements in column response were lower in columns containing larger amounts of tie steel. Therefore effectiveness of using steel fibres to enhance the performance of HSC columns could be better understood keeping the lateral steel content relatively low.

Marvel et al. (2014) investigated the axial behavior of HSC columns confined by multiple spirals. The process involved confinement with two opposing spirals internally and comparing results with traditional columns containing single spirals in terms of strength and ductility. Specimens used had spacing of S (for both single spiral and cross spiral) and 2S (for another group of cross spirals). The longitudinal reinforcement ratios were too varied for specimens. The results obtained were that for each column group, the cross spiral columns with spacing of 2S (with volumetric confinement ratio being same as single spiral with spacing S) had average increase in confined compressive strength of 10.5% without lowering the column ductility, thus reducing congestion in heavily reinforced sections. Also cross spiral columns with spacing S (that is volumetric confinement ratio getting doubled as compared to single spiral with spacing S) had an average increase in compressive strength by 53.4% and increase in ductility too.

El-Kholy & Dahish. (2016) proposed the technique of confining reinforced concrete square columns internally with expanded metal mesh (EMM) layer additionally wrapped over ties (cage). The objective was to enhance confinement and improve performance of RC columns by using EMM along with ties as lateral reinforcement. They evaluated that adding single layer of EMM as lateral reinforcement to regular volumetric ratio (=0.2714%) of ties increased the ultimate load capacities with 11.02% and 18.55% for columns with slenderness ratio of 7.33 and 14 respectively. The ultimate load capacity gets reduced by small %age (7.08%) when volumetric ratio of ties was reduced by 70% with slenderness ratio of 7.33. In addition to this for columns with slenderness ratio of 14 the EMM layer reduced the volumetric ratio of ties by 70% without loss in ultimate load bearing capacity. Thus it was concluded that ultimate load capacity of columns increased, ductile behavior improved and volumetric ratio of ties got reduced by wrapping additional EMM layer.

2.2 External Confinement

J.F. Berthet et al. (2004) studied the compressive behavior of NSC and HSC short columns confined externally by carbon and E-glass FRP jackets. Their objective was to identify the main parameters such as confinement level, properties of composite jackets and concrete core that affect the mechanical behavior of columns. Also the confined samples studied had no internal reinforcement. Conclusions made after experimental studies were that the ultimate strengths and strains increased significantly with enhancement of number of composite layers and confinement level. Significant increase of structural ductility was observed for all confined concretes with enhancement of confinement level.

Li, (2006) conducted experimental study of FRP confined concrete cylinders that were confined in two different ways, one those confined by FRP jackets and others confined with tube encasing. The purpose of paper was to understand the structural performance or behavior of concrete cylinders when they were confined insufficiently. Along with this effect of concrete strength on confinement efficiency and the interfacial bonding effect on FRP tube encased concrete cylinders was also determined. It was concluded that for the FRP tube encased cylinders, higher interfacial bonding strength resulted in higher compressive strength and ductility. This behavior was different from the jacketed cylinders, in which the interfacial bonding strength had little effect that might be due to lower axial stress in the FRP jacket.

Choi et al. (2008) studied the behavior of concrete cylindrical columns confined by Shape Memory Alloy (SMA) wires. The target of study was to apply prestrained SMA wires to confine (by wrapping) concrete cylinders to show potential for jacketing RC columns in bridges and measure the recovery stresses with varying prestrain levels. They concluded that confinement both by martensitic and austenitic SMA wires increased the ductility to great extent as compared to strength of plain concrete cylinders.

Cui & Sheikh (2010) experimentally studied the NSC and HSC confined with Fire Reinforced Polymers (FRP).The focus of study was to know the effect of various parameters such as effect of precracking loads, amount of FRP, FRP properties, unconfined concrete strength and size effect on confined concrete behavior. Conclusions were made that as unconfined concrete strength got increased, there was remarkable decrease in strength enhancement, ductility factor and energy absorption capacity and energy index at rupture of FRP jackets. Also after the rupture of FRP was initiated, large size columns displayed a much more ductile behavior compared to small cylinders.

Xiong et al. (2011) evaluated the ductility and load carrying capacity of circular concrete columns confined by ferrocement including steel bars (FS).The objective was to compare the behavior that is study properties such as strength, ductility, energy absorption capacity and deformability of confined columns under axial compression for three different arrangements that are confining by FS, BM (Bar Mat Mortar) and FRP. It was observed that both, strength and ductility of columns tested could be enhanced significantly by constructing additional ferrocement cage including steel bars. Also it was found out that due to occurrence of much more cracks in mortar layer of FS confined columns, the ductility of FS columns was higher than those of BM or FRP confined columns.

Soliman (2011) studied the behavior of long concrete columns confined by means of proper plastic tubes(FRP).The objective of the work was to investigate the influence of column slenderness ratio on columns axial load carrying capacity, axial strains and radial strains along with failure mechanisms involved. After studies it was found that the values of compressive strength ratios (of confined and unconfined column specimen) improved by decrease of column slenderness ratios. The compressive strength ratio was approximately increased by 28%, 48% and 80% for column slenderness ratios 17, 15 and 12.5 respectively(with column diameter 120 mm) and increased by 30%, 52% and 99% approximately for slenderness ratio 14, 12.5 and 10 (with column diameter 150 mm) respectively.

Lai & Ho (2013) carried the uni axial compression test of Concrete Filled Steel Tube (CFST) Columns confined by tie bars. The test variables included the varying of CFST columns dimensions, concrete strength and spacing of tie bar. The objective was to improve the interface bond between concrete and steel tube by adopting tie bars as confining material. It was concluded from test results that with addition of tie bars, the axial load carrying capacity improved (maximum, 16%; average, 5%) and the strength degradation rate reduced, which can be attributed to the fact that tie bars can provide early confining pressure at bolted location and hence limit the lateral dilation of steel tube and core concrete to some extent.

Khairallah (2013) studied the mechanical behavior of confined circular columns under concentric axial loading using both self compacting (SCC) as well as normal strength concrete(NSC) and made their comparison. CFRP wrap, FRP tube, GFRP wrap and spiral steel hoops were used as confining techniques. The performance of columns was evaluated based on compressive strength, degree of confinement, mode of failure, ductility and load displacement curve. It was noticed that NSC columns sustained higher compressive strengths values than those of SCC columns which may be attributed to the fact that SCC is often associated with higher shrinkage and lower coarse aggregate content compared to that of NSC. Also it was found that confining via FRP tube increased compressive strength significantly both in NSC and SCC columns. It was also noted that SCC columns exhibited higher ductility indices values than NSC columns. The columns confined with spiral steel hoops showed highest ductility indices value with decreasing trend when confining with FRP tube, followed by GFRP wrap and CFRP wrap.

Lai & Ho (2014) studied the confinement effect of Ring-Confined CFST columns under uni-axial load casted with normal strength and high strength concrete. Since due to fact that steel dilates (that is expands by volume) more than concrete at early elastic stage, thus reducing elastic strength and stiffness due to imperfect interface bonding, the technique of confinement in form of external rings was proposed. The objective was to invest the effect of confining with different ring spacing in terms of axial load carrying capacity, elastic stiffness and strength degradation rate. It was found that addition of external rings can improve the load carrying capacity by maximum 49% and on average 8% and thus decreased the strength degradation rate.

Wei & Wu (2014) investigated the compression behavior of concrete columns confined by high strength steel wires (HSW having strength more than 1500 MPa). The work aimed at quantitative investigation on technology used and study stress-strain response, peak strength and strain, ultimate strain and failure modes of columns by varying the spacing of HSW. It was found that HSW confinement significantly increased the ultimate compressive strength. Also compared with FRP columns, HSW confined columns were more ductile with yield plateau from peak point to rupture of 1st HSW providing abundant warning before collapse of columns.

Yu et al. (2016) studied the compressive behavior of FRP-confined concrete-encased steel columns (CFSC) both when loaded concentrically and eccentrically. The specimen used were square as well as circular containing I-section inside and confined with varying thickness of GFRP tube externally. After tests it was observed that buckling of I-section was well constrained and concrete was effectively confined in CFSCs, leading to very ductile behavior under both concentric and eccentric compression. Along with this the load bearing capacity decreased with load eccentricity but ductility of columns increased with load eccentricity. Decrease in load capacity for eccentrically loaded columns was due to the fact that BM and bending deformation were both larger for specimen tested at large eccentricity (about major axis).

2.3 Confinement Using Geo-Grid as Reinforcing Material

Chidambaram & Agarwal (2014) studied the confining effect of geo-grid on mechanical properties of concrete specimen containing steel fibres (maximum 2%) under compression and flexure. The objective of study was to pave out a new way of confining concrete and compare the test results with conventional technique used. For the four cylindrical specimens the axial compression behavior and direct split behavior were studied, while for twelve beam specimen flexural behavior along with energy dissipation was noticed. It was observed that there was significant improvement in the axial stress strain behavior of cylindrical specimen after it was confined with geogrids as compared to conventional concrete specimen or when compared to those with steel fibres too. Also geo-grid along with steel fibres was able to reverse the failure mechanism that is from sudden brittle failure to ductile failure without any significant loss of strength. In case of split tension behavior, the geogrids confinement does not only contribute in increase of tensile strength but also managed to sustain deflection at larger extent. The flexure test on beam specimens revealed that the strength of geogrids and their number of layers provided play an important role in improving load deformation behavior as well as crack propagation, thus proving to be an alternative of tensile reinforcement in reinforced concrete specimen.

Chidambaram & Agarwal (2015) studied the flexural and shear behavior of geo-grid confined RC beams with SFRC. The objective was to examine the feasibility of geo-grid as additional shear reinforcement in RC beam specimens with respect to properties such as load-deflection behavior, stiffness degradation, energy dissipation and ductility and crack pattern with failure analysis. The variables for three different sets of beam specimens (confined, moderately confined, lightly confined) included ratio of longitudinal and transverse reinforcement, strength of geogrids and volume of steel fibres. It was observed that for all three types of beam specimens there was remarkable improvement in energy dissipation capacity and post yield behavior after additional confinement by geogrids along with steel fibres. It was also observed that rate of degradation in strength and stiffness of conventionally confined beam specimens decreased as the amount of transverse reinforcement increased. The geo-grid confined beam specimen with and without steel fibres showed gradual and stable loss in stiffness and strength as the post rotation increased even with specimens with large spaced transverse reinforcement. The test results proved that use of geo-grid along with steel fibres not only helped to achieve the desired objectives but also changed the failure mechanism of beam from brittle shear to flexural failure.

CHAPTER 3

EXPERIMENTAL PROGRAMME

The main objective of this thesis is to examine the behavior of columns partially confined with geo-grid under axial load. The reason that geogrids are replaced partially and not fully with stirrups is that being polymer material geogrids are not as rigid as steel. The specimens were casted using normal concrete (NC) as well as steel fibre reinforced concrete (SFRC). Other variables included were the spacing of stirrups (150 mm and 450 mm) and the geogrids (with average tensile strengths of 100 and 200 kN/m) used as partial replacement for stirrups.

3.1 Materials used and their properties:

Cement, fine aggregate (sand), coarse aggregate (10 mm and 20 mm) and reinforcing steel bars (10 mm and 6 mm diameter) were used as materials for casting concrete columns. Along with this steel fibres and geo-synthetic material (geogrids) were used as additional variables. The details of these materials are described as below;

3.1.1 Cement

Ordinary Portland cement of grade 43 (OPC 43) (Ambuja cement) was used in mix for concrete. Numbers of tests were conducted on cement as per BIS 8112:1989 which is listed in the Table 3.1. Cement bags were stored inside lab thus preventing them from exposed environment and moisture.

Table 3.1 Physical properties of cement

Serial no.	Property	Value obtained	Standard value as per code BIS 8112:1989
1	Standard consistency	32 %	-
2	Fineness as retained on 90 micron sieve	8 %	Not more than 10 %
3	Initial setting time	110 min	Minimum 30 min
4	Final setting time	270 min	Maximum 600 min
5	Specific gravity	3.06	3.15

3.1.2 Fine Aggregates

Sand (fine aggregate) used for concrete mix was available locally. The sand was in conformation with IS: 383-1970 specifications. Total of three samples were taken for sieve analysis. The results for physical properties and sieve analysis are listed in Tables 3.2 and 3.3 respectively.

Table 3.2 Physical properties of sand

Serial no.	Property	Value obtained
1	Fineness modulus	3.2
2	Specific gravity	2.544
3	Water absorption	0.97 %
4	Grading zone	Zone II

Table 3.3 Sieve analysis for fine aggregate

Total weight of sample taken = 1000 g

sieves	Weight retained							
	Sample 1 (g)	Sample 2 (g)	Sample 3 (g)	Mean value (g)	%age weight retained	Cumulative %age retained	%age passing	Specifications for zone II as per BIS: 383-1970
4.75 mm	39.5	42	45.5	42.33	4.233	4.233	95.766	90-100
2.36 mm	162.5	171.5	152	162	16.276	20.528	79.472	75-100
1.18 mm	241	241.5	227	236.5	23.761	44.289	55.711	55-90
600 μ	167.5	155	159.5	160.66	16.141	60.43	39.57	35-59
300 μ	332	313.5	312	319.6	32.09	92.5	7.5	8-30
150 μ	52	72.5	91.5	72	7.23	99.73	0.27	0-10
pan	1.5	2	4.5	2.66	0.27	100	0	

Fineness modulus for sand = (4.233+20.528+44.289+60.43+92.5+99.73)/100

=3.2172

3.1.3 Coarse Aggregates

Coarse aggregates of size 20 mm and 10 mm in ratio 0.6:0.4 were used in concrete mix. The aggregates were sieved properly each time for concrete mix in order to get pronounced results as per mix design. The results for sieve analysis are shown in Tables 3.4 and 3.5 respectively, and some physical properties for both 20 mm and 10 mm aggregates are listed in the Table 3.6.

Table 3.4 Sieve analysis for coarse aggregates (20 mm)

Total weight of sample taken=10000 g

Serial no.	Sieve size	Weight retained (g)	%age weight retained	Cumulative %age retained	%age passing
1	40 mm	0	0	0	100
2	20 mm	34	.34	.34	99.66
3	10 mm	7139	71.39	71.73	28.27
4	4.75 mm	2361	23.61	95.34	4.66
5	pan	466	4.66		
Total				147.41	
Fineness modulus of 20 mm coarse aggregates = (147.41 + 500)/100 = 6.47					

Table 3.5 Sieve analysis of coarse aggregates (10 mm)

Total weight of sample taken =10000 g

Serial no.	Sieve size	Weight retained (g)	%age weight retained	Cumulative %age retained	%age passing
1	40 mm	0	0	0	100
2	20 mm	0	0	0	100
3	10 mm	874	8.74	8.74	91.26
4	4.75 mm	8127	81.27	90.01	9.99
5	pan	999	9.99		
Total				98.75	
Fineness modulus of 10 mm coarse aggregates = (98.75 +500)/100 = 5.99					

Table 3.6 Physical properties of coarse aggregates (20 mm and 10 mm)

Serial no.	Property	20 mm	10 mm
1	Specific gravity	2.59	2.59
2	Water absorption	2.89 %	1.46 %
3	Fineness modulus	6.47	5.99

3.1.4 Water

Good quality water, free from any kind of organic material, silt, sand, oil, chloride or any other acidic substance as per Indian standard is used for entire mixing process when required.

3.2 Steel Fibres

Duraflex^{TM} hook end loose steel fibres (1 %) were added to normal concrete so as to form SFRC. The fibres were issued from Kasturi metal composite private limited. The fibres were made from high tensile strength wire > 1000 MPa. The properties of steel fibres used in our research purpose are listed in Table 3.7. The benefits of using steel fibres are listed below:

- Improved structural strength
- Reduced steel reinforcement requirements
- Improved ductility
- Reduced crack widths and controlled crack widths tightly, thus obtaining improved durability
- Improved impact and abrasion resistance

Table 3.7 Properties of steel fibres used

Material	Low Carbon Drawn Fibre
Aspect Ratio	65
Length (mm)	35 mm
Diameter (mm)	0.55 mm
Tensile Strength (mm)	>1100 MPa
Appearance	Clear, bright, loose unglued with hook end anchorage
Conforms to	EN 14889-1, ASTM A820 M04 Standards

Figure 3.1 Steel Fibres

3.3 Steel

Tata Tiscon 500D high strength ribbed TMT bar was used for reinforcement in concrete. Here 500 specify the superior strength of bars that is 500 MPa and 'D' represents its higher ductility. Tata Tiscon 500D adheres the most updated standard (last revised in 2012) as per Bureau of Indian standards (BIS). Some of chemical and mechanical properties of these bars are listed in Tables 3.8 and 3.9 respectively.

Table 3.8 Chemical properties for reinforcement bars

Chemical properties(maximum)	**Tata Tiscon 500D**
%age carbon	0.250
%age carbon equivalent (CE)	0.400
%age Sulphur (S)	0.035
%age Phosphorus (P)	0.035
%age nitrogen (PPM)	120

Table 3.9 Mechanical properties for reinforcement bars

Mechanical properties (minimum)	**Tata Tiscon 500D**
Yield stress-YS (N/mm^2)	500
Ultimate tensile stress-UTS(N/mm^2)	600
UTS/YS ratio	1.12

3.4 Concrete Mix

After obtaining the required physical properties of materials to be used for concrete preparation as listed in the Tables, mix design was prepared as per Indian standard code BIS: 10262-2009 for M30 grade of concrete. Numbers of trial were conducted in order to get the required value of compressive strength. The ratio obtained for casting of specimen was 1:1.5:2.62 (cement: fine aggregates: coarse aggregates) with value of w/c (water cement ratio) as 0.45. Hand mixing was done each time for casting purposes. The material was assembled and dry mixed properly before addition of water that is wet mix. The value of slump obtained was 45 mm. Two types of concrete were used, normal concrete (NC) and steel fibre reinforced concrete (SFRC). Cubes were casted each time after the mix was prepared and cured for 28 days.

Figure 3.2 Steel fibres dry mixed uniformly

3.5 Casting of Reinforced Concrete Columns

The column of diameter 150 mm and height 500 mm was chosen for casting and testing purposes. The slenderness ratio obtained is 3.33, so column can be listed as short column (since slenderness ratio is less than 12). Total of sixteen specimens were casted which included two for each kind. The variables included are spacing of stirrups (150 mm and 450 mm), type of concrete used for casting (NC or SFRC) and type of geo-grid used (average tensile strength 100 kN/m and 200kN/m) for partial reinforcement purposes. The list of specimen casted is summarized in the Table 3.10.

Table 3.10 Data for specimen casted

Specimen ID	Specimen Details	Volume of steel fibres used
$CC_{150}C$	Conventional with 150 mm spacing of stirrups c/c	-
$CC_{450}C$	Conventional with 450 mm spacing of stirrups c/c	-
$CC_{150}F$	SFRC with 150 mm spacing of stirrups c/c	1%
$CC_{450}F$	SFRC with 450 mm spacing of stirrups c/c	1%
$CC_{450}G_{100}$	NC with 450 mm spacing of stirrups c/c and Geo-grid confined with average tensile strength of 100 kN/m	-
$CC_{450}G_{200}$	NC with 450 mm spacing of stirrups c/c and Geo-grid confined with average tensile strength of 200 kN/m	-
$CC_{450}F+G_{100}$	SFRC with 450 mm spacing of stirrups c/c and Geo-grid confined with average tensile strength of 100 kN/m	1%
$CC_{450}F+G_{200}$	SFRC with 450 mm spacing of stirrups c/c and Geo-grid confined with average tensile strength of 200 kN/m	1%

3.6 Confinement of column specimen

As described earlier the column specimen were confined providing two different spacing of stirrups namely 150 mm and 450 mm respectively. The 10 mm diameter bars, each being 6 in number for single column were used as longitudinal reinforcing bars. And 6 mm diameter bars on conversion into stirrups were used as transverse reinforcement for confining effect. The Figure 3.3 illustrates the prepared reinforcement cages.

Figure 3.3 Reinforcement cages with spacings 150 mm and 450 mm

3.7 Application of geogrids

Geo-grid was used as partial replacement of stirrups in reinforcement cages prepared with spacing of 450 mm. Both of geogrids with average tensile strength of 100 kN/m and 200 kN/m were cut of width 85 mm and length 450 mm each as shown in Figure 3.5 and wrapped as shown in Figure 3.6. The geo-grid were wrapped properly using steel wire so that they could hold longitudinal bars tightly and perform their required purpose of confining efficiently.

(a) **(b)**

Figure 3.4 (a) Geo-grid with average tensile strength 200 kN/m ; **(b)** Geo-grid with average tensile strength 100 kN/m

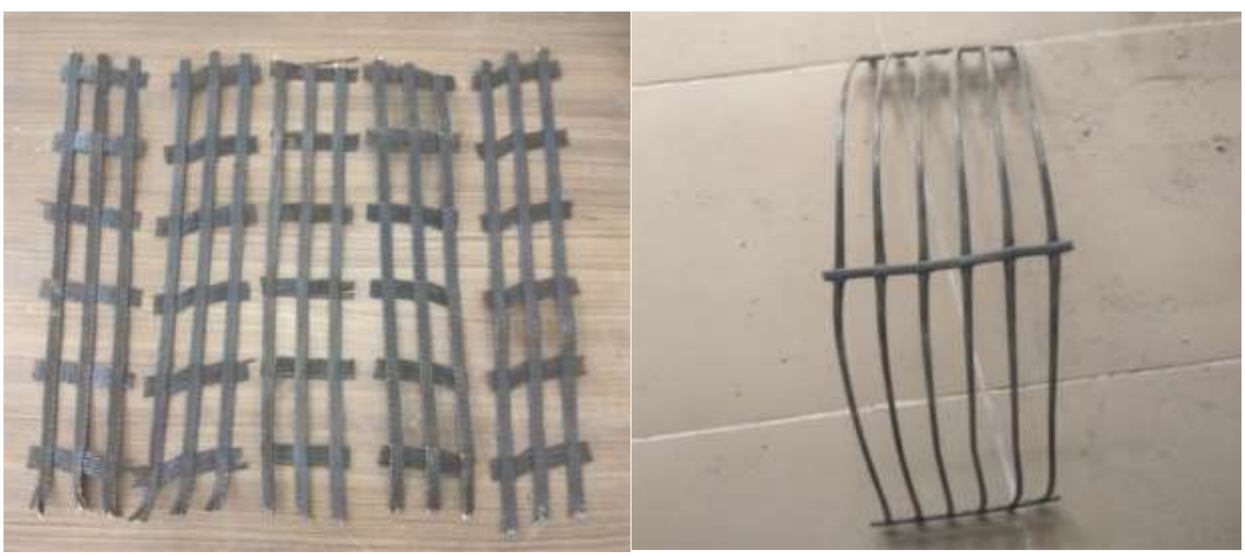


Figure 3.5 Geo-grid strips after being cut for confining purposes

Figure 3.6 Application of geo-grids

Figure 3.7 Application of geogrids for 450 mm spacing of stirrups

3.8 Casting of Column Specimens

Hand mixing of materials was adopted as per obtained ratio in mix design. All the materials were weighed as per required quantity, assembled and dry mixed thoroughly, prior to addition of water and obtaining final mix. Uniform concrete paste for two specimens was prepared together at each time of casting. Not only for normal concrete but also for FRC hand mixing was adopted. Fibres were added to dry mix and mixed uniformly avoiding congestion. Measured quantity of water was then added to get uniform paste free from any lumps. Plastic pipes were used as mould for casting purposes that were held in position effectively by clamps. Reinforcement cages were installed properly providing required concrete cover (20mm) on sides. Concrete cover of 25 mm was provided at top and bottom as per design. Needle vibrator was used for compaction. Moulds were opened after 24 hours of casting specimens. For each batch of mixing (that is for two columns of same type) three cubes were casted in order to obtain the compressive strength of casted specimen at 28 days at the same day of testing columns.

Figure 3.8 Mould used for casting purposes along with top view showing steel reinforcement

3.9 Curing of specimens

28 days of wet burlap (using jute sacks) curing was ensured before testing of column specimen. Cubes too were immersed in water for 28 days before testing for compressive strength.

Figure 3.9 Curing of column specimen using jute sacks

3.10 Wrapping of GFRP

Glass fibre reinforced polymer (GFRP) sheet with 10 numbers of turns was overlapped at top of column using Dr. Fixit epoxy resin 211. The GFRP was wrapped in order to ensure that the failure takes place somewhere at center and not only at top by crushing, so as to study the confining effect provided by geo-grids effectively.

Figure 3.10 GFRP wrapped at top of columns

3.11 Surface Preparation

Before testing of specimen it was ensured that top and bottom surfaces were properly leveled with help of concrete grinder so as to maintain the verticality (90^0 positions) of columns during testing. Such positioning was important in order to impose load axially, thus avoiding any eccentricity during load propagation. Besides this the columns were white washed so that crack formation could be studied easily.

3.12 Testing of Specimen

Testing of specimen was carried out on a UTM of maximum capacity up to 1000 kN. Another important aspect here is the end conditions provided during testing that help us to determine effective length of column. Both ends of column were kept hinged. So effective length comes out to be 500 mm.

Figure 3.11 Test setup for columns (UTM)

Figure 3.12 Control Equipment for UTM

CHAPTER 4

RESULTS AND DISCUSSION

4.1 General

This chapter deals with the analysis and study of various strength parameters of columns. As already mentioned, the columns were subjected to axial load under UTM with maximum capacity of 1000 kN. The load deflection curves were plotted and parameters such as ultimate load, maximum axial displacement, secant stiffness, ductility and energy dissipation were evaluated and compared.

4.2 Compressive strength of concrete mix

Prior to casting of columns, each time three cubes were casted from same mix in order to evaluate the compressive strength of concrete used for that particular column casting. The cubes were opened after 24 hours and put in water tank for curing purposes for 28 days. The cubes were then tested in ACTM and the values of average compressive strengths obtained are summarised in Table 4.1. From the results obtained it can be concluded that addition of steel fibres doesn't impart or lead to sufficient increase of compressive strength, the difference in compressive strengths for NC and SFRC being minor. So it is generally the w/c ratio that controls the compressive strength, not the addition of fibres.

Table 4.1 Average compressive strength of cubes (28 days)

Specimen id	**Average compressive strength of cubes (MPa)**
$CC_{150}C$	36.13
$CC_{150}F$	40.76
$CC_{450}C$	35.80
$CC_{450}F$	40.60
$CC_{450}G_{100}$	36.89
$CC_{450}G_{200}$	36.52
$CC_{450}F+G_{100}$	37.45
$CC_{450}F+G_{200}$	39.93

4.3 Test Results for Columns

The behavior of columns tested under UTM was evaluated from the load-deflection curves that were obtained upon testing. For each column type two specimens were casted and tested. Thus two load deflection curves were obtained for each type of column. The average values of two curves were considered as final values and resulting graphs are obtained and comparisons are shown in Figure 4.1 to Figure 4.6. As already mentioned, the columns were casted using NC and SFRC, so comparisons were made accordingly. Column with spacing of 150 mm and 450 mm composed of NC were considered as control specimen and their behavior was compared with other specimen. The test results in form of peak load, secant stiffness and energy dissipation are summarized in Table 4.2.

Table 4.2 Test results for columns

Specimen ID	**Ultimate Load (kN)**	**Displacement (mm) at Ultimate Load (kN)**	**0.8 times Ultimate load (kN)**	**Displacement (mm) at 0.8 times Ultimate load (kN)**	**Secant stiffness $P_u/\Delta u$ (kN/mm)**	**Energy dissipation (kN-mm)**
	P_u (kN)	**Δu (mm)**	**P_f (kN)**	**Δf (mm)**		
$CC_{150}C$	558.510	6.702	446.808	7.141	83.335	2195.219
$CC_{150}F$	660.456	5.191	528.364	7.082	127.231	3268.624
$CC_{450}C$	433.451	5.039	346.761	6.594	86.019	1034.495
$CC_{450}F$	521.904	5.375	417.523	6.567	97.098	1456.379
$CC_{450}G_{100}$	450.645	5.654	360.516	7.380	79.704	2145.753
$CC_{450}G_{200}$	563.315	6.403	450.652	7.304	87.977	2518.563
$CC_{450}F+G_{100}$	522.973	5.990	418.378	7.150	87.307	2224.816
$CC_{450}F+G_{200}$	615.245	5.621	492.196	10.366	109.455	4364.407

4.3.1 Effect on peak load

The comparison of peak loads of columns is shown in Figure 4.1 to Figure 4.6. The trend is discussed with reasons along with graphs one by one.

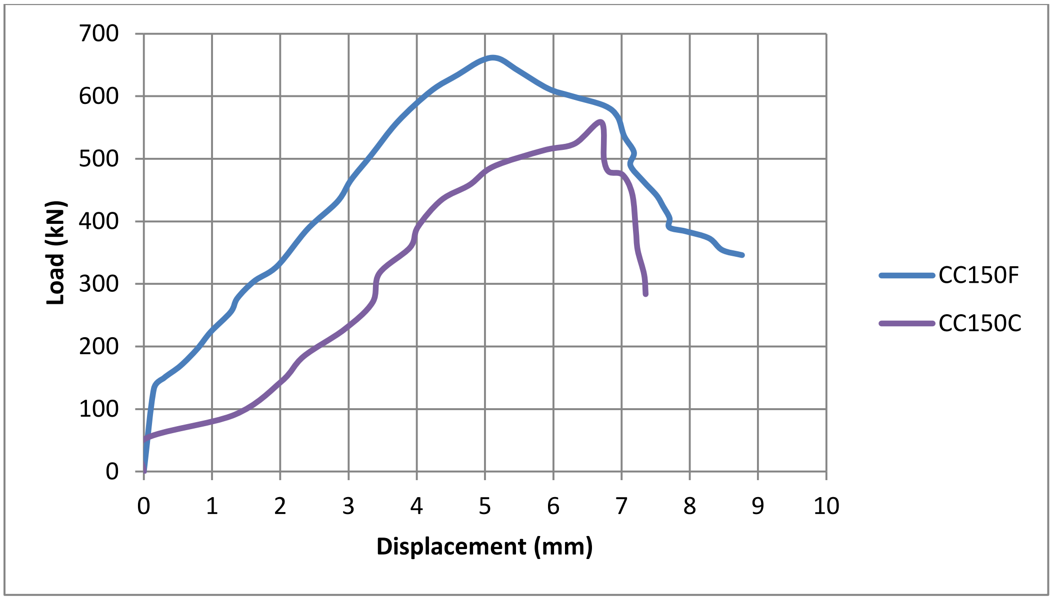


Figure 4.1 Comparison of load-deflection behavior of $CC_{150}F$ with control specimen

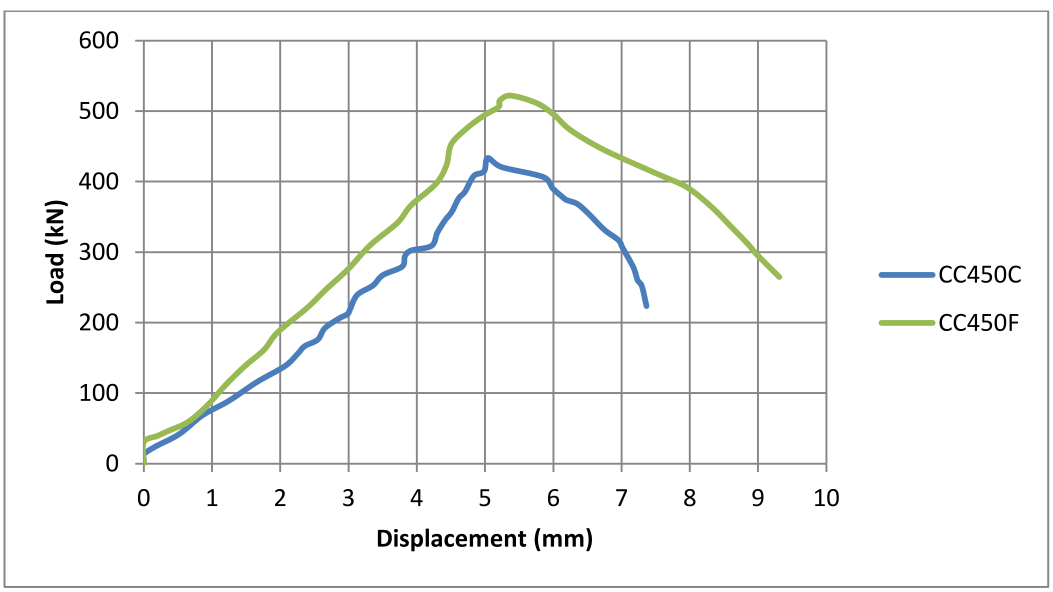


Figure 4.2 Comparison of load-deflection behavior of $CC_{450}F$ with control specimen

From Figure 4.1 and Figure 4.2 it can be concluded that FRC column with similar spacing of stirrups to that of NC columns exhibit larger values of ultimate loads and show highly ductile behavior. It is due to the reason that fibres present in the column prevent the early spalling of concrete cover and thus increase its load carrying capacity. Also addition of fibres impart ductility to columns as their addition gives some kind of residual strength or residual post cracking load carrying capacity, that is more load is sustained in the post peak region. On other hand columns composed of NC exhibit little bit of brittle behavior after peak load is obtained. It is so because once peak load is obtained the cracks get so widened that load decline rapidly as compared to displacement.

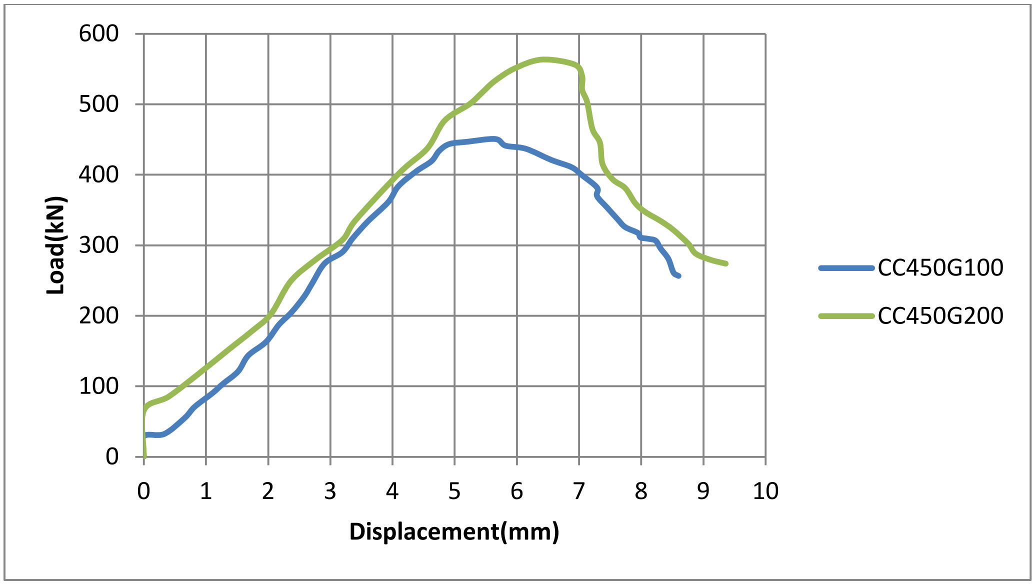


Figure 4.3 Comparison of load-deflection behavior of geogrids confined NC columns

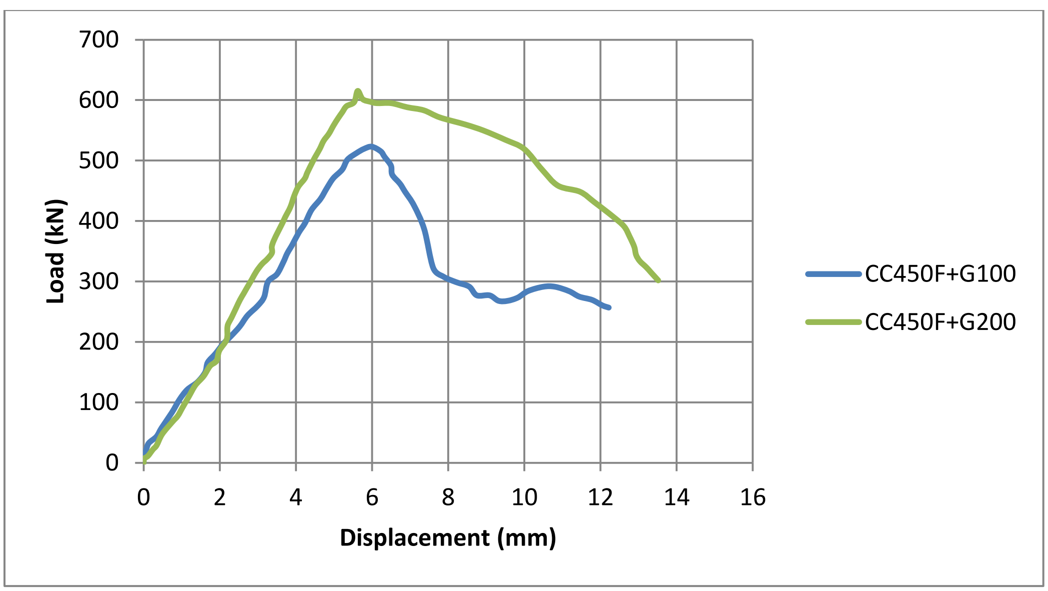


Figure 4.4 Comparison of load-deflection behavior of geogrids confined SFRC columns

Graphs plotted in Figure 4.3 and Figure 4.4 shows that type of geogrids used for confining purposes effect the ultimate load carrying capacity of columns. The uniaxial geogrids of same length and width but varying average tensile strengths of 100 kN/m and 200 kN/m, with single layer were wrapped as partial reinforcement in place of stirrups. Beside this the geometry of the geogrids varied, G_{100} comprising of small spaced strings while G_{200} comprising of wide strips in mat form. Column confined with G_{200} showed higher peak load value. Thus it can be concluded that with increase in average tensile strength of geogrids used, there is increase in load bearing capacity of column. Again the addition of fibres to concrete showed the higher values of ultimate load and higher ductility compared to NC geogrids confined columns.

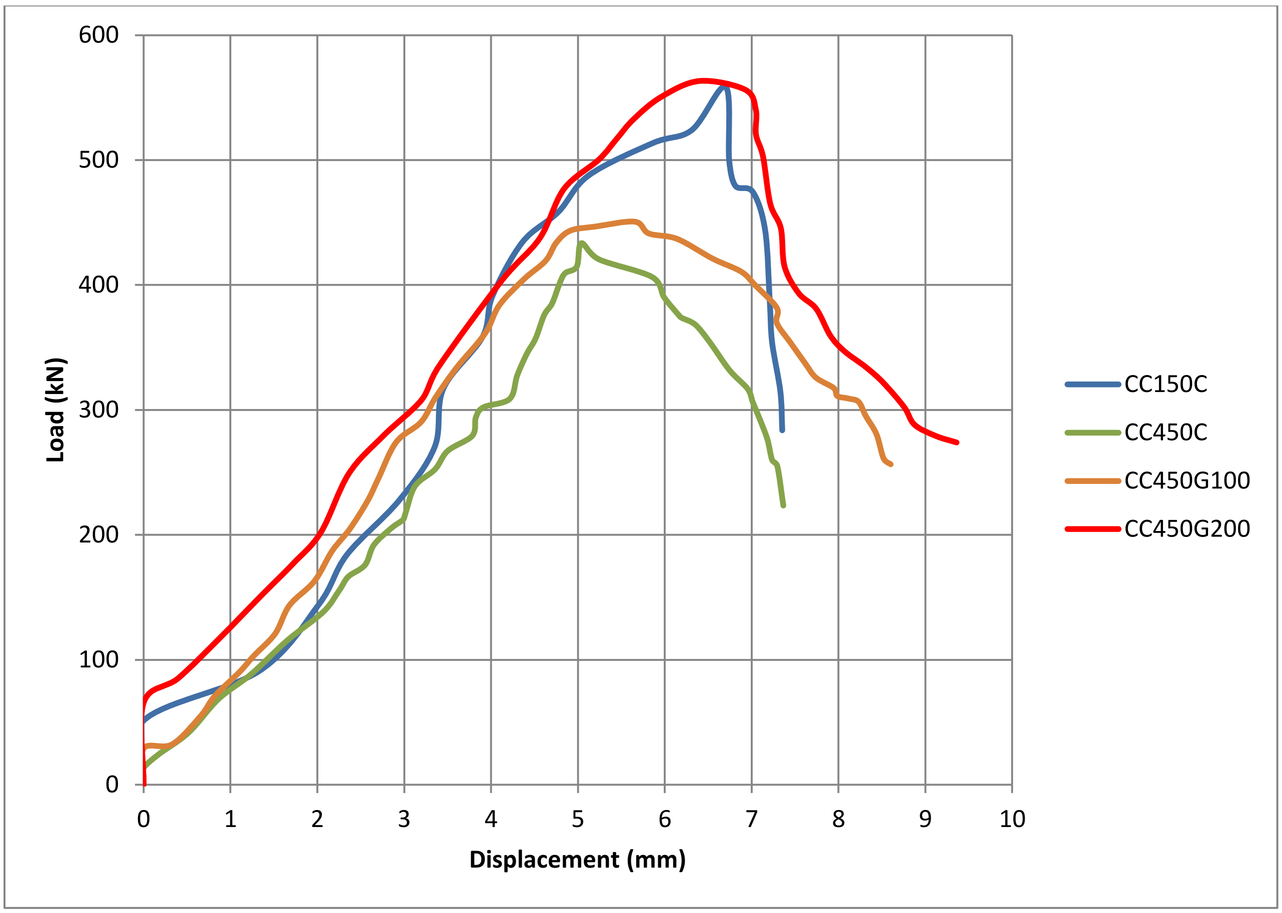


Figure 4.5 Comparison of load-deflection curve of geogrids confined NC columns with control specimen

It is clear from Figure 4.5 that as the spacing of lateral reinforcement that is stirrups increases there are decline in load carrying capacity of columns. But confining columns with geogrids give positive results with increment of peak loads compared to $CC_{450}C$ column. The peak load for $CC_{450}G_{200}$ and $CC_{150}C$ are nearly same with values 563.315 kN and 558.51 kN, thus proving geogrids confinement with G_{200} be effective alternative technique for confining replacing stirrups.

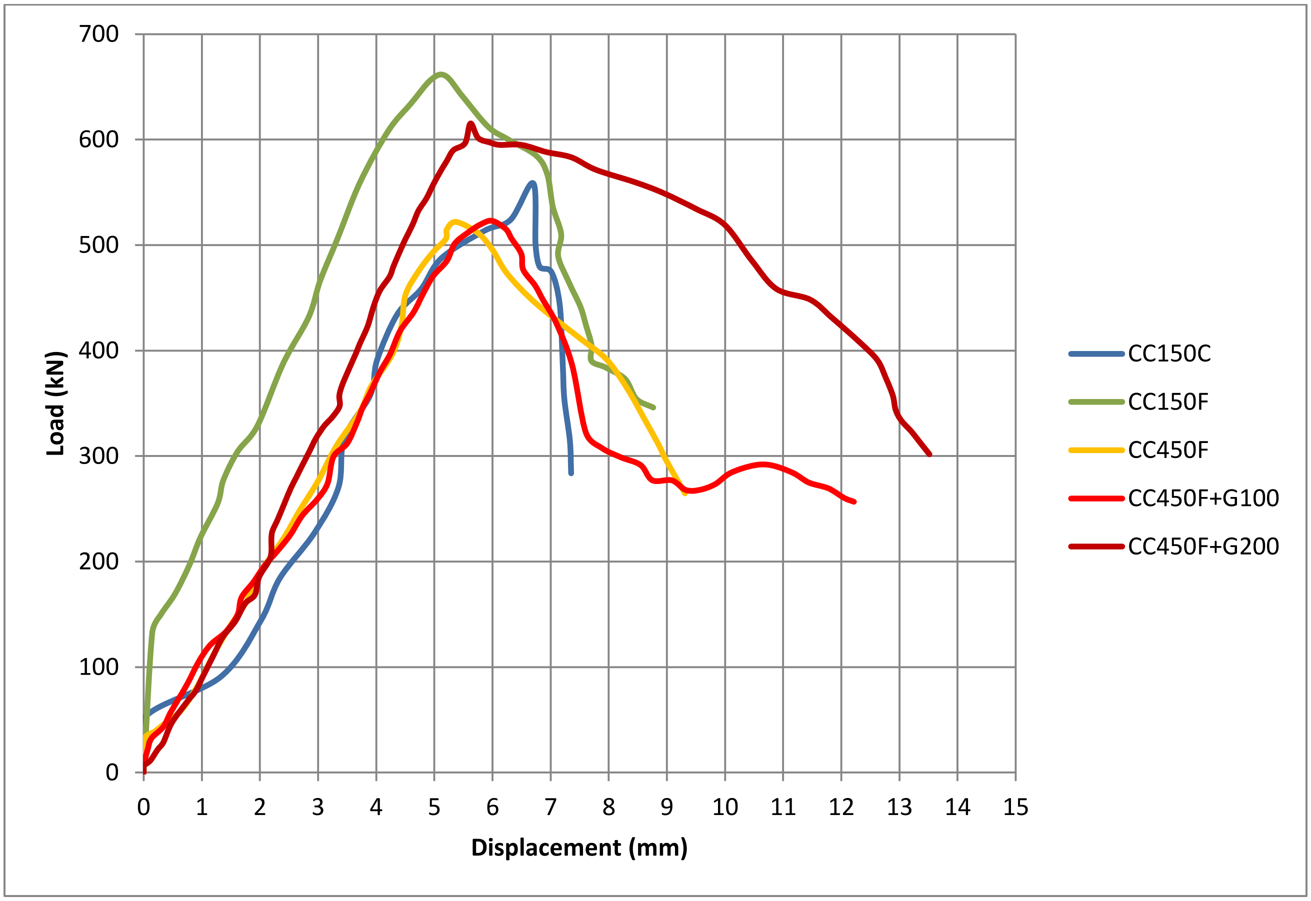


Figure 4.6 Comparison of load-deflection curve of geogrids confined SFRC columns with control specimen

The trend of the curves in Figure 4.6 shows that addition of fibres result in increased load capacities and somehow enhanced ductile behavior. $CC_{150}F$ gave highest value of load as compared to any other case while geogrids confined FRC columns showed highly ductile behavior sustaining higher values of load after peak load, proving the fact that geogrids contributed to holding the longitudinal bars and concrete together that helped them to sustain higher loads after ultimate load is attained.

The values of peak loads for geogrids confined specimen are summarized and compared in Table 4.3 and Table 4.4 for NC and SFRC columns respectively.

Table 4.3 Comparison of ultimate load of NC geogrids confined columns with other NC columns

Specimen id	Ultimate load (kN)	Control specimen	Comparison of ultimate load of other specimens with control specimen	Comparison of ultimate load of CC_{450} G_{100} with other specimen	Comparison of ultimate load of $cc_{450}G_{200}$ with other specimen
$CC_{150}C$	558.51	100 %	-	-19.31 %	+0.86 %
$CC_{450}C$	433.451	-	-22.39 %	+3.81 %	+23.05 %
$CC_{450}G_{100}$	450.645	-	-19.31 %	-	+20.00 %
$CC_{450}G_{200}$	563.315	-	+0.86 %	-25.00 %	-

Table 4.3 shows that as spacing of stirrups is increased from 150 mm to 450 mm, the value of ultimate load decreases by 22.39 %. While confining specimen with geogrids in case of $CC_{450}G_{100}$ lead to decrease in value of peak load by 19.31 %. On other hand $CC_{450}G_{200}$ gave ultimate load almost equal with minor increment of 0.86 % when compared to $CC_{150}C$. Again comparison of ultimate load of $CC_{450}G_{200}$ with other specimen showed increment of load for all cases of NC columns as shown in Table 4.3.Thus conclusion can be made that geogrids served their function in meaningful positive way.

Table 4.4 Comparison of ultimate load of SFRC geogrids confined columns with other columns

Specimen id	Ultimate load (kN)	Control specimen	Comparison of ultimate load of other specimens with control specimen	Comparison of ultimate load of $CC_{450}F+G_{100}$ with other specimen	Comparison of ultimate load of $CC_{450}F+G_{200}$ with other specimen
$CC_{150}C$	558.510	100 %	-	-6.36 %	+10.16 %
$CC_{150}F$	660.456	-	+18.25 %	-26.28 %	-7.35 %
$CC_{450}F$	521.904	-	-6.55 %	+0.20 %	+15.17 %
$CC_{450}F+G_{100}$	522.973	-	-6.36 %	-	+14.99 %
$CC_{450}F+G_{200}$	615.245	-	+10.16 %	-17.64 %	-

It can be found from Table 4.4 that addition of fibres resulted in increment of peak loads when compared to conventional control column $CC_{150}C$ with increment of 18.25 % for $CC_{150}F$. While $CC_{450}F$ and $CC_{450}F+G_{100}$ showed decrement by values 6.55 and 6.36 % only. $CC_{450}F+G_{200}$ gave efficient results by sustaining value of peak load 10.16 % higher than control column. It can also be concluded that confining with G_{100} gave minor increment of 0.20 % while G_{200} gave increment of 15.17 % when compared to $CC_{450}F$ showing that G_{200} had better performance than G_{100}.

The comparison of peak loads of columns with and without fibres is as shown in Figure 4.7.

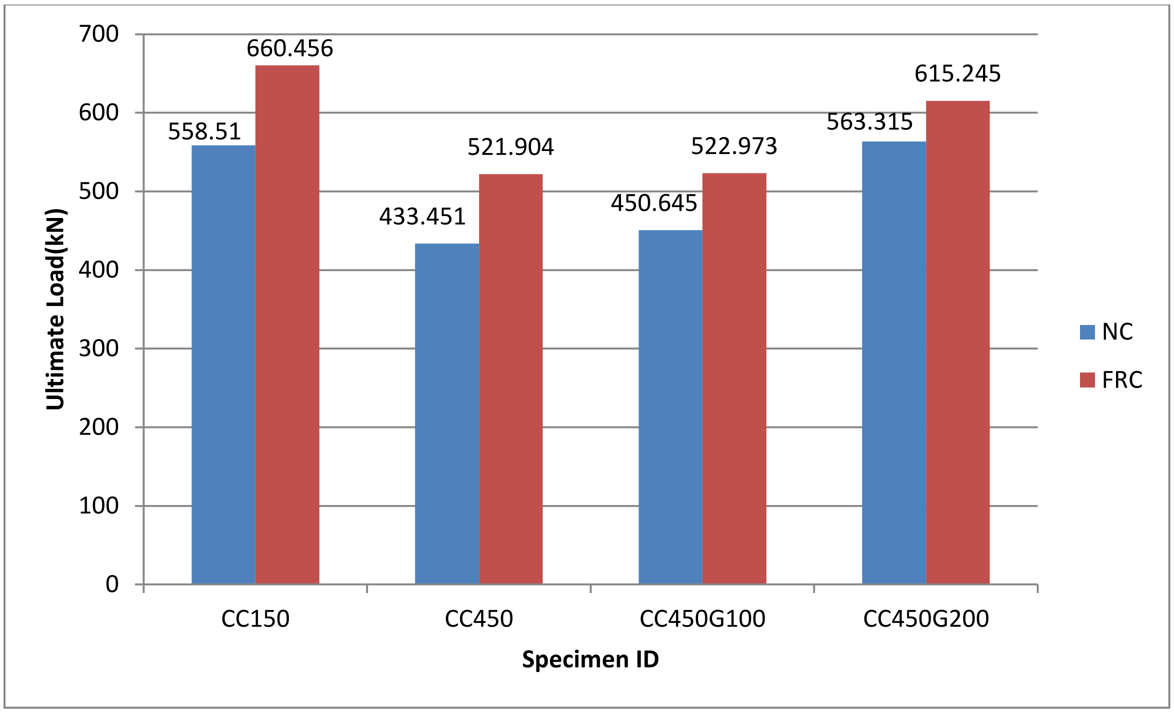


Figure 4.7 Comparison of ultimate loads of NC and FRC columns

4.3.2 Effect on Secant stiffness

Generally stiffness is defined as load required for unit displacement. It can also be defined as rigidity of material or object that is the extent to which it resists displacement in response to applied load. Secant stiffness can be defined as ratio of ultimate load to displacement at ultimate load as shown in Figure 4.8. The values of secant stiffness are summarized in Table 4.2 respectively. Comparison of secant stiffness of geogrids confined columns with other columns is shown in Tables 4.5 and 4.6 respectively.

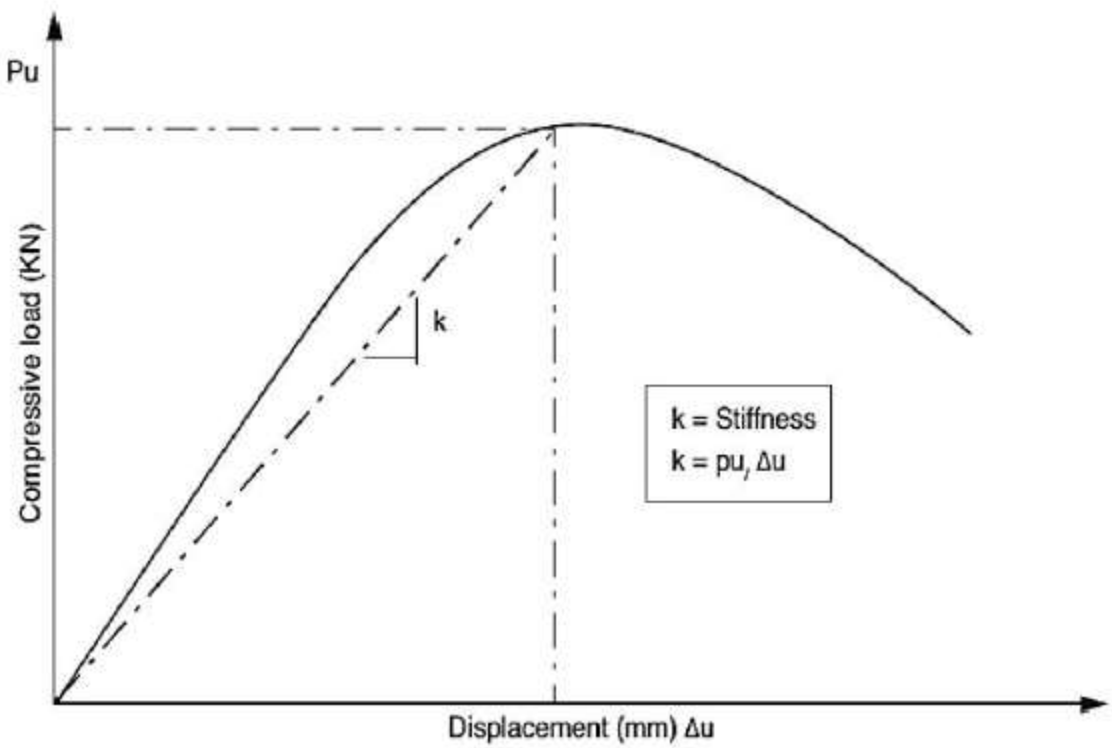


Figure 4.8 Calculation of secant stiffness from load displacement curve (Danie et al., 2014)

Table 4.5 Comparison of secant stiffness of NC geogrids confined columns with other NC columns

Specimen id	**Ultimate load (kN)**	**Displacement at ultimate load (mm)**	**Secant stiffness (kN/mm)**	**Control specimen**	**Comparison of secant stiffness of other specimens with control specimen**	**Comparison of secant stiffness of CC_{450} G_{100} with other specimen**	**Comparison of secant stiffness of $cc_{450}G_{200}$ with other specimen**
$CC_{150}C$	558.510	6.702	83.335	100 %	-	-4.36 %	+5.57 %
$CC_{450}C$	433.451	5.039	86.019	-	+3.22 %	-7.92%	+2.23 %
$CC_{450}G_{100}$	450.645	5.654	79.704	-	-4.36%	-	+9.43 %
$CC_{450}G_{200}$	563.315	6.403	87.977	-	+5.57 %	-10.38 %	-

Table 4.6 Comparison of secant stiffness of SFRC geogrids confined columns with other columns

Specimen id	Ultimate load (kN)	Displacement at ultimate load (mm)	Secant stiffness (kN/mm)	Control specimen	Comparison of secant stiffness of other specimens with control specimen	Comparison of secant stiffness of $CC_{450}F+G_{100}$ with other specimen	Comparison of secant stiffness of $CC_{450}F+G_{200}$ with other specimen
$CC_{150}C$	558.510	6.702	83.335	100 %	-	+4.77 %	+31.34 %
$CC_{150}F$	660.456	5.191	127.231	-	+52.67 %	-45.73 %	-16.24 %
$CC_{450}F$	521.904	5.375	97.098	-	+16.52 %	-11.21 %	+11.29 %
$CC_{450}F+G_{100}$	522.973	5.990	87.307	-	+4.77 %	-	+20.23 %
$CC_{450}F+G_{200}$	615.245	5.621	109.455	-	+31.34 %	-25.37 %	-

It can be concluded from Table 4.5 and 4.6 that addition of steel fibres to concrete lead to increase in stiffness of columns when compared to non-fibrous columns. It is the steel fibres that have increased the structural integrity that has led to increased stiffness. On other side use of G_{100} showed lesser value of stiffness compared to other specimen proving that it couldn't make good bond with concrete matrix. It is so because of its geometrical and surface property of being in form of thin strings and being plane (not rough) that it couldn't form good bond and didn't provide enough rigidity to columns compared to others. Besides this use of G_{200} showed increased stiffness value for nearly all cases (except $CC_{150}F$), showing its compatible integrity with concrete mix.

Figure 4.9 represents the comparison of secant stiffness of fibrous and non-fibrous columns.

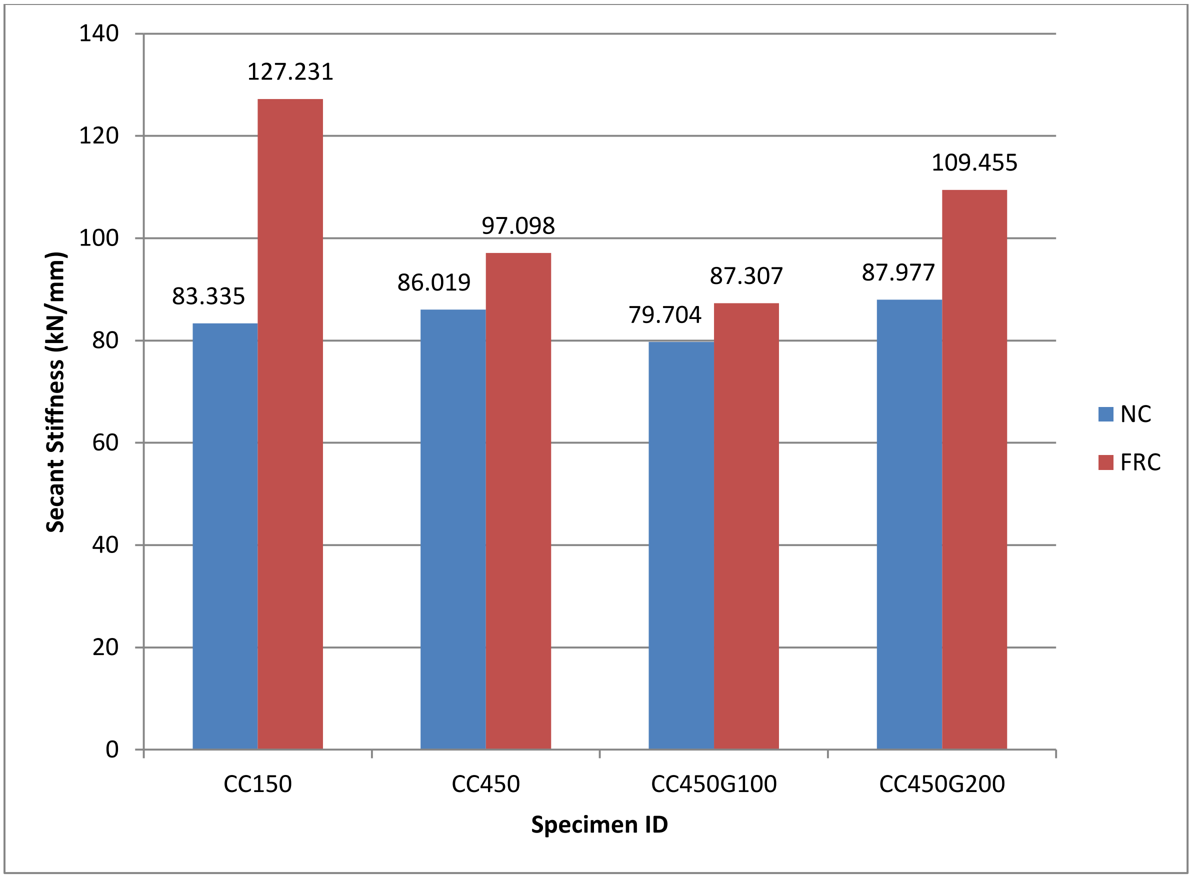


Figure 4.9 Comparison of secant stiffness of NC and FRC columns

4.3.3 Effect on energy dissipation

Energy dissipation can be defined as amount of energy a material can absorb before failure. For any reinforced concrete element or member, energy dissipation is sum of energy dissipated by steel as well as that by concrete. Studies reveal that for reinforced concrete steel bars dissipate more energy compared to concrete. But since we are dealing with columns exhibiting axial load under compression, role of concrete becomes equally important in energy dissipation. Energy dissipation can be calculated as area under load-deformation curve. The energy dissipation capacities were calculated up to 0.8 time's ultimate load on descending portion of curve as shown in Figure 4.10. The energy dissipation values of all specimens are tabulated in Table 4.2. The comparison of energy dissipation values of geogrids confined columns with other columns are summarized in Tables 4.7 and 4.8 respectively.

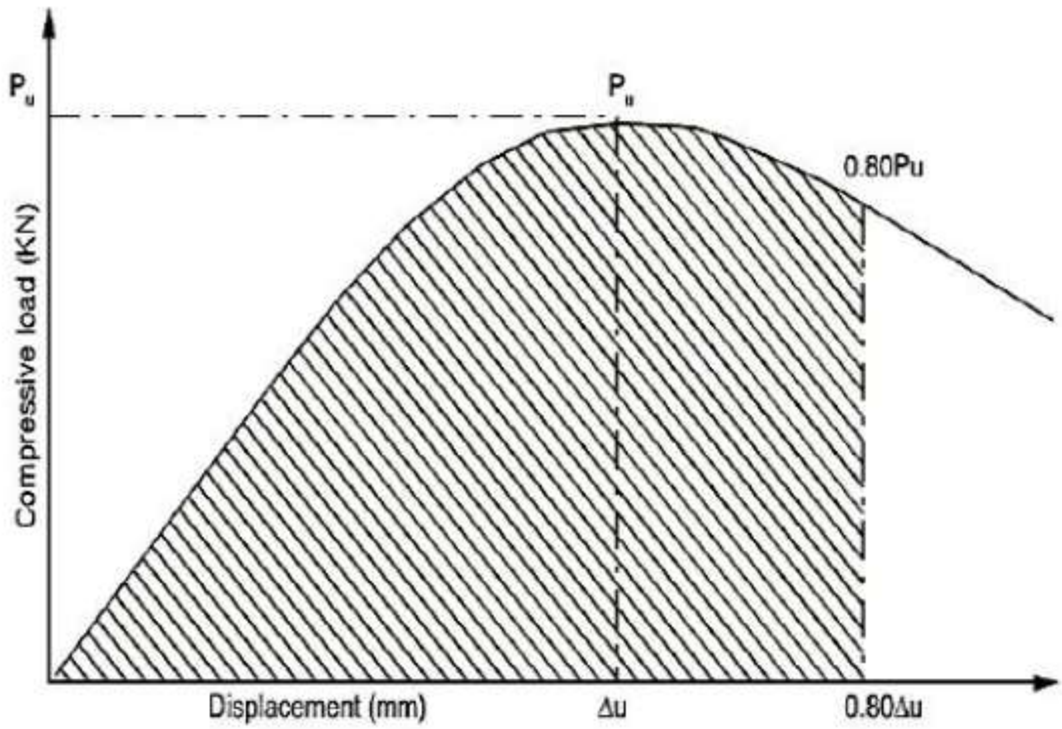


Figure 4.10 Calculation of energy dissipation from load displacement curve (Danie et al., 2014)

Table 4.7 Comparison of energy dissipation of NC geogrids confined columns with other NC columns

Specimen id	**Energy dissipation (kN-mm)**	**Control specimen**	**Comparison of energy dissipation of other specimen with control specimen**	**Comparison of energy dissipation of CC_{450} G_{100} with other specimen**	**Comparison of energy dissipation of $cc_{450}G_{200}$ with other specimen**
$CC_{150}C$	2195.219	100 %	-	+2.25 %	+14.73 %
$CC_{450}C$	1034.495	-	-52.88 %	+51.79 %	+58.93 %
$CC_{450}G_{100}$	2145.753	-	-2.25 %	-	+14.80 %
$CC_{450}G_{200}$	2518.563	-	+14.73 %	-17.37 %	-

Table 4.8 Comparison of energy dissipation of SFRC geogrids confined columns with other columns

Specimen id	Energy dissipation (kN-mm)	Control specimen	Comparison of energy dissipation of other specimen with control specimen	Comparison of energy dissipation of $CC_{450}F+G_{100}$ with other specimen	Comparison of energy dissipation of $CC_{450}F+G_{200}$ with other specimen
$CC_{150}C$	2195.219	100 %	-	+1.35 %	+98.81 %
$CC_{150}F$	3268.624	-	+48.90 %	-46.92 %	+25.10 %
$CC_{450}F$	1456.379	-	-33.66 %	+34.54%	+66.63 %
$CC_{450}F+G_{100}$	2224.816	-	+1.35 %	-	+49.02 %
$CC_{450}F+G_{200}$	4364.407		+98.81 %	-96.17 %	-

Conclusions can be drawn from Tables 4.4 and 4.8 that increasing spacing of stirrups that is decrease in lateral reinforcement result in decline of energy dissipation capacity of columns. But addition of steel fibres compensates the decrease in lateral reinforcement by providing increased energy dissipation to columns. Again the use of geogrids alone and in combination with fibres had positive impact with sounding values of energy absorption. The comparison of energy dissipation for NC and FRC columns is presented in Figure 4.11.

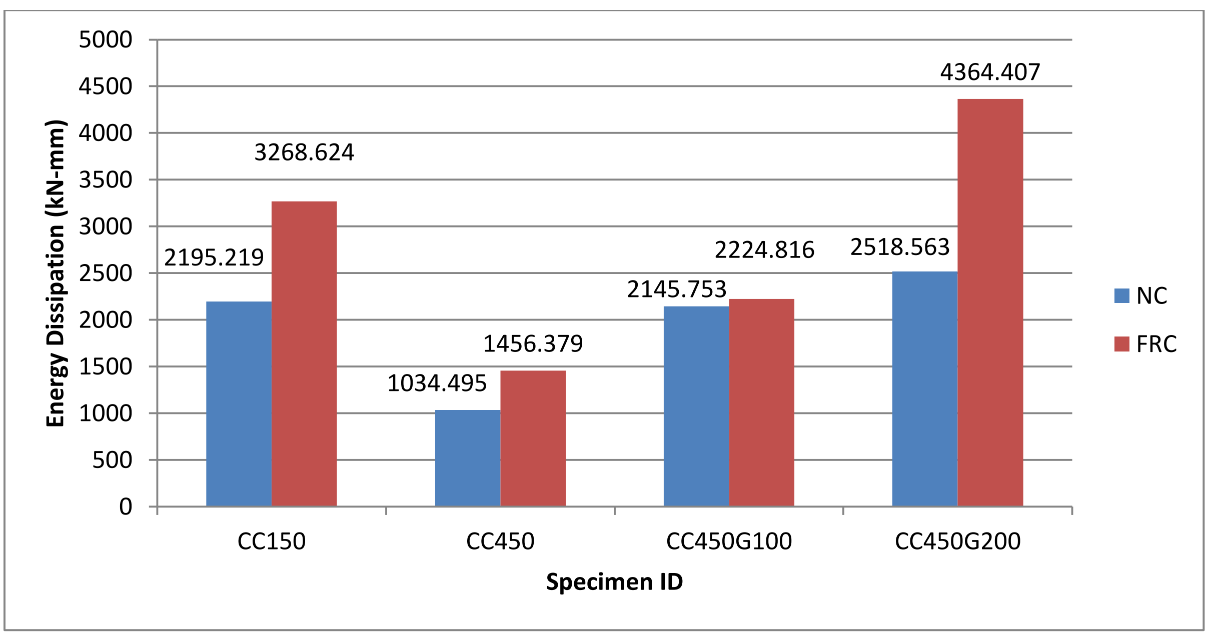


Figure 4.11 Comparison of energy dissipation of NC and FRC columns

CHAPTER 5

CONCLUSIONS AND FUTURE SCOPE

5.1 Conclusions

The experimental program was conducted to study the behavior of geogrids confined columns with and without steel fibres. Total of sixteen columns (8 types) were casted. The parameters included spacing of stirrups (150 mm and 450 mm), use of type of concrete (NC and SFRC) and use of type of geogrids (average tensile strength of 100 kN/m and 200 kN/m). The columns were subjected to axial load under UTM and their load deflection curves were plotted and parameters such as ultimate load, maximum axial displacement, secant stiffness, ductility and energy dissipation were evaluated and compared. Some of the important conclusions and observations are summarized below:

1. FRC column with similar spacing of stirrups to that of NC columns exhibit larger values of ultimate loads and show highly ductile behavior. For spacing of 150 mm, addition of steel fibres added to 18.25 % increase in peak load compared to $CC_{150}C$ while for 450 mm spacing addition of fibres lead to 20.41 % increase in peak load compared to $CC_{450}C$. It is due to the reason that fibres present in the column prevent the early spalling of concrete cover and thus increase its load carrying capacity. Also addition of fibres impart ductility to columns as their addition gives some kind of residual strength or residual post cracking load carrying capacity, that is more load is sustained in the post peak region.
2. Columns composed of NC exhibit little bit of brittle behavior after peak load is obtained. It is so because once peak load is obtained the cracks get so widened that load decline rapidly as compared to displacement.
3. With increase in average tensile strength of geogrids used, there is increase in load bearing capacity of column. For NC columns confining with G_{200} gave peak load values 0.86 % and 23.05 % more than $CC_{150}C$ and $CC_{450}c$ respectively. While confining with G_{100} gave peak load values just 3.81 % higher than $CC_{450}C$ proving least contribution of G_{100} in increasing ultimate load. But it had good intent sustaining higher loads compared to control specimen in post peak region. On other side using geogrids along with fibres resulted in 10.16 % increase in peak load compared to $CC_{150}C$ in case of G_{200} and minor decrement of 6.36 % compared to $CC_{150}C$ in case of G100.

4. Addition of steel fibres to concrete lead to increase in stiffness of columns when compared to non-fibrous columns. Compared to $CC_{150}C$, $CC_{150}F$ and $CC_{450}F$ had increased stiffness by 52.67 % and 16.52 % respectively. It is the steel fibres that have increased the structural integrity that has led to increased stiffness. On other side use of G_{100} showed lesser value of stiffness compared to other specimen proving that it couldn't make good bond with concrete matrix. It is so because of its geometrical and surface property of being in form of thin strings and being plane (not rough) that it couldn't form good bond and didn't provide enough rigidity to columns compared to others. Besides this use of G_{200} showed increased stiffness value for nearly all cases (except $CC_{150}F$), showing its compatible integrity with concrete mix.
5. Increasing spacing of stirrups that is decrease in lateral reinforcement resulted in decline of energy dissipation capacity of columns. But addition of steel fibres compensated the decrease of lateral reinforcement by providing increased energy dissipation to columns. Again the use of geogrids alone and in combination with fibres had positive impact with sounding values of energy absorption. G_{200} gave value of 98.81 % and 14.73 % higher compared to $CC_{150}C$ when used along with fibres and without fibres respectively.

The observations provide us with positive intake of application of geogrids in columns. But still more and more studies need to be carried out to really rely upon its use in field as reinforcement for columns.

5.2 Future scope

Application of geogrids in construction as reinforcement material for concrete is still new of its type, with very few experimental programs being carried out till now. Further it hasn't been applied practically in field because of insufficient studies to rely upon. Extensive studies need to be carried out to get better knowledge of its behavior as confining material. Further studies could be carried out by varying parameters such as providing multiple layers of wrapped geogrids, fully wrapping it internally along with lateral reinforcement and using other geogrids with higher values of average tensile strength than that used in this study.

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