SHEAR STRENGTH OF REINFORCED CONCRETE CIRCULAR CROSS-SECTION USING GEO-GRIDS AND STEEL FIBRES

A Thesis Submitted in Fulfillment of the Requirement
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Submitted by

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DECLARATION

I, Narendra Kumar Karn, hereby declare that the work presented in this thesis entitled **"Shear Strength of Reinforced Concrete Members with Circular Cross-Section using Geo-grids and Steel Fibres"** in fulfillment of the requirement for the award of degree of **Master of Engineering** in **Structures**, submitted at **Civil Engineering Department**, **Thapar Institute of Engineering & Technology**, **Patiala**, is an authentic record of work carried out under the guidance of **Dr. A. B. Danie Roy**, **Thapar Institute of Engineering & Technology**, **Patiala.** 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.

Date: 14/08/2019

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CERTIFICATE

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

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ABSTRACT

Reinforced concrete members with circular cross-sections are used frequently in construction practice. They are used as columns, piers, and piles because of their identical properties in all direction. The present research deals with the study of shear strength of the RC circular sections using geogrids and steel fibres, where the steel stirrups are partially replaced by the geogrids. Geogrids being good at tension and flexible in nature, the idea to use it as a stirrup was generalized for the research. Addition of steel fibres known to resist the cracking in concrete, both geogrids, and steel fibres was used to study the performance of the concrete. Sixteen specimens were casted with parameters such as steel stirrups spacing (75 mm, 100 mm, 150 mm, 450 mm and 700 mm), use of type of concrete (Reinforced Concrete and Steel Fibre Reinforced Concrete) and use of different tensile strengths of geogrids (100 KN/m and 200 KN/m). The testing of circular specimens was carried out on a loading frame having a hydraulic jack of capacity 600 KN. Each specimen was simply supported and subjected to a point load at mid-span. The load-deformation curves were plotted for each specimen and compared for the ultimate load, secant stiffness, energy dissipation, and displacement ductility. The test results revealed that application of geogrids along with the steel fibres significantly improved the ductility and strength of the specimen.

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LIST OF ABBREVIATIONS

ACI	American Concrete Institute
ASCE	American Society of Civil Engineers
ASTM	American Society for Testing and Materials
BS	British Standard
COV	Coefficient of Variation
CSTR	Concrete Society Working Group, Technical Report
CTM	Compression Testing Machine
HSC	High-Strength Concrete
IS	Indian Standard
MCFT	Modified Compression Field Theory
NC	Normal Concrete
OPC	Ordinary Portland Cement
RC	Reinforced Concrete
SFRC	Steel Fibre Reinforced Concrete
TM	Trademark
TMT	Thermo Mechanically Treated
UCSD	University of California San Diego

1. INTRODUCTION

1.1 GENERAL

Structural engineering; a civil engineering branch, is moreover concerned about the analysis and design of the structures such as buildings, industries, bridges, towers, flyovers and many other structures. The load acting on a structure and the forces and stresses generated within that structure due to such loads are identified and these structures are designed to successfully resist and support such loads. The loads can be self-weight of the structure, live load, any other dead load, wind load, seismic load, etc. Designing the structure to be safe and serviceable is the major role of a structural engineer.

In civil engineering, we deal with the structures composed of reinforced concrete; concrete being main constituent material along with steel as reinforcement material. For the ductility in the section, we provide longitudinal reinforcement so that it has the tendency to hold the deformation occurring in the plastic region, as concrete in plain is brittle in nature. Transverse reinforcements are provided in the form of hoops or ties to hold these longitudinal reinforcements and add necessary shear strength as well.

While designing reinforced concrete beams and columns, where flexural behavior is predominant we need to ensure that ductile failure occurs resisting shear or bond failure. For this, proper assessment of shear strength of RC beams is required. Sudden failure due to less ductility or brittle nature is not desirable. Thus, the shear strength of every member in the structure should exceed the flexural strength and it depends upon various parameters such as the grade of concrete, longitudinal reinforcement (main reinforcement), shear reinforcement (stirrups), shear span by depth ratio, etc.

1.2 CIRCULAR SECTIONS

Circular sections are widely used in bridges as piers and pilings, columns, etc. Because of its advantage of having omnidirectional strength or constant strength in all direction, it is very useful in seismically active regions. In bridges, such piers may subject to the lateral loads due to braking and acceleration forces on the roadway by vehicles as well as the load from the bridge deck.

1.2.1 ADVANTAGES OF CIRCULAR SECTIONS

i) Circular sections have uniform torsional characteristics.

ii) Circular sections have omnidirectional strength characteristics under wind and seismic loads.

iii) They are symmetrical over one axis.

iv) They are more stable and have better strength than rectangular sections.

v) Resistance to bending or deflection is greater than rectangular sections having the same area.

vi) For a given dimension, they require less material to build providing maximum surface area.

1.2.2 APPLICATIONS OF CIRCULAR SECTIONS

i) They are used in seismically active regions as piers and piles.

ii) Circular sections as columns are aesthetically pleasing structures.

iii) To avoid edges in the building, a circular section can be used.

iv) They are widely used in bridges as piers and pilings.

1.3 GEOGRIDS

A geogrid is a material made up of geo-synthetics used in the construction industry as a reinforcing material. It is made up of polymer materials, such as polyester, polyvinyl alcohol, polyethene or polypropylene. Geogrids are formed by means of intersecting grids. It has various uses in the construction industry, such as soil reinforcement or reinforcement of retaining walls and many more. Since it is good in tension and has a higher ability to distribute loads across large area geogrids has high demands in construction. Heerten (2007) studied for the improvement of bearing capacity of soils using geogrids. Tang et al. (2008) studied the application of geogrids for stabilization of weak pavement subgrade. Ziegler (2017) discussed the application of geogrids as reinforced in constructions. Meski et al. (2013) studied the application of geogrids in concrete beams for flexural behavior.

1.3.1 TYPES OF GEOGRIDS

i) Uniaxial geogrids: In such geogrids, the stretching is only along a longitudinal direction. Therefore, the material has a higher tensile strength in the longitudinal direction than in the transverse direction.

Fig 1.1(a): Uniaxial Geogrid (theconsturctor.org)

ii) Biaxial geogrids: In such geogrids, the stretching is along with two directions (longitudinal and transverse). Therefore, the tensile strength is equal in both the direction.

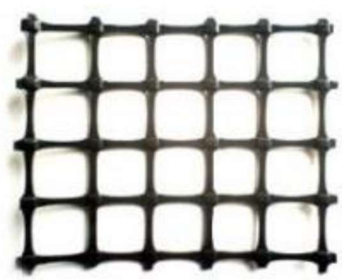

Fig 1.1 (b): Biaxial Geogrid (theconstructor.org)

1.3.2 ADVANTAGES OF GEOGRIDS

i) Free from corrosion.

ii) No water absorption.

iii) Flexible in nature and has high tensile strength.

iv) Light in weight.

v) Environment-friendly.

vi) Simple handling and installation.

vii) High durability and highly resistant to environmental influences.

1.3.3 APPLICATIONS OF GEOGRIDS

i) In the construction of retaining walls: Geogrids in retaining wall are used in the area of soil backfills. Because of its high flexibility nature, it's very adaptable in retaining wall making the retaining wall more stable and earthquake resistant. The cost of construction is also considerably reduced compared to the conventional concrete retaining wall.

ii) In foundation soil: Geogrids in the shallow foundation can be used to stabilize the soil below foundation. It increases the bearing capacity of the soil.

iii) In pavement construction:

- **Improvement of subgrade –** Geogrids can be used to make the subgrade solid and strong. Soft subgrade problem can be solved using geogrid as the subgrade is the most important load-bearing strata.
- **Reinforcement of pavement base –** Increasing the thickness of the base increases the stiffness of the base but turning it to be uneconomical. So, reinforcing the base layer would stiffen the base as well as reduce the thickness and time of construction. And because of its high flexural strength, it can increase the durability of the pavement.

iv) In erosion control: Use of geogrid prevents the soil from erosion. It can minimize the effect of erosion providing permanent protection.

v) Inlining: Geogrids have their applications in tunnel lining, canal lining and landfill lining.

There are many more applications of geogrids. In this research, its application is tested as partial replacement of shear reinforcement for circular RC section. Itani et al. (2016) studied the use of geogrid reinforcement to enhance the performance of concrete. Geogrid reinforcement was found to increase crack resistance with substantial ductility.

1.4 STEEL FIBRES

Steel fibres are metal reinforcement mixed into the concrete. They are short with discrete length with an aspect ratio of about 30 to 100 with various cross-sections. A certain amount of steel fibre in concrete causes a qualitative change in its physical properties.

1.4.1 TYPICAL PROPERTIES OF STEEL FIBRES

As per BS EN 14889-1:2006, the properties of the steel fibres are

- Cross-section: Round, flat, crescent, etc.
- Deformations: Straight, wavy, end hook, etc.
- Length: 19 to 60 mm
- Aspect ratio: 30 to 100
- Tensile strength: 345 to 1700 N/mm^2
- Young's modulus: 205 KN/mm^2

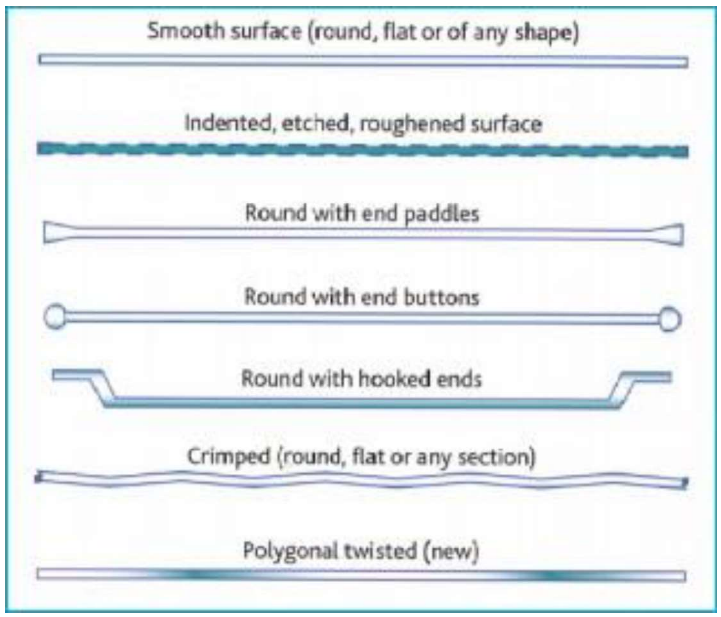

Fig 1.2: Types of steel fibres (CSTR 63, 2007)

1.4.2 BENEFITS OF STEEL FIBRES

i) Increases resistance to cracking.

ii) Improves the structural strength of the section.

iii) Reduces the requirement of steel reinforcement.

iv) Improves the ductility of section.

v) Increases the resistance to impact, fatigue, abrasion and bending, increasing the durability of the section.

1. 5 OBJECTIVES OF STUDY

The main objectives are:

- To study the feasibility of geo-grid confinement in RC circular section as a partial replacement of shear reinforcement with the addition of steel fiber.
- To evaluate the effect of different tensile strengths of geogrids on shear strength of circular sections.
- To study the modes of failure for the sections composed of normal concrete and steel fibre reinforced concrete.

1. 6 ORGANISATION OF THE DISSERTATION

Chapter - 1. INTRODUCTION: Deals with the general inception about the topic and materials used with its advantages and applications.

Chapter - 2. BACKGROUND: Highlights the topic with the roles of using reinforcement, equations for shear strength calculations and the types of failure.

Chapter - 3. LITERATURE REVIEW: Provides the overview of past studies regarding the shear strength and different types of materials used.

Chapter - 4. EXPERIMENTAL PROGRAMME: Discusses the material properties, procedures carried out for casting and testing of the specimens.

Chapter - 5. RESULTS AND DISCUSSION: Shows and discusses the results in the form of graphs and tables with valid reasons.

Chapter - 6. CONCLUSIONS AND FUTURE SCOPE: Summary of the thesis with the important observations are listed along with the future scope.

2. BACKGROUND

2.1 GENERAL

Shear strength of concrete plays an important role in structural design because of the strength it offers in resisting the sudden and violent shear failure which needs additional care and results in the enrollment of higher safety factor. Concrete is brittle in nature, the mode of shear failure cannot be neglected.

Some of the researchers (Ahmad et al., Ghaffer et al., etc) have reviewed the methods that estimated the strength for shear of reinforced concrete (RC) rectangular sections. Although, the shear strength predictions in comparison to experimental results show considerable scatter, the margin of safety against shear failure in code based methods is fairly conservative and significantly larger than the margin against flexural failure (Balakrishnan et al, 2016). The research on the shear behavior for circular sections is very limited. ACI 318-14, suggests the equation for shear design of circular section based on equivalent rectangular section.

Majorly, the tests carried out on shear of RC members are moreover focused on rectangular sections. Knowing that the circular members have identical properties, sometimes it is preferred in members such as columns, piers, piles, etc over rectangular sections. In such beam-columns, shear forces and bending moments are caused by wind, earthquake, vehicle impact, etc., due to the lateral loads. As the presence of axial compression enhances the shear strength marginally, the beneficial effect is mostly ignored in the design practice.

2.2 ROLE OF LONGITUDINAL REINFORCEMENT IN RC SECTIONS

Plain concrete is strong in compression and weak in tension. Therefore, adding longitudinal bars to the section plays a vital role in resisting any tension that might develop in the section due to bending caused by any shear / transverse load or moments. The tensile strength is improved, thereby enhancing the resistance of a section against crack opening and propagation. It changes the mode of failure preventing from sudden failure of the section providing the necessary ductility to the section. It also reduces the effect of creep and shrinkage in a section. Therefore, the main purpose of the longitudinal reinforcement is to increase ultimate capacity and gain necessary ductility in the section.

2.3 ROLE OF SHEAR REINFORCEMENT IN RC SECTIONS

A force which tends to cause a sliding failure on a section/material along a plane parallel to the force direction applied is called a shear load. The shear reinforcement is designed to resist such a load to avoid shear failure. Shear reinforcement or transverse reinforcement or lateral ties are the reinforcement provided in the form of hoops or ties; stirrups, which holds the main reinforcement in place and increases the shear strength to take the shear and avoid the shear cracks to develop. So, the main purpose of the shear reinforcement is to hold the longitudinal reinforcement as well as avoid the shear failure in the section.

2.4 AXIAL LOAD

The axial load applied to the circular section increases the shear strength marginally. Therefore, the axial compression load is ignored in the design practice to avoid this beneficial effect. To study the impact of axial compressive stress on the shear capacity of the circular section detailed experiment needs to be done which is a different topic.

2.5 TYPES OF FAILURE

According to ACI-ASCE Committee 426 (1973), there are four types of failure in beam-column.

a) Flexural Failure: Due to the inadequate thickness of the beam, this kind of failure may occur in the beam-column.
b) Shear Tension Failure: This failure may occur due to diagonal crack propagating horizontally along with the longitudinal tensile reinforcement.
c) Diagonal Tension Failure: Due to inadequate shear reinforcement, this type of failure may occur. The diagonal crack forms at 45^{o} and propagates rapidly causing failure in the member.
d) Shear Compression Failure: Because of the inadequate strength of the concrete, this failure may be seen. The concrete crushes near the tip of the inclined crack in the compression zone.

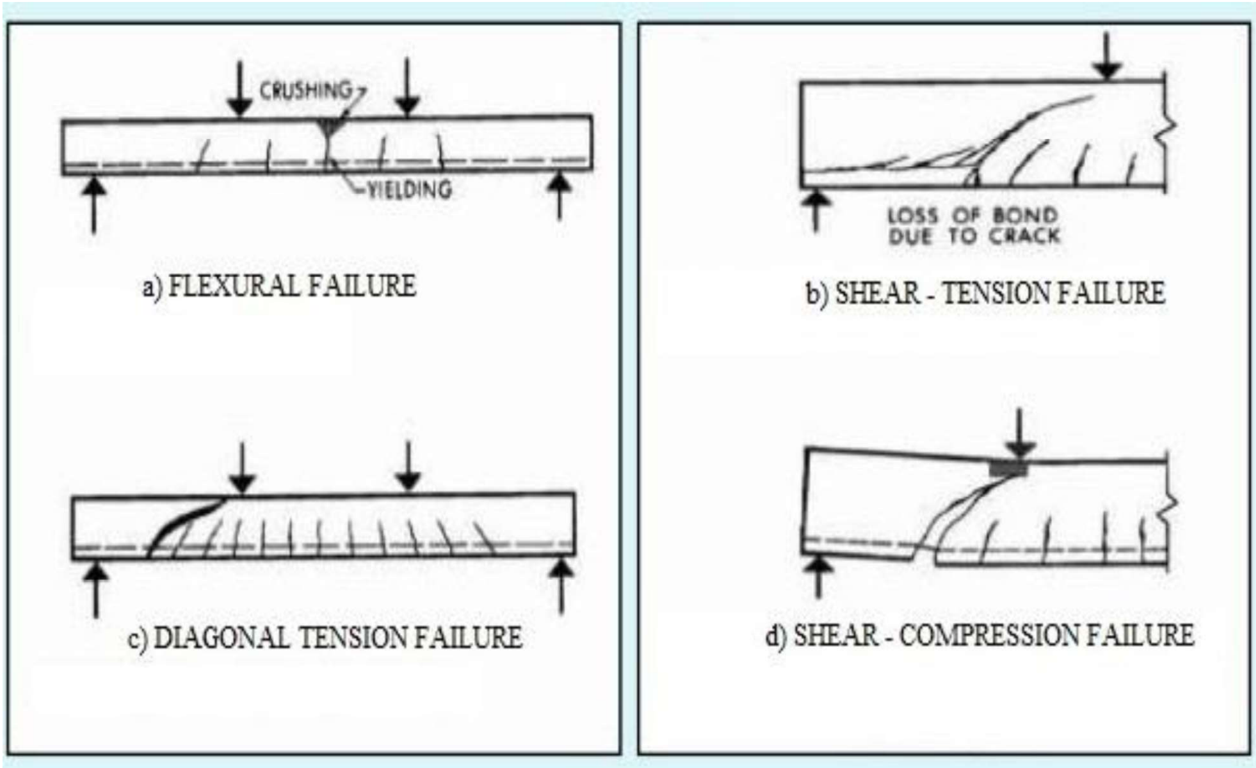

Fig 2.1: Types of failure (ACI-ASCE Committee 426, 1973)

2.6 NOMINAL SHEAR STRENGTH OF CONCRETE IN RECTANGULAR SECTIONS

The nominal shear strength (V_n) for any cross section has two components:

- due to concrete without shear reinforcement (V_c)
- due to the stirrups (V_s).

The design shear strength as per IS 456:2000, is obtained by

$$V_n = V_c + V_s \quad \text{(i)}$$

V_c for any rectangular and flanged sections is the product of average ultimate shear stress (τ_c) and an effective area ($b_w d$), where, 'd' is the effective depth and 'b_w' is the breadth of the web portion.

$$V_c = \tau_c b_w d \quad \text{(ii)}$$

The nominal average shear stress of concrete (τ_c) depends upon the grade of concrete, percentage of tension steel, and shear-span by depth ratio.

2.7 NOMINAL SHEAR STRENGTH CONTRIBUTION OF STIRRUPS IN RECTANGULAR SECTIONS

'V_s' is the nominal shear strength due to the presence of stirrups.

$$V_s = f_{yt}A_v(d/s) \text{ ….. ……………………………….(iii)}$$

Where,

f_{yt}: specified yield strength

A_v: shear reinforcement area

d: effective depth

s: stirrups spacing

Equation (ii) and (iii) are calculated and substituted in equation (i) to obtain shear strength of the rectangular reinforced section.

2.8 EQUIVALENT RECTANGULAR SECTION TO ASSESS SHEAR STRENGTH IN CIRCULAR SECTIONS

The ACI 318-14 recommends considering an effective area having a width as the diameter (D) and effective depth may be approximated as d = 0.8D.

Accordingly, the following approximation may be adopted to evaluate V_c and V_s and substituted in equation (i) to obtain the shear strength for a circular reinforced section.

$$V_c = 0.8\tau_c D^2$$

$$V_s = f_{yt}A_v(0.8D/s)$$

Where,

τ_c: average ultimate shear stress

f_{yt}: specified yield strength

A_v: shear reinforcement area

D: dia of the circular column

s: stirrups spacing

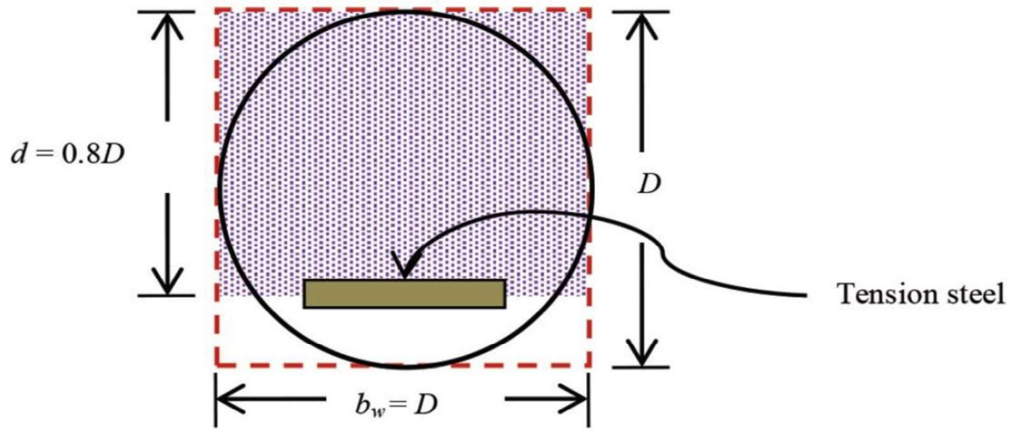

Fig 2.2: Equivalent rectangular cross-section (ACI 318-14)

3. LITERATURE REVIEW

3.1 RECTANGULAR SECTION

Ahmad et al. (1986) predicted shear capacity of rectangular beams using ACI equations and design provisions. They tested 36 RC beams using high-strength concrete (HSC) which had a uniaxial compressive strength greater than 42 MPa. All the beams were singly reinforced without shear reinforcement. The concrete strength varied from 63 to 70 MPa. The beams were tested in different shear-span by depth ratios and longitudinal bars (reinforcement). The tests resulted in a reduction of measured to predicted shear capacity to about 1, using ACI design, for the beams that were slender with high shear strength and low main reinforcement. The test also showed that the ACI design was over conservative for short beams ($1<a_v/d<2.5$) and not conservative for higher shear span by depth ratios. They suggested an empirical formula to estimate the ultimate shear capacity based on the experimental results and other studies.

Vecchio and Collins (1986) presented an analytical model that was capable of anticipating the load-deformation response of RC elements subjected to shear and normal stress. They considered cracked concrete as their new material having their own stress-strain characteristics, where they tested 30 RC panels under a variety of well-defined uniform biaxial stress including pure shear. The MCFT was developed in torsion and shear from the theory of compression field for RC. MCFT predicted the response of the RC elements to in-plane shear and axial stresses taking into consideration of equilibrium conditions, compatibility requirements and stress-strain relationships, all taken as average stresses and average strains.

Bentz et al. (2006) summarized the results on RC panels of 100 pure shear tests. They showed the new and simplified method of analyzing the strength of these panels. They summarized the relationships with MCFT which could model the full load-deformation response of RC panels subjected to arbitrary biaxial loading and shear loading. The average ratio of experimental-to-predicted shear strength of the Simplified MCFT is 1.11 and the COV is of 13%, whereas that for MCFT is 1.01 and 12.2%, respectively. With a small difference in both, the theory is simple and easy to understand and near to accurate for the shear strength prediction.

Ghaffar et al. (2010) considered three parameters (compressive strength, tensile reinforcement percentage and shear-span by depth ratio) and predicted the equation for shear strength. They cast 19 beams with tension reinforcement provided at the bottom without using shear reinforcement in the section. The curing was done for 28 days. These parameters either increased or decreased the shear capacity of the beam. The study's objective was to develop the equation of shear capacity.

Rao and Injaganeri (2011) reported the analysis of the impact of depth of the beam and various parameters on the shear strength of reinforced concrete beams. The model was suggested with the functions of compressive strength of the concrete, percentage of flexural reinforcement and depth of the beam. The model suggested for predicting the ultimate shear strength was simple and for the variety of influencing parameters, values predicted the shear strength of RC beams with a fair degree of precision on the deep, short and normal beams. The ACI code provisions used for estimating the strength for shear of RC beams appeared to be conservative, which did not involve the size impact on the design of RC beams.

3.2 CIRCULAR SECTION

Ang et al. (1989) discussed the need for design philosophy for the design of shear forces for RC columns of bridges and building structures under seismic load. 25 columns were cast and tested subjected to axial load and cyclic lateral inelastic displacements, showing the existing design (in ACI 318) to be inconsistent and very conservative for the initial strength for shear with the reduction of shear strength with increase in flexural ductility. The test showed that the shear strength depends on the axial load, the shear span by depth ratio, the percentage of transverse spiral reinforcement and the flexural displacement ductility factor.

The twenty five casted columns were tested varying the axial load, longitudinal reinforcement, stirrups (shear reinforcement or transverse reinforcement) and shear-span by depth ratio. And the test was done as simple vertical cantilever where the columns were cast monolithically with a column base which was anchored to a structural test floor. 16 mm dia and 24 mm dia longitudinal reinforcement of 275 and 380 Mpa yield strength were used, having 90-degree hook at the base and top were welded to annular steel. Maximum 20 mm size of aggregate for the M30 concrete were used with a slump of 75 mm.

Priestley et al. (1994) described elements of the shear strength under seismic loading of circular and rectangular columns. They suggested a simple method by which the axial compression separated the strength enhancement from the concrete due to shear strength and considered to result from arch action. The strength of the concrete decreased as the ductility of the flexural displacement increased. The shear strength prediction from the suggested and alternative techniques was contrasted with the outcomes from a variety of tests of columns that failed in shear showing considerably enhanced correlation with experimental outcomes.

Kowalsky and Priestly (2000) revised a three-component model for circular column seismic shear strength developed at UCSD. The revisions suggested account for the effect of the concrete compression zone on the mobilization of the transverse steel, as well as the impact of aspect ratio and longitudinal steel ratio on the strength of the concrete shear-resistant mechanism. 47 columns were analyzed to validate the suggested model. The revisions include modifications for the impact of depth of neutral axis, aspect ratio, displacement ductility and longitudinal steel ratio. The revised model was shown to improve the overall scatter of the experimental database when compared with the original model and provided a much better correlation.

Merta and Kolbitsch (2006) analytically derived the effective shear area of circular sections. The ratio of the area of effective shear to the area of cross section was expressed as a function of the depth of the neutral axis for different concrete cover values. For a typical value of depth of the neutral axis, it was shown that the area of effective shear varied from 0.6 and 0.8 times the gross area of the section depending on the concrete cover depth. Thus, an average value of 0.7 is taken for design purposes and, moreover, it is in good agreement with other proposals.

Merta (2007) discussed a model of shear capacity of RC members with circular cross-section transversely reinforced with circular hoops. The proposed model was based on the analogy of truss by adding to the shear reinforcement capacity a concrete contribution term. It is driven by the fact that a curved reinforcing bar subjected to tension also induces compression in the radial direction. Thus, the element having this compressive force in the direction of external shear could be regarded as an additional or extra shear enhancement mechanism of the hoops and its magnitude can be expressed by the frictional force between steel and the concrete after the section has been cracked and the bond has been partially destroyed. The validity of the proposed model has been compared to other proposed models for monotonic load and it has been shown that the shear capacity predicted by the proposed model is in stronger correlation with the experimental values than by other existing proposals.

Jensen et al. (2010) presented the outcomes on a series of trials of heavily shear reinforced circular concrete members with the shear reinforced specimens up to more than 3 times the maximum percentage observed in the normal existing tests. The test results showed that the shear strengths exceeding the upper limit normally imposed on rectangular members can be obtained. 16 circular specimens were cast out of which 4 were without shear reinforcement and 12 were with shear reinforcement. The specimen's dia was 250 mm having a length of 1800 mm and was subjected to a mid-span point load. It was noticed that the specimens without having stirrups or shear reinforcement experienced brittle shear failure with only very few noticeable diagonal cracks, whereas the specimens with stirrups or hoops or shear reinforcement showed a ductile shear failure mode with several diagonal cracks forming. Severe spalling of the cover was seen at a load close to the ultimate load for some heavily shear reinforced specimens.

Balakrishnan et al. (2016) established the need for an additional correction factor of 2/π to the shear strength estimation of circular stirrups, based on the formula used for rectangular stirrups. As formerly, the shear strength of a circular section was generally based on equivalent rectangular section, as per ACI 318-14. Shear design formulas were based on models for rectangular section and were also used for circular sections by implementing an equivalent rectangular cross-section idea, suggested by ACI 318-14.

30 RC circular beams subjected to mid-span point load, simply supported with support saddles of 85mm wide, were tested for shear. The circular specimen size was of 230 mm dia. The specimens for testing were adjusted for different span by depth ratios (a_v/d) as 1, 1.5 and 2.5. For the test, three different a_v/d (1, 1.5 and 2.5) and five different percentages (0, 0.33, 0.52, 0.58 and 0.90) of shear reinforcement, varying the grades of concrete (mean cylinder strength in the range of 20 to 37.6 Mpa) were used with longitudinal reinforcement having yield strength of 500 Mpa (either of six 16 mm dia bars with f_y = 550Mpa or eight 20 mm dia bars of f_y = 463 Mpa). The circular stirrups used were of 8 mm and 10 mm dia bars. The test results showed that the degree of conservatism decreases with increase in span-depth ratios and an increase in shear reinforcement.

Rendy et al. (2017) presented experimentation on the shear and flexural behavior of RC members of a solid circular section. 6 tests were done of which 3 were confined with circular hoops and the remaining 3 without confinement, and were subjected to two-point monotonic loads. Experimental results and theoretical results for shear capacity were compared, figuring out how conservative the equation is. The test showed that the shear and flexure capacity depends upon the amount of longitudinal reinforcement significantly.

The confined hoops were of 10 mm dia having a yield strength of 389 Mpa. The longitudinal bars or reinforcements were of 13 mm, 16 mm and 19 mm dia having a yield strength of 394 Mpa, 380 Mpa and 400 Mpa, respectively. The specimen was kept at a clear span of 2000 mm. The distance between the two point loads was 400 mm, keeping the length of the shear span as 800 mm. The length of the end anchorage was kept 150 mm beyond the support and the dia of the cross section was 250 mm. The load was applied using 500 KN capacity hydraulic jack.

3.3 USING GEOGRIDS AS STIRRUPS

Chidambaram and Agarwal (2014) studied the confining effect of geogrids with steel fibres (maximum 2%) under compression and flexure. 4 cylindrical specimens were cast and tested for the behavior of axial compression and direct split. 12 specimens were cast and tested for the flexural behavior along with the energy dissipation. Substantial improvement in the behavior of axial stress-strain was observed with the geogrids used for the confinement of the specimen compared to normal reinforced concrete specimens and those with the steel fibres. Specimens with sudden brittle failure overturned the failure pattern or mechanism to ductile failure after using geogrids and steel fibres without any significant loss of strength. For split tensile behaviour, geogrids used for confinement not only increased the tensile strength but also managed to sustain larger deflection. The flexure test on the specimen showed that the geogrid strength and their number of layers provided plays a significant aspect in enhancing the deformation behavior as well as crack propagation. Thus the study shows that geogrids can be used as an alternative to steel tensile reinforcement in reinforced concrete sections.

Chidambaram and Agarwal (2015) studied the flexure and shear behavior of geogrids with steel fibre in RC beams. Three different sets of beam specimens (confined, moderately confined and lightly confined) were cast with the parameters to be the ratio of longitudinal and transverse bar or reinforcement, geogrid strength and the volume of steel fibres. Remarkable improvements in energy dissipation capacity and post-yield behavior after additional confinement of geogrids with steel fibres were observed for all these 3 different specimens. With an increase in the amount of transverse reinforcement, the rate of degradation in strength and stiffness of conventionally confined beam specimen decreased. Gradual and stable loss in stiffness and the strength was seen as the post rotation increased even with specimens with large spaced transverse reinforcement for the geogrid confined specimen with and without steel fibres.

The test result showed that the use of geogrid along with the steel fibres altered the mechanism of failure from brittle shear to flexural failure.

4. EXPERIMENTAL PROGRAMME

The experimental program was conducted to achieve similar or improved shear strength than the circular cross-section control specimen, replacing shear reinforcement partially with geogrids and adding a certain amount of steel fibres. Since the geogrids are made up of polymer materials, they are not as rigid as steel. Therefore, the stirrups were partially replaced by geogrids, not fully. The geogrids were replaced in such a way that, centre to centre spacing of the geogrids was 150 mm. The circular sections were subjected to a mid-span point load, being simply supported, thus, tested for shear.

Sixteen specimens were cast of size 150 mm dia and 1500 mm length of RC (reinforced concrete) and SFRC (Steel Fibre Reinforced Concrete) using M30 concrete mix. The specimens were cast for different tensile strengths of geogrids (100 KN/m and 200 KN/m) and for different steel stirrups spacing (75 mm, 100 mm, 150 mm, 450 mm and 700 mm). The steel stirrups at 150 mm spacing were replaced by geogrids partially as stirrups between 450 mm and 700 mm steel spacing for its respective specimen.

4.1 MATERIALS USED AND THEIR PROPERTIES

The materials used for casting the circular section specimen were cement, fine aggregates (sand), coarse aggregates (10 mm and 20 mm) and reinforcing steel bars (10 mm and 6 mm) along with the steel fibres and geogrids.

4.1.1 CEMENT

The cement of grade 43 (OPC 43) was used in the mix for the specimen. A number of tests were done as per IS 8112:1989 to obtain its physical properties as listed in Table 4.1. The cement bags were stored inside the lab to avoid moisture and any environmental exposure.

4.1.2 FINE AGGREGATES

For the concrete mix, sands were used as fine aggregates. The sand properties were in conformation with IS 383:1970 specifications. The sieve analysis was done taking 3 samples. The results for physical properties and sieve analysis are as in Table 4.2 and 4.3, respectively.

Table 4.1 Physical properties of the cement

Serial no.	Property	Value obtained	Standard value as per code BIS 8112:1989
1	Standard consistency	31%	-
2	Fineness as retained on 90-micron sieve	8%	Not more than 10%
3	Initial setting time	100 mins	30 mins (minimum)
4	Final setting time	280 mins	600 mins (maximum)
5	Specific gravity	3.10	3.15

Table 4.2 Physical properties of sand

Serial no.	Property	Value obtained
1	Fineness modulus	3.15
2	Specific gravity	2.61
3	Water absorption	0.95%
4	Grading zone	Zone II

Table 4.3 Sieve analysis of sand

Total weight of sample taken = 1000 g

Sieves	Weight retained				%age weight retained	Cumulative %age retained	%age Passing	Specifications for Zone II as per IS: 383-1970
	Sample 1 (g)	Sample 2 (g)	Sample 3 (g)	Mean Value (g)				
4.75 mm	38.00	40.50	43.50	40.67	4.07	4.07	95.93	90-100
2.36 mm	160.50	169.00	150.00	159.83	15.98	20.05	79.95	75-100

1.18 mm	239.00	239.50	225.00	234.50	23.45	43.50	56.50	55-90
600 μ	165.00	153.00	157.50	158.50	15.85	59.35	40.65	35-59
300 μ	325.50	310.50	308.00	314.67	31.47	90.82	9.18	8-30
150 μ	49.00	69.50	85.50	68.00	6.80	97.62	2.38	0-10
Pan	23.00	18.00	30.50	23.83	2.38	100.00	0.00	-

Fineness modulus = (4.07 + 20.05 + 43.50 + 59.35 + 90.82 + 97.62)/100 = 3.15

4.1.3 COARSE AGGREGATES

Coarse aggregates of sizes 10 mm and 20 mm were used in the proportion of 40% and 60%, respectively, for concrete mix. The results for sieve analysis for 10 mm and 20 mm are shown in Table 4.4 and Table 4.5, respectively. Table 4.6 shows these coarse aggregates physical properties.

Table 4.4 Sieve analysis of 10 mm coarse aggregates

Total weight of sample taken = 10000 g

Serial no.	Sieve	Weight retained (g)	Percentage weight retained	Cumulative percentage retained	Percentage Passing
1	40 mm	0.00	0.00	0.00	100.00
2	20 mm	0.00	0.00	0.00	100.00
3	10 mm	870.00	8.70	8.70	91.30
4	4.75 mm	8220.00	82.20	90.90	9.10
5	Pan	910.00	9.10		0.00
Total				99.60	

Fineness modulus = (99.60 + 500)/100 = 6.00

Table 4.5 Sieve analysis of 20 mm coarse aggregates

Total weight of sample taken = 10000 g

Serial no.	Sieve	Weight retained (g)	Percentage weight retained	Cumulative percentage retained	Percentage Passing
1	40 mm	0.00	0.00	0.00	100.00
2	20 mm	38.00	0.38	0.38	99.62
3	10 mm	7897.00	78.97	79.35	20.65
4	4.75 mm	1642.00	16.42	95.77	4.23
5	Pan	423.00	4.23		0.00
Total				175.50	

Fineness modulus = (175.50 + 500)/100 = 6.76

Table 4.6 Physical properties of coarse aggregates (10 mm and 20 mm)

Serial no.	Property	10 mm	20 mm
1	Specific gravity	2.68	2.68
2	Water absorption	1.48%	2.91%
3	Fineness modulus	6.00	6.76

4.1.4 WATER

Good quality of water, free from any kind of organic material, silt, sand, oil, chloride or any other acidic substance as per Indian Standard was used for the concrete mix as well as curing the specimens.

4.1.5 STEEL FIBRES

Duraflex^{TM} hook end loose steel fibres (1%) were added to normal reinforced concrete to form SFRC. The fibres were brought from Kasturi metal composite private limited. These fibres were made from high tensile strength wire greater than 1100 Mpa. Table 4.7 shows these steel fibres properties.

Table 4.7 Properties of steel fibres

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

Fig 4.1: Steel Fibres

4.1.6 STEEL

Tata Tiscon 500D high strength ribbed TMT bars were used for reinforcement in concrete where '500' specifies the bar strength (ie. 500 Mpa) and 'D' reflects its higher ductility. It is the most updated standard as per BIS (last revised in 2012). 6 mm and 10 mm bars were used for the reinforcement in the concrete. Table 4.8 and 4.9 shows the chemical and mechanical properties of these bars, respectively.

Table 4.8 Chemical properties of the reinforcement bars

Chemical properties (maximum)	Tata Tiscon 500D
Carbon percentage	0.250
Carbon equivalent percentage (CE)	0.400
Sulphur percentage (S)	0.035
Phosphorus percentage (P)	0.035
Nitrogen percentage (PPM)	120

Table 4.9 Mechanical properties of the 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

4.2 CONCRETE MIX

The mix design of concrete grade M30 was performed in accordance with IS 10262:2009. Few trials were done to obtain the compressive strength as per M30. Finally, the ratio obtained was 1:1.5:2.62 (cement: fine aggregates: coarse aggregates) with w/c ratio to be 0.45 for casting specimens. Hand mixing was done for all the specimens and trials. Two types of concretes were used; RC and SFRC. Three sample cubes were cast for each specimen and were cured in a water tank present in the lab for 28 days to achieve compressive strength.

Fig 4.2: Hand mixing for normal concrete

Fig 4.3: Dry mix of steel fibres

4.3 SHEAR REINFORCEMENT OF CIRCULAR SPECIMEN

The shear reinforcement or transverse reinforcement or steel stirrups provided for different specimens are at a different spacing such as 75 mm, 100 mm, 150 mm, 450 mm and 700 mm, respectively. The dia of the reinforced circular section is 150 mm. Therefore, six long (1450 mm each) bars of 10 mm dia were used as longitudinal reinforcement for each specimen and 6 mm dia bars depending upon the spacing of the shear reinforcement to be provided for the specimen were used as transverse or shear reinforcement for each specimen.

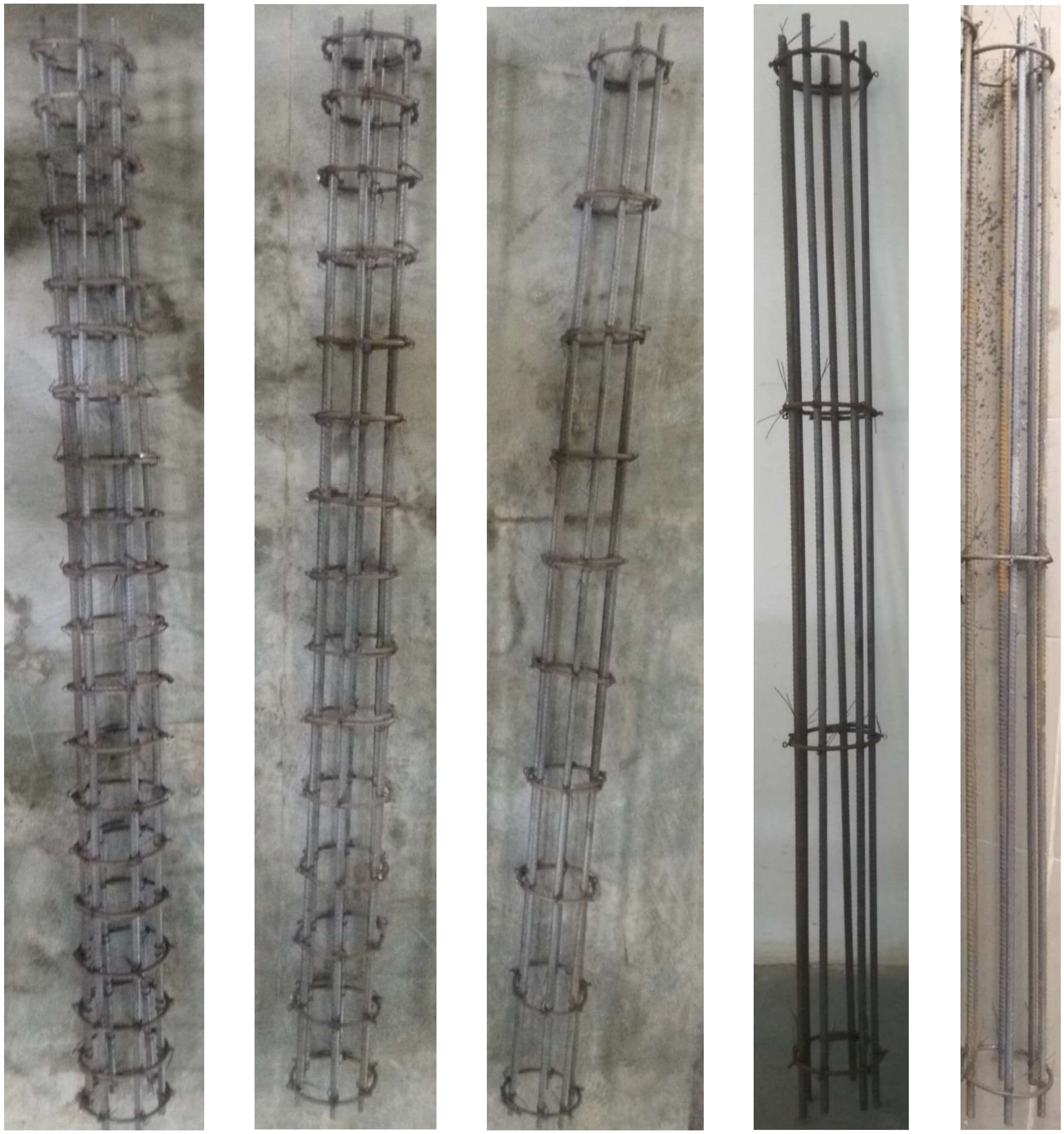

Fig 4.4: Shear reinforcement at 75 mm, 100 mm, 150 mm, 450 mm and 700 mm spacing

4.4 USING GEOGRIDS IN THE CIRCULAR RC SECTION

Geogrids in circular RC sections were used as a partial replacement of stirrups. Both geogrids having the average tensile strength to be 100 KN/m and 200 KN/m were cut at 85 mm wide and 450 mm long (Fig 4.6) and wrapped at required spacing (Fig 4.8 & Fig 4.9). The steel stirrups were replaced in such a way that, centre to centre spacing of the geogrids is 150 mm. The geogrids were wrapped properly with steel wire to hold longitudinal reinforcements tightly.

Fig 4.5 (a): Geogrids (100KN/m)

Fig 4.5 (b): Geogrids (200KN/m)

Fig 4.6: Geogrids strip after cutting to required length and width

Fig 4.7: Applying geogrids on the sections.

Fig 4.8: Applying geogrids for 450 mm stirrups spacing

Fig 4.9: Applying geogrids for 700 mm stirrups spacing

4.5 CASTING OF REINFORCED CONCRETE SPECIMENS

Hand mix of materials was done as discussed earlier. All the materials were weighed as per the required and dry mixed carefully and thoroughly. The required amount of water was added for the final mix and mixed to obtain a uniform concrete paste. The mould used for casting circular section was a plastic pipe which was held by clamps to position the mould effectively, as shown in Fig 4.14. The respective reinforcement cages or sections were installed properly inside the mould keeping 25 mm concrete cover on sides, as shown in Fig 4.11. 25 mm cover was provided both at top and bottom of the section.

Needle vibrators were used for the compaction. After casting, the specimen on the mould was left for 24hrs for air dry. And after 24 hours, the mould was opened and allowed for curing for 28 days. For every specimen, three cubes were cast to obtain compressive strength at 28 days.

Sixteen circulars reinforced specimens were cast of dia 150 mm and 1500 mm long. The specimens cast were varied with the spacing of stirrups (75 mm, 100 mm, 150 mm, 450 mm and 700 mm), types of concrete used (RC or SFRC) and types of geogrids used (average tensile strength of 100 KN/m and 200 KN/m). Three specimens of 75 mm, 100 mm and 150 mm stirrups spacing were cast initially. Then, the spacing of the stirrups was increased to 450 mm and 700 mm, partially replacing 150 mm steel stirrups by geogrids. The two types of geogrids used have the average tensile strength 100 KN/m and 200 KN/m. Table 4.10 shows the details of the specimen cast.

Table 4.10 Specimen details

Specimen as per SN	**Specimen ID**	**Specimen details**	**Volume of steel fibres used**
RC1	RC_{75}	Reinforced concrete with 75 mm spacing of stirrups c/c	
RC2	RC_{100}	Reinforced concrete with 100 mm spacing of stirrups c/c	
RC3	RC_{150}	Reinforced concrete with 150 mm spacing of stirrups c/c	-
RC4	RC_{450}	Reinforced concrete with 450 mm spacing of stirrups c/c	-
RC5	RC_{700}	Reinforced concrete with 700 mm spacing of stirrups c/c	-
RC6	$RC_{150}F$	Steel fibre reinforced concrete with 150 mm spacing of stirrups c/c	1%
RC7	$RC_{450}F$	Steel fibre reinforced concrete with 450 mm spacing of stirrups c/c	1%
RC8	$RC_{700}F$	Steel fibre reinforced concrete with 700 mm spacing of stirrups c/c	1%
RC9	$RC_{450}G_{100}$	Reinforced concrete with 450 mm spacing of stirrups c/c and Geogrid confined with an average tensile strength of 100 KN/m	-
RC10	$RC_{700}G_{100}$	Reinforced concrete with 700 mm spacing of stirrups c/c and Geogrid confined with an average tensile strength of 100 KN/m	-

RC11	$RC_{450}G_{200}$	Reinforced concrete with 450 mm spacing of stirrups c/c and Geogrid confined with an average tensile strength of 200 KN/m	-
RC12	$RC_{700}G_{200}$	Reinforced concrete with 700 mm spacing of stirrups c/c and Geogrid confined with an average tensile strength of 200 KN/m	-
RC13	$RC_{450}F+G_{100}$	Steel fibre reinforced concrete with 450 mm spacing of stirrups c/c and Geogrid confined with an average tensile strength of 100 KN/m	1%
RC14	$RC_{700}F+G_{100}$	Steel fibre reinforced concrete with 700 mm spacing of stirrups c/c and Geogrid confined with an average tensile strength of 100 KN/m	1%
RC15	$RC_{450}F+G_{200}$	Steel fibre reinforced concrete with 450 mm spacing of stirrups c/c and Geogrid confined with an average tensile strength of 200 KN/m	1%
RC16	$RC_{700}F+G_{200}$	Steel fibre reinforced concrete with 700 mm spacing of stirrups c/c and Geogrid confined with an average tensile strength of 200 KN/m	1%

Fig 4.10: Reinforced sections with concrete cover

Fig 4.11: Reinforced section placed inside the mould

Fig 4.12: Dry hand mix of the concrete

Fig 4.13: Dry mix of the steel fibres

Fig 4.14: Concrete placing inside the mould

Fig 4.15: Needle vibrator for the compaction

4.6 CURING OF THE SPECIMENS

Jute sacks were used to cure the circular specimens. The sacks were placed over the specimens and water curing was done for 28 days (three times a day). Cubes were immersed in the water curing tank available in the laboratory for 28 days as well.

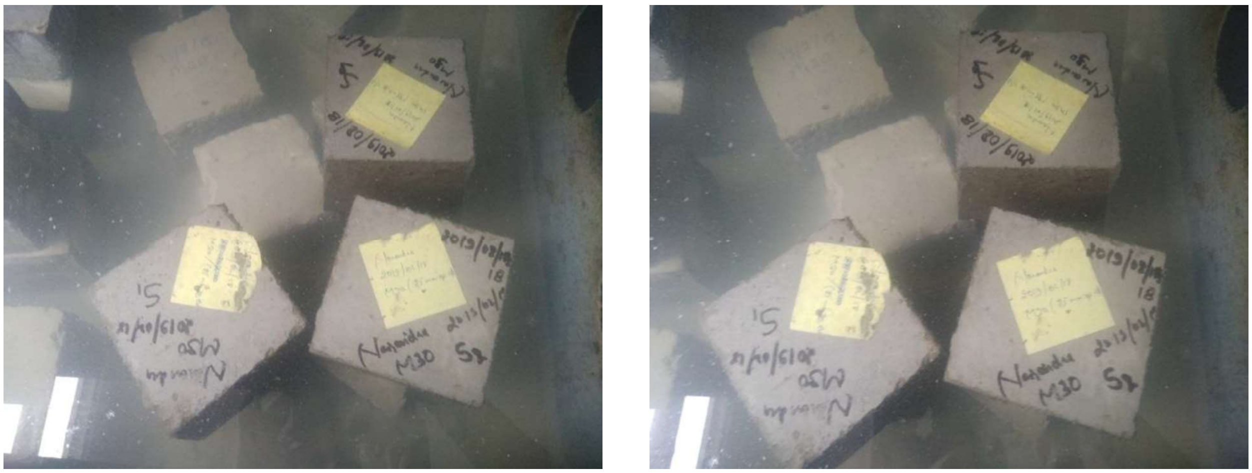

Fig 4.16: Curing of the cubes inside curing tank.

Fig 4.17: Curing circular specimens with jute sacks placed over it

4.7 SURFACE PREPARATION OF THE SPECIMENS

After curing for 28 days, the circular specimens were whitewashed so that during the testing of the specimen when loads were applied on it, crack formation could be studied easily and properly.

4.8 TESTING OF THE SPECIMENS

Testing of the circular specimen was carried out on a loading frame having a hydraulic jack of maximum capacity 600 KN. Each specimen was simply supported and subjected to a mid-span point load. 50 mm wide saddle supports were made to adapt the geometry of the circular section at the supports and load point. The saddle was made up of steel and placed on top of the support.

Fig 4.18: Experimental setup for shear testing

5. RESULTS AND DISCUSSION

5.1 GENERAL

The test was successfully done obtaining the ultimate shear strength and mid-span displacement of each specimen. The ultimate shear strength for the control specimens was analyzed and calculated theoretically comparing it with the obtained experimental values. The load-deformation graphs were plotted and various parameters such as ultimate load, secant stiffness, deflection ductility and energy ductility with energy dissipation were evaluated and compared.

5.2 COMPRESSIVE STRENGTH OF CONCRETE MIX

Three cubes for every specimen were cast for testing them for compressive strength of the concrete used for the casting of the specimens. The cast cubes were left for air dry for 24 hours and then these cubes were taken out from the moulds and kept into the water tank available in the structure lab for curing for 28 days. The cubes were removed from the water tank after 28 days and allowed to dry for 2 hours and tested in CTM for compressive strength. Table 5.1 shows the average compressive strength values.

The test results for compressive strength showed that adding steel fibres to the concrete results to a small increase in compressive strength, as the main purpose of adding steel fibres is to increase the resistance to crack and a minimal increase in compressive strength (Richardson and Landless, 2009).

Table 5.1 Average compressive strength of cubes (28days)

Specimen ID	Average compressive strength of cubes (Mpa)
RC_{75}	32.23
RC_{100}	31.18
RC_{150}	33.57
RC_{450}	32.5
RC_{700}	33.43
$RC_{150}F$	36.19
$RC_{450}F$	35.94

$RC_{700}F$	35.88
$RC_{450}G_{100}$	31.24
$RC_{700}G_{100}$	32.12
$RC_{450}G_{200}$	32.73
$RC_{700}G_{200}$	33.28
$RC_{450}F+G_{100}$	36.22
$RC_{700}F+G_{100}$	36.51
$RC_{450}F+G_{200}$	35.78
$RC_{700}F+G_{200}$	36.03

5.3 TEST RESULTS FOR THE SHEAR TEST ON CIRCULAR SPECIMEN

The predicted shear strength capacities for the controls are calculated and compared with the experimental results as shown in Table 5.2.

Table 5.2 Results of shear tests on RC control specimens and comparison with the theoretical predictions of shear strength for those control specimens

S. No.	Specimen ID	Shear Capacity, KN		V_{exp}/V_{IS}	Modes of failure
		V_{exp}	V_{IS}		
1	RC_{75}	52.360	61.175	0.856	Flexural Failure
2	RC_{100}	46.674	49.804	0.937	Flexural Failure
3	RC_{150}	44.548	38.630	1.153	Flexural Failure
4	RC_{450}	39.032	23.491	1.662	Flexural Failure
5	RC_{700}	37.548	20.850	1.800	Flexural Failure
			Mean	1.282	
			Standard Deviation	0.427	

Considerable scatter can be seen in the strength for shear prediction comparison to the experimental results. The margin of safety is fairly conservative against shear failure. And the modes of failure during the experiment were seen to have a flexural failure in all the tested specimens. Therefore, the specimens with the steel fibres addition and partially replacing stirrups with geogrids should have near about or better shear strength than the RC_{150} specimen.

Table 5.3 Results of shear tests on casted circular specimens

S.No.	**Specimen ID**	**V_{exp}**
1	RC_{75}	52.360
2	RC_{100}	46.674
3	RC_{150}	44.548
4	$RC_{150}F$	44.828
5	RC_{450}	39.032
6	$RC_{450}F$	41.524
7	$RC_{450}G_{100}$	42.476
8	$RC_{450}G_{200}$	44.912
9	$RC_{450}F+G_{100}$	44.884
10	$RC_{450}F+G_{200}$	47.264
11	RC_{700}	37.548
12	$RC_{700}F$	39.984
13	$RC_{700}G_{100}$	41.888
14	$RC_{700}G_{200}$	44.240
15	$RC_{700}F+G_{100}$	43.624
16	$RC_{700}F+G_{200}$	46.144

The table shows a marginal increase in the ultimate load with the addition of steel fibres. When the stirrups at spacing 150 mm are partially replaced with geogrids and steel fibres are added to it, a marginal increase in the ultimate load can be seen.

5.3.1 COMPARISON OF ULTIMATE LOAD

The ultimate load of the specimens are compared for the shear strength obtained during the test.

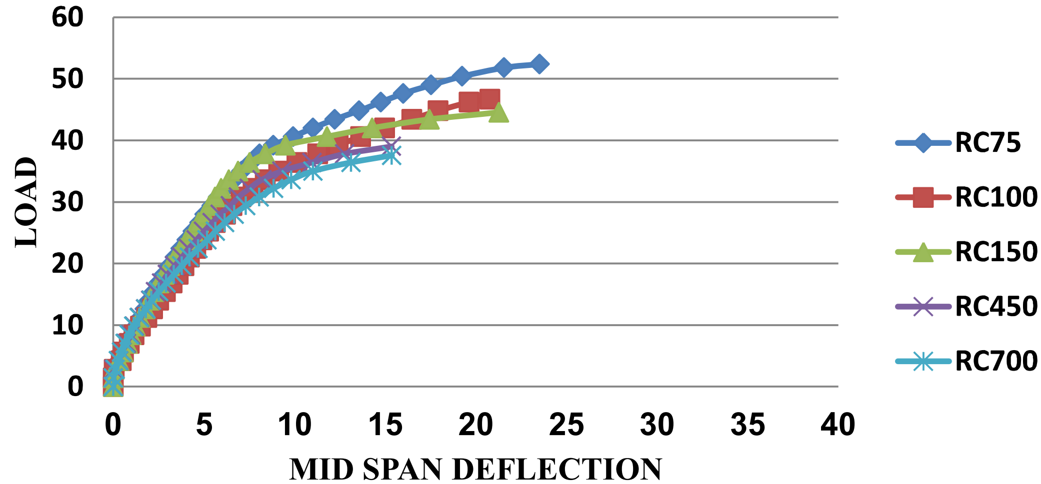

Fig 5.1: Comparison of all the control specimens

The above figure shows the ultimate load obtained by the control specimens (RC_{75}, RC_{100}, RC_{150}, RC_{450} and RC_{700}). With the increase in the spacing of the stirrups for the control specimen, the ultimate load decreases. Therefore, it shows the role of stirrups in the ultimate load.

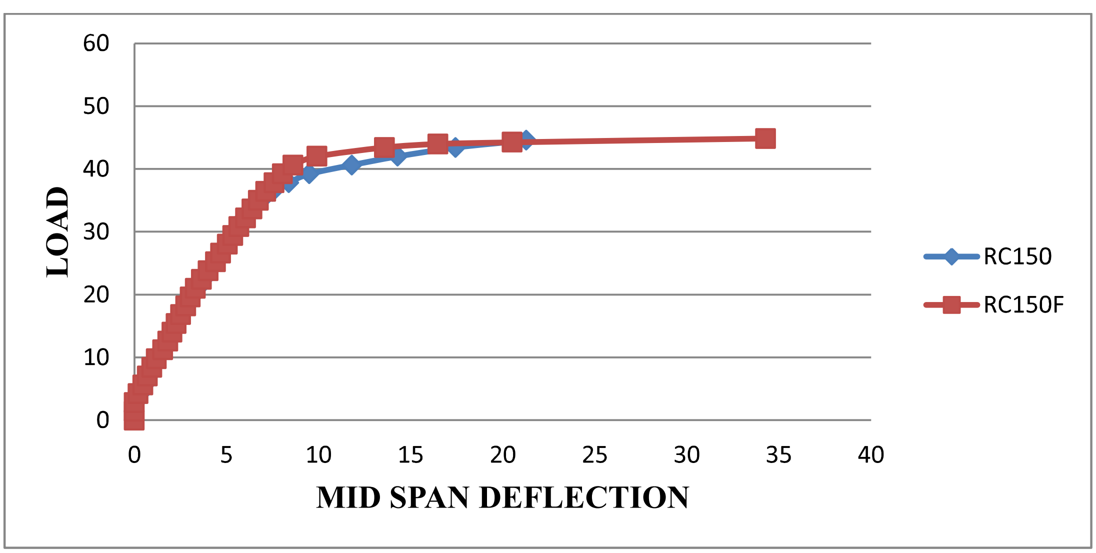

Fig 5.2: Comparison of 150 mm parameters

Figure 5.2 shows no difference in ultimate load but better ductility in the specimen with the steel fibres addition. The specimen with 150 mm stirrup spacing contributes better strength as seen in Table 5.2. Adding steel fibres in the specimen, improved the ductility of the section as seen in Fig 5.2. The reason might be due to the resistance to cracking offered by the steel fibres addition on the specimen. These numbers of fibres intercept the micro-cracks and prevent the propagation by controlling tensile strength. Richardson and Landless (2009) discussed the ability of steel fibres to absorb energy and its great effect in controlling the cracks and enhancing the toughness of the concrete.

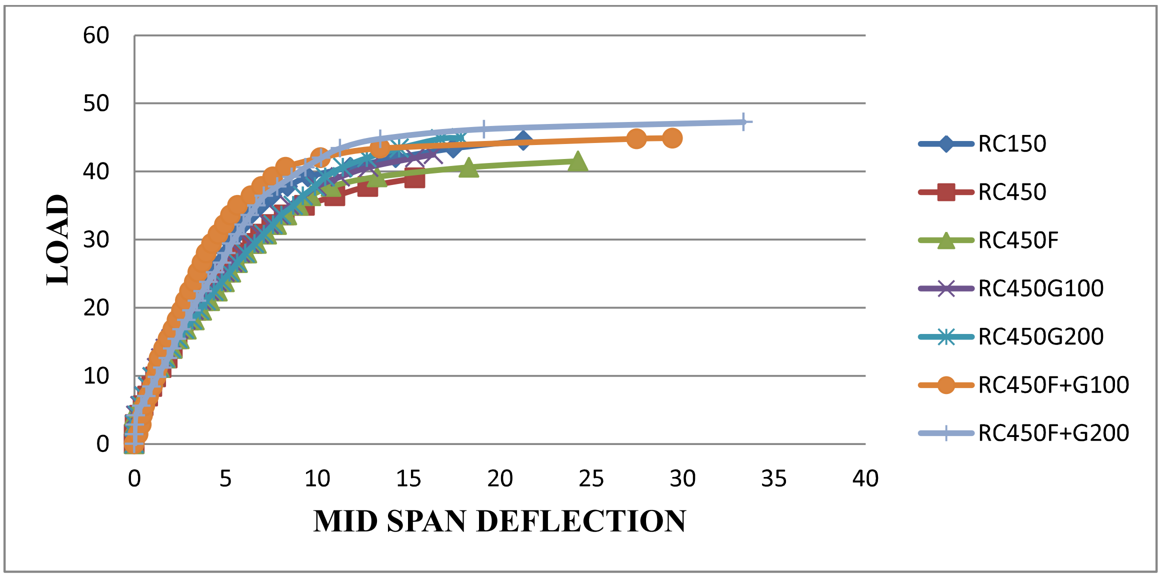

Fig 5.3: Comparison of 150 mm control specimen and 450 mm parameters

Figure 5.3 shows that, from 150 mm specimen to 450 mm specimen, there is a clear reduction in ultimate shear strength (*ie.* from 44.548 KN to 39.032 KN). But with the steel fibres addition, there is a marginal increase in ultimate load compared to 450 mm control specimen (*ie.* 41.524 KN) and better ductility. The ultimate load is still lesser than the 150 mm control specimen. As the addition of steel fibres helps in resisting crack rather than increasing the ultimate load to higher values, better ductility can be seen compared to 150 mm control spacing.

Replacing the stirrups partially with geogrids does not increase the ultimate load compared to a 150 mm control specimen. Using 200 KN/m tensile strength geogrids gives a similar result to the 150 mm control specimen as compared to 100 KN/m tensile strength geogrids. Addition of 1% of steel fibres with partially replacing stirrups with geogrids (200

KN/m) gives a better result. It improves the strength marginally and increases ductility compared to 150 mm control specimen.

The geogrid with tensile strength 100 KN/m gives a similar result to the 150 mm control specimen with increased ductility. Therefore, adding 1% of steel fibres to the specimen replacing the stirrups partially with geogrids (200 KN/m) is seen more effective, as it increases the ultimate load carrying capacity as well as ductility of the specimen. The reason can be because the geogrids has good tensile strength property, it contributes to ductile behavior and with the steel stirrups it contributes to slightly better ultimate strength. And, the steel fibres addition improves the resistance to cracking, contributing to the ductile behavior as well.

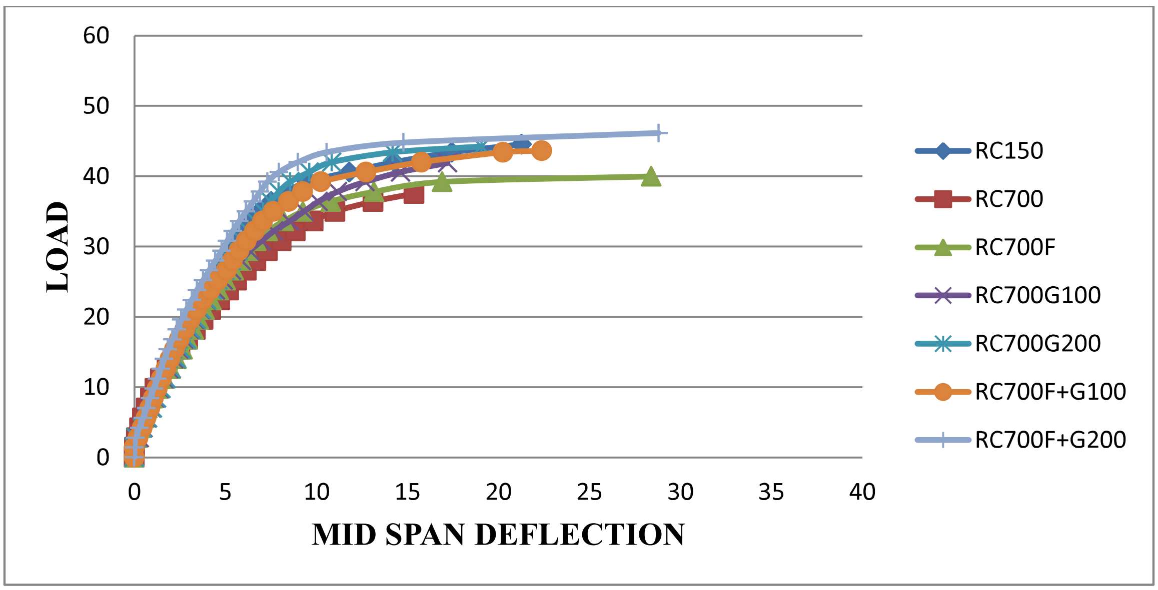

Fig 5.4: Comparison of 150 mm control specimen and 700 mm parameters

Fig 5.4 shows the reduction of ultimate strength from 44.548 KN to 37.548 KN comparing 150 mm spacing control specimen to 700 mm spacing control specimen. So, just addition of steel fibres or just partially replacing the stirrups with geogrids improves the ductility but is not comparable to the control specimen of spacing 150 mm. The figure shows, replacing stirrups partially with geogrids (200 KN/m) and adding steel fibres to the specimen give near about result to control specimen of spacing 150 mm with better displacement. A slight increase in strength (*ie.* 46.144 KN) can be seen with the steel fibres addition and partially replacing stirrups with geogrids (200 KN/m).

Fig 5.3 and 5.4 shows that, with the steel fibres addition to the specimen and using 200 KN/m geogrids for partial replacement of stirrups, the shear strength has increased with much-improved ductility compared to the 150 mm spacing control specimen. Because of the better tensile strength of the geogrids (200 KN/m) and crack resisting purpose of the steel fibres, the specimen has better strength and high ductility.

5.3.2 ENERGY DISSIPATION AND DEFLECTION DUCTILITY

Energy dissipation is the amount of energy absorbed by a material before failure. For any reinforced concrete member, energy dissipation is the sum of energy dissipated by steel and concrete. Energy dissipation for a specimen is calculated by area under the load-deflection curve. The maximum energy carried by a specimen is calculated by area under the load-deflection curve up to the ultimate load carried by a specimen.

Table 5.4.1 Test Results for control specimens

Specimen Id	Yield Load (KN)	Ultimate Load (KN)	Displacement at Yield Load (mm)	Displacement at Ultimate Load (mm)	Deflection Ductility Factor	Energy at Yield Load (KN.mm)	Energy at Ultimate Load (KN.mm)	Energy Ductility Factor
RC_{75}	39.12	52.36	7.85	23.52	2.996	210.254	901.945	4.290
RC_{100}	33.84	46.68	7.48	20.78	2.779	168.410	678.974	4.032
RC_{150}	37.95	44.55	6.78	21.29	3.140	194.877	736.066	3.777
RC_{450}	32.90	39.03	6.35	15.35	2.418	148.936	434.841	2.920
RC_{700}	26.43	37.55	5.60	15.37	2.744	101.496	412.879	4.068

Table 5.4.1 shows that, with an increase in the spacing of stirrups, the energy dissipation decreases. The optimum deflection ductility factor was obtained for RC_{150} specimen. The mode of failure for all the specimens was a flexural failure. All the specimens behaved as a ductile member. The ductility factor shows the ductile behavior of the specimen. The comparison of the specimen's energy dissipation is done with respect to the RC_{150} specimen. In further tables, the increase or decrease of energy dissipation with respect to RC_{150} specimen can be seen.

Table 5.4.2 Test Results for 150 mm parameters

Specimen Id	Yield Load (KN)	Ultimate Load (KN)	Displacement at Yield Load (mm)	Displacement at Ultimate Load (mm)	Deflection Ductility Factor	Energy at Yield Load (KN.mm)	Energy at Ultimate Load (KN.mm)	Energy Ductility Factor
RC_{150}	37.95	44.55	6.78	21.29	3.140	194.8772	736.066	3.777
$RC_{150}F$	43.20	44.83	7.60	34.28	4.511	417.1608	912.973	2.189

Table 5.4.2 shows that with the steel fibres addition there is an increase in energy dissipation and deflection ductility factor, which clearly shows the high ductility behavior for the specimen. Addition of steel fibres, even if there is no increase in ultimate load it shows the higher ductile behavior in the specimen increasing the deflection ductility factor by 43.66% (from 3.140 to 4.511). The resistance to cracking increases the ductility factor as shown in the table above. Table 5.2 shows the theoretical value for RC_{150} to be 38.63 KN, but the value obtained during the experiment was 44.55 KN and the mode of failure was a flexural failure. If without increasing ultimate load ductility behavior is to be increased, adding 1% of steel fibres gives higher ductility behavior.

Table 5.4.3 Test Results of 150 mm control specimen with 450 mm parameters

Specimen Id	Yield Load (KN)	Ultimate Load (KN)	Displacement at Yield Load (mm)	Displacement at Ultimate Load (mm)	Deflection Ductility Factor	Energy at Yield Load (KN.mm)	Energy at Ultimate Load (KN.mm)	Energy Ductility Factor
RC_{150}	37.95	44.55	6.78	21.29	3.140	194.877	736.066	3.777
RC_{450}	32.90	39.03	6.35	15.35	2.418	148.936	434.841	2.920
$RC_{450}F$	36.90	41.52	7.70	24.28	3.153	218.977	803.081	3.667
$RC_{450}G_{100}$	33.42	42.48	6.50	16.36	2.517	167.517	499.883	2.984
$RC_{450}G_{200}$	36.50	44.91	7.80	17.87	2.291	206.241	570.752	2.767
$RC_{450}F+G_{100}$	42.90	44.88	5.95	29.45	4.950	426.929	1138.77	2.667
$RC_{450}F+G_{200}$	44.00	47.26	7.90	33.33	4.219	407.007	1334.35	3.278

Table 5.4.4 Energy dissipation and deflection ductility

Specimen ID	Energy Dissipation	Comparison of energy dissipation with respect to RC_{150} (%)	Comparison of energy dissipation with respect to RC_{450} (%)
RC_{150}	736.066	-	+69.272
RC_{450}	434.841	-40.924	-
$RC_{450}F$	803.081	+9.105	+84.684
$RC_{450}G_{100}$	499.883	-32.087	+14.958
$RC_{450}G_{200}$	570.752	-22.459	+31.255
$RC_{450}F+G_{100}$	1138.767	+54.710	+161.881
$RC_{450}F+G_{200}$	1334.347	+81.281	+206.859

A positive sign (+) and a negative sign (-) indicates an increase and decrease in the percentage of energy dissipation with respect to the specimen id mentioned, respectively. Table 5.4.4 shows a significant increase in the percentage of energy dissipation with the addition of steel fibres and partially replacing steel stirrups between 450 mm spacing with geogrids (200 KN/m).

Table 5.4.5 Test Result of 150 mm control specimen with 700 mm parameters

Specimen Id	Yield Load (KN)	Ultimate Load (KN)	Displacement at Yield Load (mm)	Displacement at Ultimate Load (mm)	Deflection Ductility Factor	Energy at Yield Load (KN.mm)	Energy at Ultimate Load (KN.mm)	Energy Ductility Factor
RC_{150}	37.95	44.55	6.78	21.29	3.140	194.877	736.066	3.777
RC_{700}	26.43	37.55	5.60	15.37	2.744	101.496	412.879	4.0679
$RC_{700}F$	37.80	39.98	7.36	28.41	3.862	346.623	947.695	2.7341
$RC_{700}G_{100}$	32.28	41.89	6.35	17.21	2.710	152.093	517.840	3.4048
$RC_{700}G_{200}$	40.80	44.24	7.55	19.08	2.527	235.627	643.952	2.7329
$RC_{700}F+G_{100}$	38.00	43.62	7.13	23.38	3.280	217.013	766.718	3.5331
$RC_{700}F+G_{200}$	43.45	46.14	6.95	28.81	4.145	304.725	1130.358	3.7094

Table 5.4.6 Energy dissipation and deflection ductility comparison of 150 mm control specimen with 700 mm parameters in percentage

Specimen ID	Energy Dissipation	Comparison of energy dissipation with respect to RC_{150} (%)	Comparison of energy dissipation with respect to RC_{700} (%)
RC_{150}	736.066	-	+78.276
RC_{700}	412.8792	-43.907	-
$RC_{700}F$	947.695	+28.751	+129.533
$RC_{700}G_{100}$	517.8403	-29.648	+25.422
$RC_{700}G_{200}$	643.9521	-12.514	+55.966
$RC_{700}F+G_{100}$	766.7183	+4.164	+85.700
$RC_{700}F+G_{200}$	1130.358	+53.568	+173.775

Table 5.4.6 shows that, with the steel fibres addition and partially replacing stirrups between 700 mm spacing with geogrids (200 KN/m), it gives effective results. There is an increase in energy dissipation. From Table 5.4.4 and 5.4.6, it can be seen that the energy dissipated by specimen $RC_{450}F+G_{100}$ (+54.710%) and $RC_{700}F+G_{200}$ (+53.568%) are very much near. From both the tables, it can clearly be seen that specimen $RC_{450}F+G_{200}$ dissipates maximum energy (+81.281%) of all specimens, compared to RC_{150} specimen. Therefore, $RC_{450}F+G_{200}$ specimen can be used where higher shear strength with high ductility is needed as compared to RC_{150} specimen.

5.3.3 SECANT STIFFNESS

Stiffness is defined as the load required for unit displacement. It is the rigidity of the material or specimen that resists displacement in response to the applied load. Secant stiffness is defined as the ratio of ultimate load to its unit displacement as shown in Fig 5.5. Since, stiffness is inversely proportional to the displacement (deflection), therefore, with an increase in deflection of the specimen, secant stiffness decreases. The values of secant stiffness of the tested specimens are shown below.

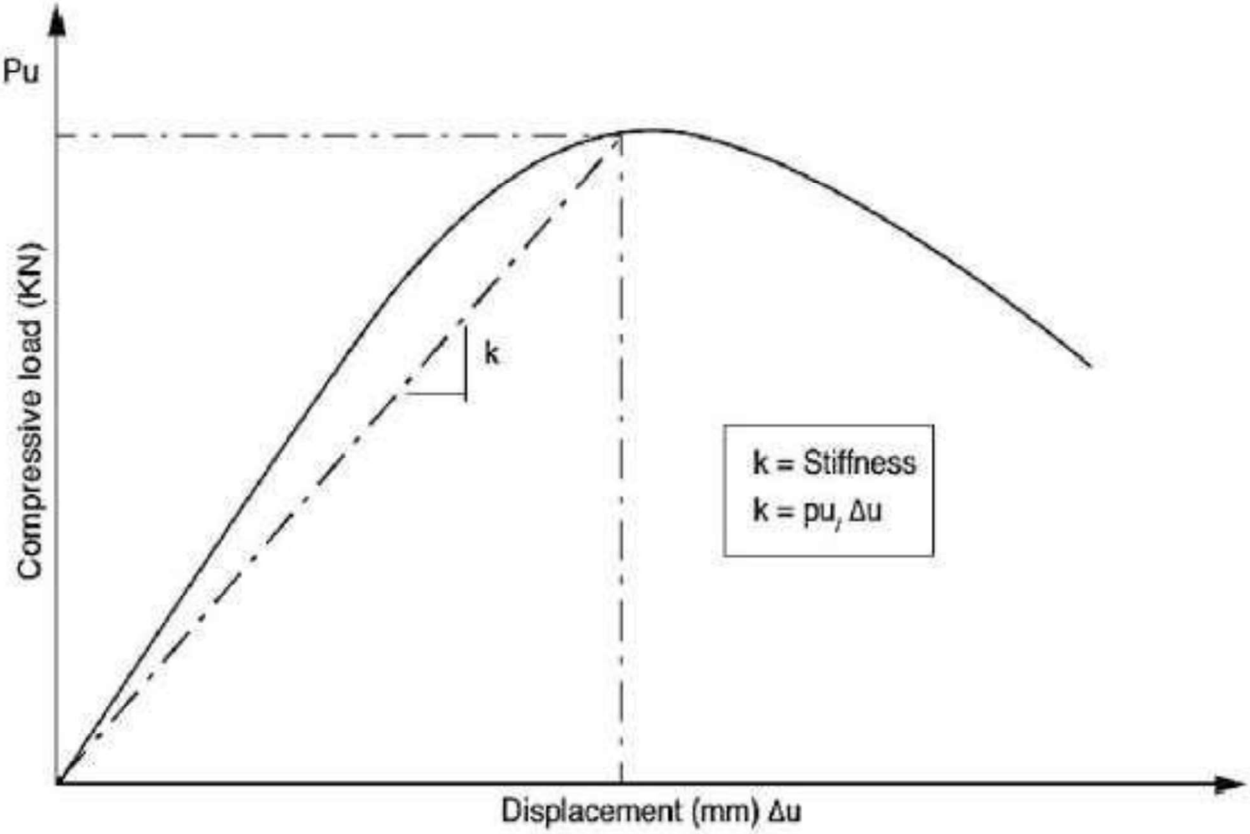

Fig 5.5: Calculation of secant stiffness from the load-displacement curve (Danie et al., 2014)

Table 5.5.1 Comparison of secant stiffness of RC_{150} with $RC_{150}F$

Specimen Id	**Ultimate Load (KN)**	**Displacement at Ultimate Load (mm)**	**Secant Stiffness (KN/mm)**	**Comparison of secant stiffness with respect to RC_{150} (%)**
RC_{150}	44.548	21.286	2.093	-
$RC_{150}F$	44.828	34.282	1.308	-37.519

Table 5.5.1 shows that with the steel fibres addition, the secant stiffness decreased by 37.519%. It is because of the improved ductility in the member, the increase in displacement for a constant load decreases the body stiffness. This allows the body to be more flexible and not allow sudden failure, improving the ductility and have ductile failure rather than shear failure.

Table 5.5.2 Comparison of secant stiffness of RC_{150} with RC_{450} parameters

Specimen Id	Ultimate Load (KN)	Displacement at Ultimate Load (mm)	Secant Stiffness (KN/mm)	Comparison of secant stiffness with respect to RC_{150} (%)	Comparison of secant stiffness with respect to RC_{450} (%)
RC_{150}	44.548	21.286	2.093	-	-17.685
RC_{450}	39.032	15.352	2.542	+21.485	-
$RC_{450}F$	41.524	24.280	1.710	-18.282	-32.734
$RC_{450}G_{100}$	42.476	16.360	2.596	+24.058	+2.119
$RC_{450}G_{200}$	44.912	17.872	2.513	+20.076	-1.160
$RC_{450}F+G_{100}$	44.884	29.450	1.524	-27.176	-40.055
$RC_{450}F+G_{200}$	47.264	33.334	1.418	-32.250	-44.232

Table 5.5.3 Comparison of secant stiffness of RC_{150} with RC_{700} parameters

Specimen Id	Ultimate Load (KN)	Displacement at Ultimate Load (mm)	Secant Stiffness (KN/mm)	Comparison of secant stiffness with respect to RC_{150} (%)	Comparison of secant stiffness with respect to RC_{700} (%)
RC_{150}	44.548	21.286	2.093	-	-14.343
RC_{700}	37.548	15.368	2.443	+16.744	-
$RC_{700}F$	39.984	28.408	1.407	-32.747	-42.393
$RC_{700}G_{100}$	41.888	17.210	2.434	+16.299	-0.382
$RC_{700}G_{200}$	44.24	19.082	2.318	+10.779	-5.110
$RC_{700}F+G_{100}$	43.624	23.380	1.866	-10.845	-23.632
$RC_{700}F+G_{200}$	46.144	28.806	1.602	-23.458	-34.436

Table 5.5.2 and 5.5.3 shows that the steel fibres addition to the specimen has decreased the stiffness compared to the RC_{150} control specimen. The reason behind this is the steel fibres in the concrete acts as steel fibre reinforced concrete and reduces crack propagation increasing the load bearing capacity for higher displacements. Because of the increase in resistance to crack and bear the load for larger displacement, there is a reduction in rigidity compared to RC_{150}. Without any addition of steel fibres and just replacing the stirrups partially by geogrids has similar strength compared to the RC_{150} control specimen, but there is a decrease in displacement. Because of this, the rigidity is increased and it is less ductile than the RC_{150} control specimen.

Addition of steel fibres and partially replacing geogrids between both 450 mm spacing and 700 mm spacing has shown better results. They show improved ductility with reduction of stiffness. There is a proper bonding between the fibres with concrete and geogrids as well as contributing to higher strength and larger displacement, increasing the ductility of the specimen compared to RC_{150} control.

$RC_{150}F+G_{200}$ specimen shows the better result of all, having higher ductility as well as better strength to RC_{150} control. The partial replacement of stirrups in this specimen with 200 KN/m tensile strength geogrids shows the better tensile strength, which holds the member for larger loads. Because of the better tensile strength, it is more flexible towards the load and can bear loads for more displacement. Since it is not as rigid as steel stirrups it carries nearly about load as RC_{150} but with slight lesser displacement. So, to improve the ductility, the steel fibres addition is done and because of the proper bonding, with the higher strength, it bears load for larger displacement as well.

6. CONCLUSIONS AND FUTURE SCOPE

6.1 CONCLUSIONS

The experimental program was done to achieve similar or improved shear strength than the circular cross-section control specimen, replacing shear reinforcement partially with geogrids and adding a certain amount of steel fibres. Total of sixteen specimens was cast and tested for shear strength. The parameters included steel stirrup spacing (75 mm, 100 mm, 150 mm, 450 mm and 700 mm), the use of concrete (reinforced and steel fibre reinforced) and use of types of geogrids (average tensile strength of 100 KN/m and 200 KN/m).

Testing of the circular specimen was carried out on a loading frame having a hydraulic jack of maximum capacity 600 KN. Each specimen was simply supported and subjected to a mid-span point load. The ultimate shear strength for the control specimens was analyzed and calculated theoretically comparing it with the obtained experimental values. The load-deformation graphs were plotted and various parameters such as ultimate load, secant stiffness, deflection ductility and energy ductility with energy dissipation were evaluated and compared. Some of the important conclusions and observations are summarized below:

1. The control specimens were tested for shear and experimental values were compared with their theoretical values. Considerable scatter was seen in the shear strength prediction comparison to the experimental results. The mean value of V_{exp}/V_{IS} was found out to be 1.282 with a standard deviation of 0.427. The margin of safety is fairly conservative against shear failure. All the control specimens showed ductile behavior.
2. Since steel stirrups were partially replaced with geogrids; meaning the specimens with 150 mm spacing of steel stirrups were replaced by geogrids between 450 mm of steel stirrups or 700 mm of steel stirrups spacing, every specimens were compared with RC_{150} specimen to achieve similar or better strength. Addition of 1% of steel fibres with partially replacing stirrups with geogrids (200 KN/m) gave a better result. It improved the strength marginally and increased ductility compared to 150 mm control specimen. The strength of RC_{150} was 44.548 KN and that for $RC_{450}F+G_{200}$ was 47.264 KN, increasing the load just by 6%.

3. Addition of steel fibres to the 150 mm stirrup spacing did not contribute much to the strength but increased the deflection ductility factor from 3.140 to 4.511 increasing it by 43.66%. Therefore, the addition of 1% of steel fibres improved ductility by 43.66%.
4. Increasing the spacing of steel stirrups decreased the ultimate load with a decrease in displacement at ultimate load. The use of geogrids (average tensile strength 100 KN/m and 200 KN/m) turned out to be quiet effective with the addition of 1% steel fibres. $RC_{450}F+G_{200}$ showed the best result with minor improved in strength and high ductility than RC_{150}. The steel fibres addition and the tensile strength of the geogrids help in resisting the crack formation and its propagation. Its flexible property allows the specimen to bear the ultimate load for larger displacement, giving good rise to ductility in the specimen.
5. With an increase in spacing of the stirrups, the energy dissipation decreased while the addition of steel fibres increased the energy dissipation. $RC_{450}F+G_{200}$ gave higher energy dissipation of 81.281% increase as compared to RC_{150} specimen. Because of the ductile behavior of the specimen, it has the capacity to store higher energy during the load applied.
6. There was a decrease in the rigidity with the steel fibres addition in the specimen. This is because it makes the specimen more ductile and allows to carry the same load for higher displacement making the specimen more flexible. While the specimens with geogrids but no steel fibres were seen to increase the stiffness. As stiffness is inversely proportional to displacement, with reduction of displacement as compared to RC_{150} specimen the specimens with geogrids are stiffer. The specimens having geogrids and 1% of steel fibres showed decrease stiffness as compared to RC_{150} specimen, as they have higher ductility which allows them to carry the ultimate load at larger displacement.

6.2 FUTURE SCOPE

Very less research in shear strength for circular members is done. Addition of steel fibres and using geogrids in construction is still new to its type. Practical application has not been seen because of the insufficient studies and researches on it. Extensive studies need to be carried out for the circular section as well as the steel fibres addition and geogrids use on it. Further studies on various parameters such as dia of the specimen, dia of longitudinal and transverse bars, shear span by depth ratios, compressive strength of concrete, percentage of steel fibres, types of geogrids, two-point load, cyclic loading, etc can be changed and tested accordingly and proper detailed study can be carried out.

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