MECHANICAL BEHAVIOUR OF CONFINED CIRCULAR COLUMNS

A Thesis

submitted in partial fulfillment of the requirements for the award of the degree of

MASTER OF TECHNOLOGY

in

CIVIL ENGINEERING

with specialization in

STRUCTURAL ENGINEERING

by

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to

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CERTIFICATE

This is to certify that the work which is being presented in the thesis titled ***"Mechanical Behaviour Of Confined Circular Columns"*** in partial fulfillment of the requirements for the award of the degree of Master of Technology in Civil Engineering with specialization in **Structural Engineering** and submitted to the Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat is an authentic record of work carried out by Abhinav Chauhan (Enrolment No. 162664) during a period from July 2017 to May 2018 under the supervision of **Dr. Gyani Jail Singh (**Assistant Professor), Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat.

The above statement made is correct to the best of our knowledge.

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Date: **Abhinav Chauhan**

ABSTRACT

In this thesis columns with varying lateral reinforcement were confined with welded wire mesh externally as well as internally and test was conducted to study the effect of confinement on behaviour of columns. Six different samples were constructed in which Group 1 samples were constructed by varying lateral reinforcements and in Group 2 columns of different mix were constructed with same number of lateral reinforcement.

Total 36 samples were constructed and tests were constructed in which it was observed that external confinement gives more axial deformation for same load capacity. For group 1 external confinement increases the load taking capacity as it can be observed that maximum increase in peak load was for columns with 3 rings (17%). In group 1 by using external confinement occurrence of peak load was delayed with respect to unconfined specimens. The increment was maximum for columns with 3 rings (32%). In group 1 peak was obtained earlier in comparisons to unconfined ones and very low percentage increase in load taking ability. For group 2 maximum increases in load capacity was for w/c 0.55 when confined internally (11%). For group 2 with w/c 0.55 shows increase in axial deformation at peak load (42%). External confinement provided more ductility. In group 1 it was also observed that external confined column with 3 and 2 rings have similar ultimate load capacity as compared to unconfined 3 and 2 rings columns respectively. There was increase in energy absorption for group 2 column having w/c 0.55 (52%). In order to enhance ultimate load capacity in large scale columns can be confined by using double or triple layer of WWM. Also diameter of wire can be increased and orientation of mesh opening can be changed i.e. using diagonal openings. Increasing the proportion of aggregate with nominal size 10mm increases concrete homogeneity which assists in achieving high increments in ultimate load capacity.

Keywords: WWM, confinement, reinforcement

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Reinforced concrete (RC) is used for various construction all around the world. A column takes the load from beams, slabs and transfers it to foundations. Columns can take high compressive forces in tall buildings and mega structures. Also columns can suffer serious damage due to overloading, fire and earthquake due to limit in ductility and strength of concrete. Failure of columns leads to collapse of structure. Some major earthquake in table 1.1 occurs in recent years give us cue that how seismic activities affect highly populated areas around the world. Areas which are highly affected by earthquake have such an infrastructure that can function after earthquake. The existing trend in the design of structure in these regions is that structure can take high loads but cannot work well in earthquake. There should be better understanding in design of structure for earthquake and providing effective confinement in critical region. In figure shown below (Figure1.1) type of failure of concrete is represented, failure occurs due to the lack of effective confinement. The percentage of volume of confinement with respect to core of column depends on compressive strength of concrete, longitudinal steel area, axial load ratio, area of confinement. On the other hand not all above variables are included in formulation of equations for percentage of confining reinforcement. Confinement equation does not include displacement and curvature demands which would result better in determining the amount of confinement reinforcement required.

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Table 1.1 Recent Earthquakes in different countries		
Countries	**Magnitude**	**Date**
Mexico	8.2	8th September 2017
Papua New Guinea	7.9	22nd January 2017
Iran	7.2	12th November 2017

Figure 1.1 Failure of concrete due to lack of confinement

1.2 CONFINED CONCRETE

Plain concrete has different stress-strain characteristics which is different than confined concrete. In case of unconfined column stress in column increases as load increases, when yield stress reaches column fail due to compression. When concrete is confined there is increase in stiffness, maximum compressive strength and increase in strain when peak stress is reached. Confined concrete can carry large deformation without decrease in load-bearing capacity and ductile failure will occur Richart et al. (1928). In order to increase the ductility the core region of concrete should be confined effectively by using sufficient lateral reinforcement and buckling of longitudinal reinforcement should be prevented. In Figure1.2 below effective confinement of core concrete was shown by using rectangular ties. The basic principle of confined concrete is that increase in strength due to confinement should compensate the loss in strength of structure due to spalling of concret**e** cover. The sensitive zone in confined concrete is the regions where large axial load is acting such as intersection of columns with footing. In case of unconfined concrete high transverse tensile strain will occur when it will strain to large deformation due to which there is creation and spreading of longitudinal micro-cracks. This results in failure of concrete in compression. To improve concrete confinement lateral stirrups spacing should be reduced. There is a critical spacing above which the effect of confinement becomes ineffective and also there is another criterion that is buckling of longitudinal bars. But large as well as small spacing both results to be short of effective confinement. High percentage of lateral reinforcement percentage led to difficulty in construction and decrease concrete homogeneity and low percentage causes deficiency in confinement.

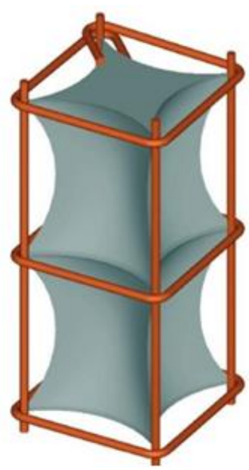

Figure 1.2 Effective confinement of core by using rectangular ties

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CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

Previous studies was done on confining columns by various methods such as confinement using expanded metal mesh (EMM), fiber reinforced polymer (FRP) ,Welded wire mesh (WWM). In most cases WWM was used in case of ferrocementing. Some previous studies are mentioned below

Sehu and Rao (1998) performed an experiment on the performance of concrete confined with ferrocement under axial loading. The specific surface factor was varied which largely affects the behavior of ferrocement. Two hundred seventy prisms of size 150×150×300 mm were casted and tested for axial compression. The following conclusion that can be made:

- Ferrocement has proved effective over lateral ties confinement and improves performance under large deformations.
- Confining with ferrocement increases the strain at ultimate strength, ultimate strength and ductility of columns.
- The ultimate strength of column confined with ferrocement has linear relationship with confinement index and specific surface factor and they established the relationship which determines ultimate strength with variables as confinement index and specific surface factor. This expression can be given by:

  $P = f_c' (0.912 + 0.055 S_f) (1.0 + 0.55 C_i)Ag + f_y A_s$ ------------------------------------ Equation 1

  Where,

  S_f = surface factor

  C_i = confinement index

- Also relationship among strain at ultimate strength, confinement index, specific factor was established which can be given by:

  $\varepsilon_{cf} = \varepsilon_c' (1.0 + 5.2 C_i) (0.90 + 0.178 S_f)$ --Equation 2

  Where,

  S_f = surface factor

  C_i = confinement index

Mau et al. (1998) tested concrete column specimens of dimension 127 × 127 × 381 mm which are laterally confined by welded wire fabric. Three different spacing of wires were chosen and five different diameters of wires were used. The ratio of longitudinal spacing to column width (S/D) varied from 0.1-0.3.There were four different S/D ratio for each diameter of a wire. Three identical specimens for each set were prepared. Twenty different sets of columns were prepared and were tested under uni-axial compression. Following conclusions were drawn from experiment:

- Confinement with welded wire fabric increases post peak ductility and compressive strength.
- For columns confined with welded wire fabric lower bound formulae was derived.
- In columns confined with welded wire fabric, S/D ratio has the main impact on the increment in strength than the volumetric ratio.
- But for small S/D ratio increase in volumetric ratio increases the strength.
- Change in mesh size does not have much impact on strength.
- They calculated ductility index which they defined as a ratio of maximum axial strain to strain at peak stress in plain concrete. For ductility the suggested the value of 8 and for a ratio below it, they said brittle.
- It was observed that welded wire fabric and concrete behaved as homogenous composites.
- They suggested ductile-brittle behavior as a function of Spacing to Width ratio and volumetric ratio.
- They give the formulae:

$$p = 15\, S/D \quad \text{(For brittle)}$$

$$p = 20\, S/D \quad \text{(For ductile)}$$

`

Corte et al. (2006) performed experiment on the use of composite materials to control the plastic collapse mechanism of existed reinforced concrete structure. The research was done on full scale structure which was obtained from building constructed in 1970s. At first original structure was tested to find the response. In order to change the plastic collapse mechanism it was retrofitted by carbon fiber reinforced polymers which results in shifting of column sway type to beam sway type. Monotonic push over curve was recorded for both original structure and strengthened structure and comparison were made as shown in Figure1.1. The push over test for original structure was done when load was applied at top story only and for strengthened column load was applied on both stories. Strengthening with FRP increases load and displacement capacity close to 100%.

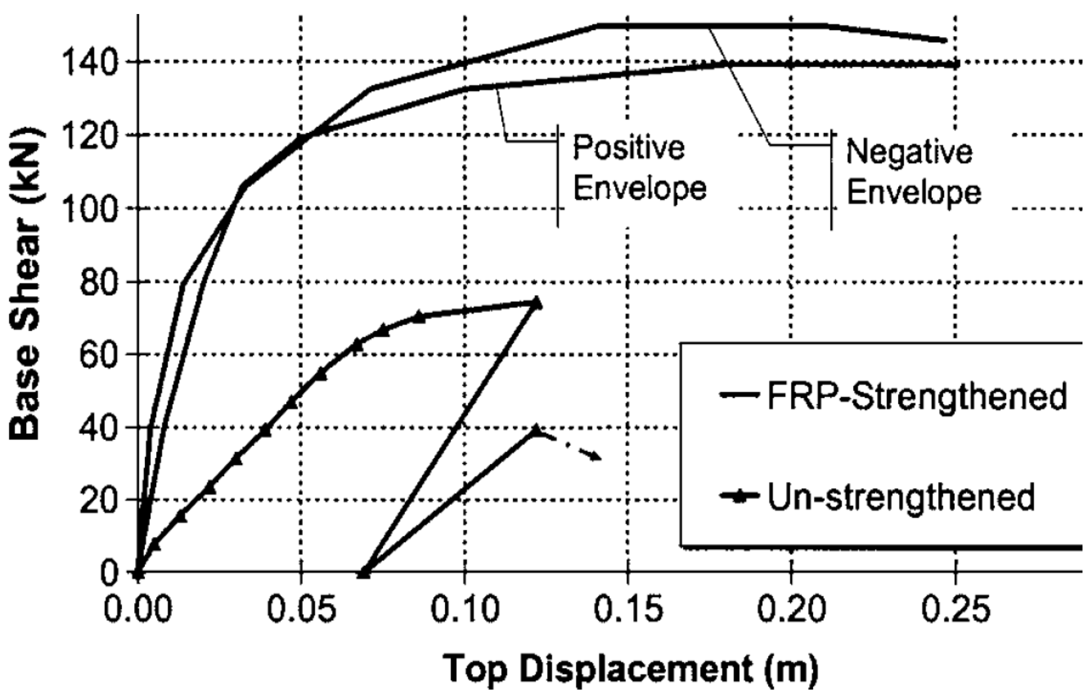

Figure 2.1 Comparison of original versus FRP rehabilitated structure response Corte et al. (2006) .

Kumar et al. (2007) conducted experiment to check the response of reinforced columns under seismic loading by using three axial load ratios. The experiment contain three working model of bridge pier specimens which are designed as shear deficient specimens and tested under different axial load. The specimens have cross-sectional area of 70mm ×12 mm and height 500mm. The columns were confined with six and four layer of mesh having volume fraction 3.46%, 2.94% respectively. The conclusions can be drawn were:

- External ferrocement confinement increases strength, ductility, energy dissipation and stiffness.
- Hysteretic response was affected by axial load on the column.
- Ferrocement confinement was effective in energy dissipation which is important aspect for earthquake resistance.
- Strength of confined columns was increased by increasing axial loading but stiffness was decreased when they were tested under cyclic loading.
- Strain in unconfined column was high and there was shear failure but in confined column the transverse strain was much lower at identical vertical displacement.
- This behavior was due to ferrocement confinement which prevents the diagonal shear cracks from widening.

Iiki (2008) performed uni-axial compression test on 68 reinforced concrete columns (circular, square and rectangular) after they were confined with fiber reinforced polymer sheets. Forty samples were casted by using low strength concrete with insufficient internal lateral reinforcement and other 28 samples were casted using medium strength concrete with adequate lateral reinforcement. The concentration were made on parameters such as cross-section shape, thickness of carbon fiber reinforced polymer, strength of concrete, percentage of internal transverse reinforcement, existence of pre-damage, corner radius, loading type , loading type, spacing, details of anchorage, corner radius, additional corner supports of carbon fiber-reinforced polymer sheets. Conclusions that can be made from experiments are:

- Using carbon fiber-reinforced polymer increases ultimate strength and ductility.

- For confined low strength concrete the increase in compressive strength by 1.4 to 6.9 times and in axial strain by 6.5 to 50 times in comparison to unconfined samples.
- Similarly for medium strength concrete the increase was 1.5 to 3.6 times and 16.5 to 26 times for compressive strength and axial strain respectively.
- The rise in deformity and strength taking capacity was seen more in low strength concrete.
- Application of carbon fiber-reinforced polymer proved to be more effective for low strength concrete structures.
- Increment in strength was proved to be more in circular columns.
- Improvement in axial strain was more for rectangular and square cross-sections both for low and medium strength concrete.
- Confinement prevents longitudinal bar buckling as well as spalling of concrete cover.
- From above point it can be concluded that at large axial deformations axial strength and ductility can be maintained.
- It benefitted the specimen by taking longitudinal reinforcement into strain hardening zone.
- Transverse strain for of carbon fiber reinforced polymer confinement were 0.007 to 0.018 and 0.012 to 0.015 respectively for low and high strength concrete in independent of confinement thickness.
- Higher axial strength rectangular columns with increasing corner radius but no significant effect observed in deformation.
- In cyclic loading there was increase in ultimate deformation while compressive strength was not influenced.
- Additional anchorage to increase the cross-sectional area and pre-damage of the samples does not influence the behavior.

Kondraivendhan and Pradhan (2009) studied the effect of external confinement to concrete specimens. The confinement used was ferrocement confinement..The effect of confinement was observed by comparing the behavior of retrofitted specimen with standard ones. Concrete compressive strength was measured by keeping different parameters constant. The parameters are number of layers, l/d ratio, shape and size of wire mesh. The cylindrical specimens have l/d ratio of 6:1 and size of 150 mm × 300 mm. Following conclusion can be drawn from the test results;

- Concrete can be confined with ferrocement effectively.
- As the grade of concrete increases, the gain in strength is reduced when confined with ferrocement.
- Ferrocement confinement leads to increase in axial and radial strain of concrete.

Table 2.1 shows strength increment with grade of concrete Kondraivendhan and Pradhan (2009)

Grade of concrete	Increment in strength %
M 25	78
M 30	54.8
M 35	54.6
M 40	60.25
M 45	46.3
M 50	47.2
M 55	45.3

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Table 2.2 shows increment in axial and radial strain with grade of concrete Kondraivendhan and Pradhan (2009)

Grade of concrete	Increment in axial strain %	Increment in radial strain %
M 25	38.8	50.7
M 30	22.3	27.2
M 35	4.02	18.8
M 40	34.5	34.4
M 45	47.3	48.8
M 50	32.3	37.8
M 55	21.9	39.2

Moghaddam et al. (2010) their study presents the results of an experiment conducted on concrete columns specimens by the application of strapping technique. It is a technique for retrofitting of concrete compressive specimens. In this technique high strength metal strips which are around the column is post tensioned by using standard strapping devices. In the experiment 72 prismatic and cylindrical samples which were confined by pre-stressed metal strips and axial compression test were performed on them. Various parameters on ductility and strength were studied which includes compressive strength of concrete, post-tensioning force in the strip , confining strip ductility , detail of strip joint ,volumetric ratio of confining strips and layers of strips confining the specimens. Results shows that above technique increases both strength and ductility of concrete.

- There were increase in strength and ductility of prismatic specimens as compared to prismatic ones.
- Active confinement which are tensioned 30% to their yield strain shows higher increment i.e. 25% in ultimate compressive strength capacity than passive ones which are post-tensioned by small force. Furthermore degradation of passively confined concrete starts earlier.

- Double layer confinement gives better strength and ductility than single layer confinement.
- Strength and ductility of confined specimens are dependent on volumetric ratio of confining strips.
- Effect of confinement on prismatic specimens with rounded corners is more as compared to chamfered ones provided same details of strengthening.
- For specimens with same details of lateral confinement poor post peak behavior was shown by high strength concrete.
- Use of ductile strips shows increase in ductile behavior of concrete under compression.

Sezen and Miller (2010) strengthen columns using five different types of jacketing that were a) Fiber reinforced composites b) Steel jackets c) Welded wire fabric d) Concrete Jacketing with spiral rebar e) Prefabricated cage system. They prepared fifteen specimens out of which: one unconfined column; three columns confined with fiber reinforce polymer composite; two were steel jacketed; and nine were confined with concrete(three with spiral reinforcement, two with welded wire fabric; and four with prefabricated cage. The unconfined specimens had 152 mm diameter, while confined specimen had 254 mm diameter. Then they study the effectiveness of each confining system in axial capacity, stiffness, ductility and displacement. The conclusions can be made from experiments were as follows:

- All confining methods increases strength and stiffness of columns.
- Confinement should be extended to top and bottom face of columns and all loads should be applied over whole cross-sectional area.
- Confinement with FRP and welded wire fabric increases the strength by 140% but brittle failure was observed.
- As fiber reinforced polymer does not increase the size of original columns, the increase in strength is due to confinement provided to existing concrete.
- Fiber reinforced polymer strips was less effective than wrapping full column by single strips.

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- For welded wire fabric and jacketing with spiral rebar had almost similar initial stiffness before cracking of concrete.
- The axial load vs. displacement curves of columns confined with spiral rebar and prefabricated cage were similar up to peak after peak there was large variations.
- Steel jacketing provides higher stiffness, strength, displacement capacity among all methods.
- Concrete jacketed specimens provide cover which are suitable for deigns where corrosion and fire resistance is required.

Soliman (2011) studied the response of fiber reinforced plastic confined long columns and investigated failure mode along with formulation of theoretical model to calculate capacity of column. Also studied the ultimate capacity, radial strains, axial strains by varying slenderness ratio of columns. Various columns were prepared and were divided into three groups with slenderness ratio varied from 9 - 18.Following conclusions that can be drawn were:

- Slenderness ratio affects the failure mode of the column.
- As slenderness ratio of long confined columns decreases there is significant increase in stiffness.
- Ratio of compressive strength of confined (f_{cu}) to compressive strength of unconfined (f_{ucu}) columns increases with decrease in slenderness ratio as shown in table 1.3 and table 1.4 for 120 mm and 150mm diameter respectively.
- With increase in slenderness ratio of axial strain in confined (ε_{cc}) to axial strain ratio in unconfined (ε_{cu}) columns decreases as shown in table 1.5 and table 1.6 for 150 mm and 120mm diameter respectively.
- Also as slenderness ratio increases the ratio of radial strain in confined (ε_{ccr}) to radial strain ratio in unconfined (ε_{ctr}) columns decreases as shown in table 1.7 and table 1.8 for 150 mm and 120mm diameter respectively.
- Slenderness has major impact on response of long confined columns and care must be taken while designing.

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- They formulate equation to determine the compressive strength of confined columns with same materials.

Table 2.3 shows value of f_{cu}/f_{ucu} (%) for different values of **λ** for 150 mm diameter column Soliman (2011)

f_{cu}/f_{ucu} (%)	λ
28	17
48	15
80	12.5

Table 2.4 shows value of f_{cu}/f_{ucu} (%) for different values of λ for 120 mm diameter column Soliman (2011)

f_{cu}/f_{ucu} (%)	**Λ**
30	14
52	12.5
99	10

Table 2.5 shows value of **$\varepsilon_{ccl}/\varepsilon_{cu}$** for different values of λ for 150 mm diameter column Soliman (2011)

$\varepsilon_{ccl}/\varepsilon_{cu}$	**Λ**
7.05	14
7.95	12
8.1	10

Table 2.6 shows value of $\varepsilon_{ccl}/\varepsilon_{cu}$ for different values of λ for 120 mm diameter column Soliman (2011)

$\varepsilon_{ccl}/\varepsilon_{cu}$	Λ
4.1	17.5
4.9	15
6.3	12.5

Table 2.7 shows value of $\varepsilon_{ccr}/\varepsilon_{ctr}$ for different values of λ for 150 mm diameter column Soliman (2011)

$\varepsilon_{ccr}/\varepsilon_{ctr}$	Λ
13.74	14
15	12
15.75	10

Table 2.8 shows value of $\varepsilon_{ccr}/\varepsilon_{ctr}$ for different values of λ for 120 mm diameter column Soliman (2011)

$\varepsilon_{ccr}/\varepsilon_{ctr}$	Λ
10.75	17.5
12	15
17.75	12.5

Xiong et al. (2011) strengthen the circular columns by using ferrocement with steel bars jacket. The uniaxial compression test on concrete confined with ferrocement with steel bars, only steel bars mat and Fiber reinforced polymer (Glass fiber and Carbon fiber) was compared. In total 51 test samples were prepared and failure modes, load -strain responses, ultimate loads and ductility of various confined samples were investigated. Results show the following:

- Crack width in mortar layer for ferrocement with steel bars was approximately equal to spacing of wire mesh.

- As more cracks occur in ferrocement with steel bars the ductility of it is higher than Fiber Reinforced Polymer and steel bar mat.
- Ferrocement with steel bars jacket enhance strength, energy absorption and ductility of concrete columns.

Ho et al. (2013) they strengthened circular columns by high performance ferrocement (wire mesh and rendering materials) which was achieved by replacing concrete cover by it. Three different types of rendering materials for high performance ferrocement were used which are a) Cement Sand screeding b) epoxy based c) polymer modified cement based. As confining property is dependent on the tensile strength of rendered materials therefore at first rendered materials were tested for direct tensile strength. Nineteen plain and nineteen plain circular column were tested under uni-axial compression Thirteen columns were detailed with 4% longitudinal reinforcement out of which eleven have lateral reinforcement p_s= 0.230% and two have p_s = 0.918%, eight of those eleven columns and another four plain columns were confined with one layer and three layers of wire mesh and three different rendering materials. Percentage of the volume of wire mesh and tensile strength of rendering materials were variables. Conclusions that can be made from tests:

- In confined plain concrete columns ultimate strength was 30 to 59 % higher than unconfined specimens.
- Confined columns with transverse reinforcement p_s= 0.230% can achieve ultimate strength as comparable to columns having transverse reinforcement p_s= 0.918.
- As confining action of confinement dependent on tensile strength of high performance ferrocement therefore tensile strength of rendering materials should be considered.
- They predicted empirical equations for peak strength of confined circular column with high performance ferrocement in which error was within ±10 % .
- Failure mode of confined columns specimens can be seen Figure 1.2 (a and b) for failure of 300 and 75mm spacing lateral reinforcement. Spalling of cover concrete before reaching ultimate strength.

- Figure 1.2 (c and d) for confined plain columns in which diagonal cracks appear at 45° approximately.
- Figure 1.2 (e and f) shows a failure of confined reinforced column specimen. The integrity of core is maintained by lateral reinforcement.

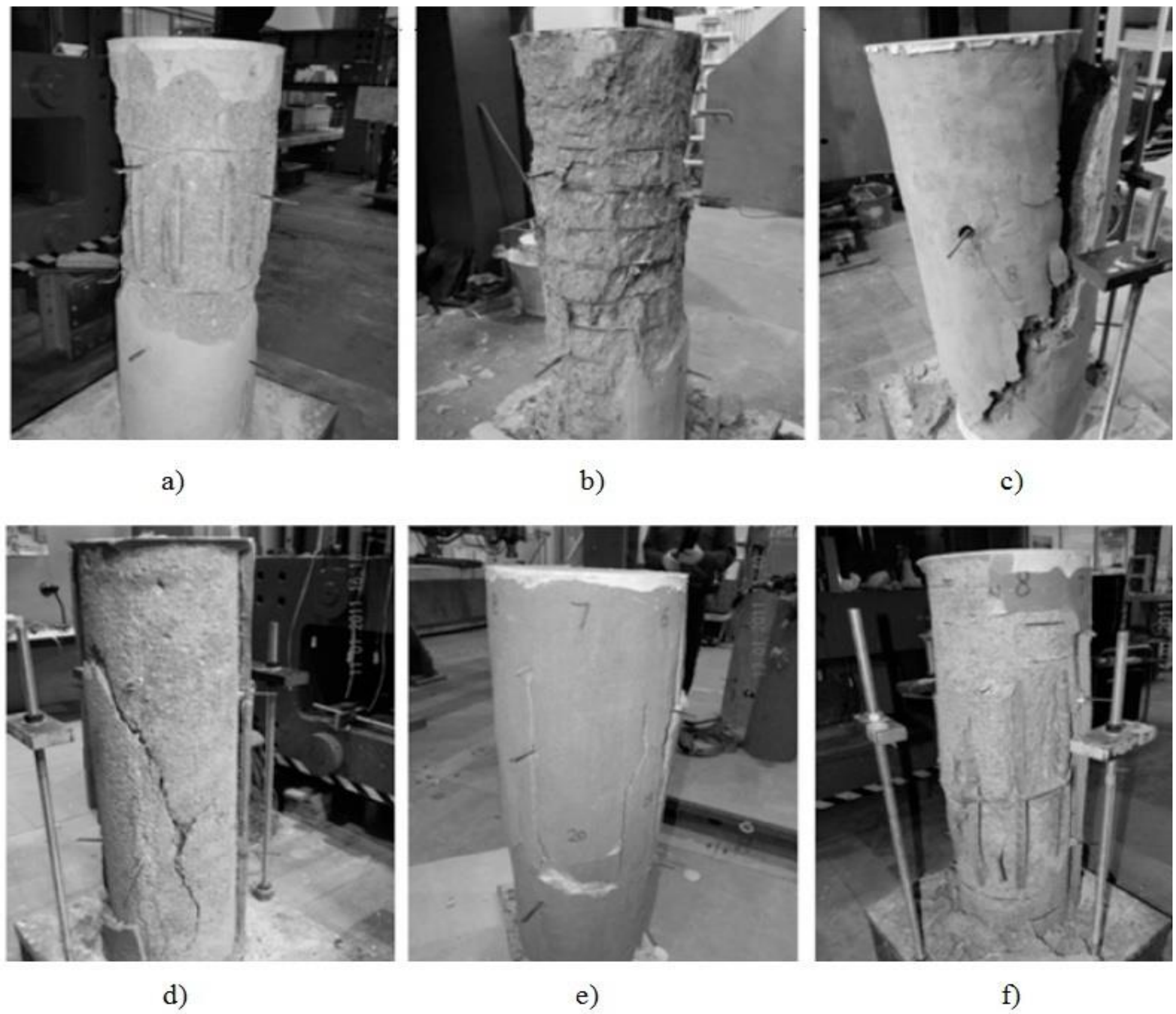

Figure 2.2 Showing modes of failure Ho et al. (2013)

Belal et al. (2014): They conducted experiments to study the behavior of reinforced columns confined using steel jacket technique. They considered three variables that were the confining system (C-sections, plates, and angles), number of batten and size of plates. Seven columns of size 200×200 ×1200 mm were prepared and were divided into two unconfined and five confined ones. Response and failure load of these columns were determined. Also, a finite element models were constructed to study the response of columns after that model was verified and matched with experiment results. Conclusions that can be drawn from analysis and experiment were:

- Steel jacketing was proved to be effective as it increases the strength of columns by minimum 20%.
- Failure of a jacketed column was ductile while for unconfined column it was brittle.
- Columns strengthened with channel or angle section with batten plate gives higher strength than columns strengthened with only plates.
- As the thickness of C channel section and batten plates were less than other section used therefore more caution is necessary as they can buckle.
- Steel jacketing increase surface area of covered concrete where thereby increases the effect of confinement.
- Simulation done using finite element analysis in ANSYS 12.0 give close results of displacement failure load as measured in experiments.

Al-Sibahy (2016) had done research to experimentally investigate the response of reinforced reinforced concrete columns under axial compression which are confined with a new array of steel wire mesh for ferrocementing. Three slenderness ratio were chosen (5, 6.7, 10) for circular and square short columns. The load capacity and both vertical and horizontal displacement were measured. Also the failure modes of columns were observed.The significance of this research was as follows:

- The slenderness ratio was the most important factor for this research as load carrying capacity of columns decrease with increase in slenderness ratio.
- Improvement in load carrying capacities of column when confined with new array of steel wire mesh as compared with unconfined samples.
- For both confined and unconfined samples square columns shows higher load capacity than circular columns because square columns exhibits larger contact area.

- As slenderness ratio increase both horizontal and vertical displacement increases and they have same trend of increment.
- They found modulus of elasticity of tested columns as two sixty times the value of compressive strength of each column.
- Failure mode starts to spread at the lower and upper end of the columns and perpetuate to a certain zone.

El-Kholy and Dahish (2016) in their paper confinement of column was done using single Expanded Metal Mesh layer with lateral ties as transverse reinforcement. They wrapped EMM confinement over ties. The study was done with a varying volumetric ratio of ties in sixteen short square reinforced column columns which are categorized according to their slenderness ratio into two groups. The samples were cast in a vertical position which simulates the work in a construction site and were tested for concentric compression till failure. Results shows following;

- Ultimate load capacity of short square reinforced column increases by 11.02% and 18.55% for slenderness ratio λ= 7.33 and 14 respectively with the addition of the single layer of Expanded Metal Mesh as lateral reinforcement when the volumetric ratio of ties is 0.2714%.
- Columns with λ= 7.33 with some minor loss in ultimate load carrying capacity the addition of Expanded Metal Mesh reduces the volumetric ratio of ties by 40%.
- Columns with λ= 14 with same ultimate load carrying capacity the addition of Expanded Metal Mesh reduces the volumetric ratio of ties by 70%.
- A reinforced column with Expanded Metal Mesh and lateral ties exhibits more ductile and plastic deformation behavior.
- By the addition of Expanded Metal Mesh in the presence of lateral ties enhances energy dissipation with 85.36% and 450.8% for columns with λ= 7.33 and 14 respectively.
- Addition of Expanded Metal Mesh provided 80% decline in the volumetric ratio of ties without much change in dissipated energy.

2.2 OBJECTIVE

- Objective of the work is to study the response of column under axial loading.
- To check the effectiveness of columns confined internally and externally by WWM with varying lateral reinforcements and different grade of concrete.

2.3 SCOPE

The deficiency in confinement given by lateral reinforcement can be increased by using welded wire mesh which is used to confine concrete core. Mesh openings should be large enough so that it does not interfere with the homogeneity of concrete and construction can be done smoothly. In this study mesh are wrapped inside and outside the longitudinal reinforcement and behavior column was studied.

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CHAPTER 3

MATERIALS AND METHODOLOGY

3.1 GENERAL

In this chapter properties of materials used in construction and confinement of columns. Methodology to construct confined column is described below in detail. Concrete mix design was prepared and theoretical load capacity of column for different mixes was calculated.

3.2 MAIN AND LATERAL REINFORCEMENT

Main reinforcement of diameter 12 mm (Fe 500) was used and it fulfill the criteria as per IS 1786 (2008)

Lateral reinforcement of 8 mm (Fe 250) was used and its properties are according to IS 432 -Part I (1982)

3.3 GI WELDED WIRE MESH

Mesh of opening 2"×2" and wire of diameter 1.5 mm was used. The material properties were provided by the manufacturer and are shown in table 3.1.

Table 3.1 Materials properties given by manufacturer

Tensile Strength (MPa)	520
Yield Strength (MPa)	450
Weld Shear Strength (MPa)	240

3.4 PURPOSED MATRIX

Columns were divided into three categories:

1. Unconfined Columns: Only transverse reinforcement was provided in columns.

2. Externally Confined Columns: Transverse reinforcement along with welded wire mesh was used to confine the columns. The mesh was wrapped outside the main reinforcement but inside the transverse reinforcement.

3. Internally Confined Columns: Transverse reinforcement along with welded wire mesh was used to confine columns. The mere wrapped beneath the main reinforcements.

3.5 CONFIGURATION OF COLUMNS

The structure of casting of columns is shown in table 3.2. Four longitudinal reinforcements of diameter 12mm were placed on outer periphery of column. Each column has diameter 150mm and height of 900mm. Transverse reinforcement used are circular in shape.

In group 1 the spacing of lateral reinforcement is varied in such a way that effect on confinement can be seen. The spacing varied from 220mm to 880mm, higher spacing is chosen to see if column can be confined with wire mesh by replacing lateral stirrups fully that is why spacing of stirrups is not according to code.

In group 2 different mixes were prepared to check the effect of confinement by varying strength of concrete.

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Table 3.2 Work Structure							
Set No.	**Unconfined Sample**	**External Confined**	**Internal Confined**	**No. of Bars 4#12mm**	**Circular Stirrups**	**No. of stirrups per sample**	**Spacing**
GROUP 1							
1	2	2	2	24	24	4	290
2	2	2	2	24	18	3	440
3	2	2	2	24	12	2	880
GROUP 2							
1	2	2	2	24	30	5	220
2	2	2	2	24	30	5	220
3	2	2	2	24	30	5	220

3.6 THEOROTICAL LOAD CALCULATION

The theoretical load carrying capacity of unconfined concrete column was predicted by using formulae given in IS 456 (2000).

$P_u = 0.4f_{ck} . A_c + 0.67f_y . A_{sc}$---equation 3

Where

P_u = axial load capacity of the member,

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

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A_c = Gross area of the concrete,

f_y = characteristic strength of the compression reinforcement and

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

From equation 3 load capacities for different characteristic strength was calculated in which gross cross-sectional area of concrete is 17671 mm^2 and for main reinforcement is 452 mm^2 for 4#12 mm bars and yield strength of steel was 500 N/mm^2.The axial load capacities for different characteristic strength of column are given in table 3.3

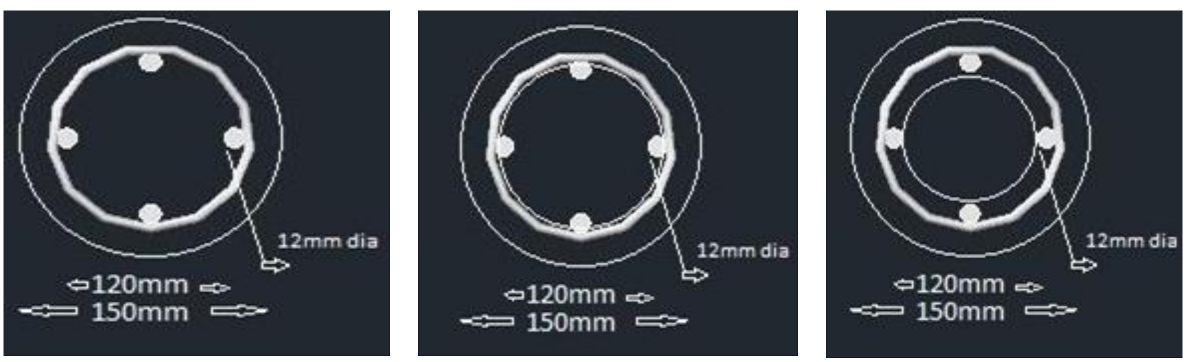
Table 3.3 Load Capacities for different grades of concrete

Grade of Concrete	**Load Capacity (kN)**
M 25	328
M 30	363
M 35	398

3.7 PREPARATION OF SAMPLES

Firstly columns moulds were prepared from 150mm diameter pipe which was cut into two different half and was joined with bolt. After that cages was prepared and lateral reinforcement were tied into their positions as. These cages were wrapped with welded wire mesh as internal and external confinement as shown in Figure3.1, 3.2, and 3.3 respectively. These cages were put into mould and columns were prepared. Columns were casted in vertically in GI pipe forms and needle vibrator was used to remove the entrapped air. All samples were level to spatula such that side surface of columns were smooth. After that columns were cured in curing tank for 28 days as shown in Figure3.4 and 3.5.

Figure 3.1 Preparation of reinforced cages



a) Unconfined b) Externally Confined c) Internally Confined

Figure 3.2 Different Columns Configurations

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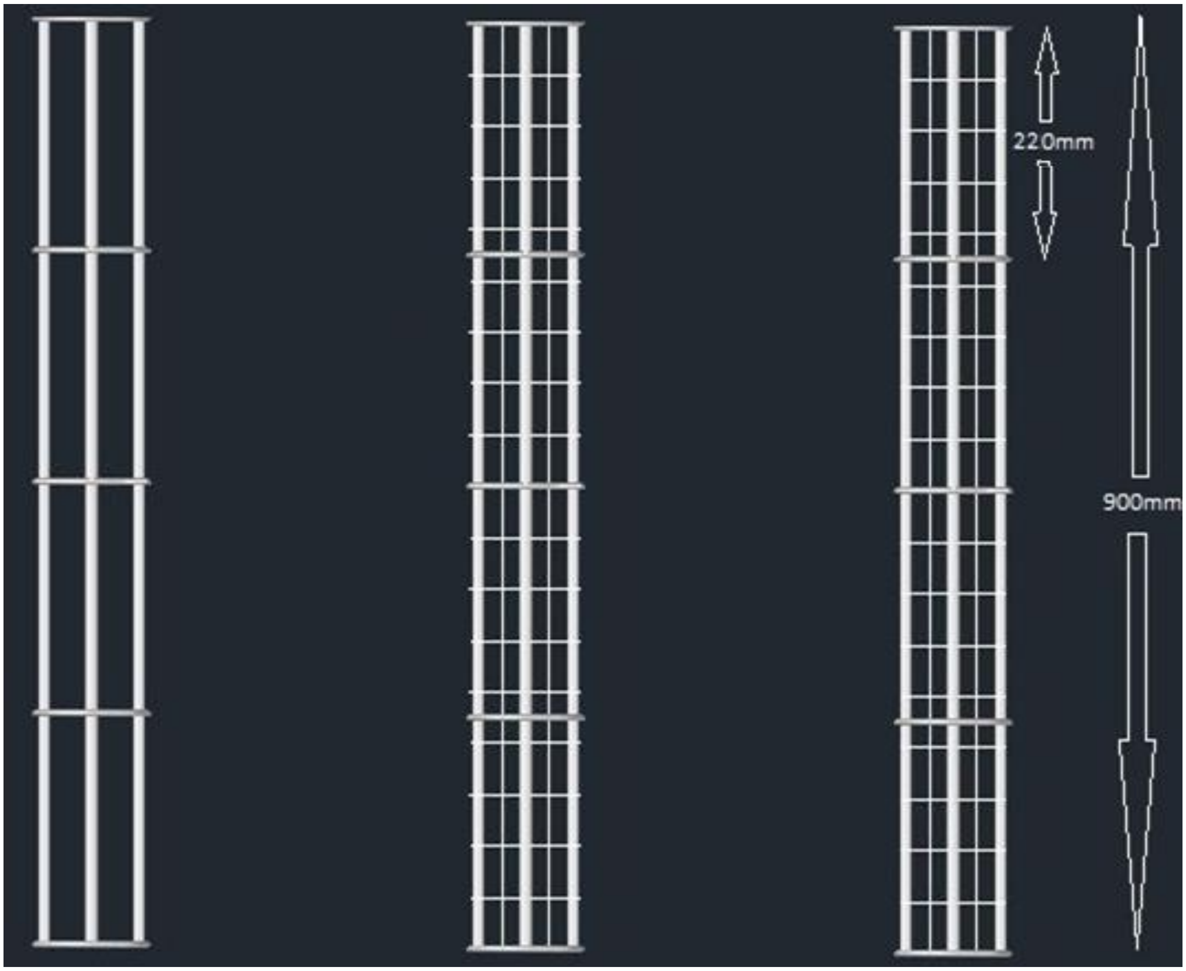

a) Unconfined b) Externally Confined c) Internally Confined

Figure 3.3 Elevation of Columns with 5 lateral reinforcements

Figure 3.4 Casted Columns

Fig3.5 Curing of Columns

3.8 COLUMN DESIGNATION SYSTEM

An identification system was consists of 5 characters as "AB1D2" was employed to put a unique name to different sets of columns. The first two characters give the type of confinement used. For example, "UC" means unconfined column, "IC" means internally confined columns, "EC" means externally confinement. The third fourth character shows w/c ratio. For example,"0.62" means 0.62 w/c ratio.

The last two characters shows number of lateral reinforcements. For example,"R5" means 5 lateral stirrups similarly "R4" means 4 lateral stirrups.

3.9 CONCRETE MIX DESIGN

The concrete was prepared with four main constituents that are cement, coarse aggregate, fine aggregate, and water. Three concrete mixes were prepared for different w/c ratios as shown in table 3.4. Ordinary Portland Cement (Grade 43) having specific gravity 3.14 was used for production of concrete.The coarse aggregate having specific gravity 2.65 were chosen such that 60% pass through 20 mm sieve and 40% pass through 10 mm sieve. Coarse aggregate dry rodded density was 1.56 t/m^3. Further fine aggregates were passed through 4.75 mm sieve, having specific gravity, fineness modulus 2.8 and 2.7 respectively. The mix was prepared were according to ACI 211.1(2002). The composition of mix are shown in table 3.5 Concrete cylinders as shown in Figure3.6 were prepared for different mix having dimensions 150mm × 300mm and tested after 28 days. Strength achieved for different w/c ratio was shown in table 3.6.

Figure 3.6 Concrete Cylinders

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Table 3.4 Different mixes	
Mix	**w/c ratio**
M1	0.62
M2	0.55
M2	0.48

Table 3.5 Mix Design										
w/c	**Slump**	**Water Content (kg)**	**Actual Water (kg)**	**Cement (Kg)**	**Coarse Aggregate**	**Fine sand**	**Correction (Water Absorption (kg)**		**% Correction**	
							CA	FA	CA	FA
0.62	150-180	210	240.3	338.7	961	845.3	13.45	16.91	0.014	0.02
0.55	150-180	210	239.5	381.8	961	802.2	13.45	16.91	0.014	0.02
0.48	150-180	210	238.3	437.5	961	746.5	13.45	16.91	0.014	0.02
Adjustment in Cement Consumption										
0.62	150-180	217.4	247.33	350.6	961	826.1	13.45	16.91	1.035	
0.55	150-180	210	239.5	381.8	961	802.2	13.45	16.91	1	
0.48	150-180	210	238.38	437.5	961	746.5	13.45	16.91	1	

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Table 3.6 Cylinder Strength of different mixes	
Mix	**28 days strength**
M1	25.2
M2	28.9
M3	33.7

3.10 TESTING PROCEDURE

All columns specimens were tested under concentric compressive loading using UTM having capacity of 1000kN.The rate at which load applied was set at 0.5mm per minute. Before testing top and bottom surface of all columns were smoothened and layer of Plaster of Paris was laid over it to ensure that there is no eccentricity.

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CHAPTER 4

RESULTS AND DISSCUSSIONS

4.1 LOAD-DEFORMATION CURVES FOR GROUP 1

After performing experiments results obtained are plotted in the form of graphs as shown in Figure4.1 -4.3.

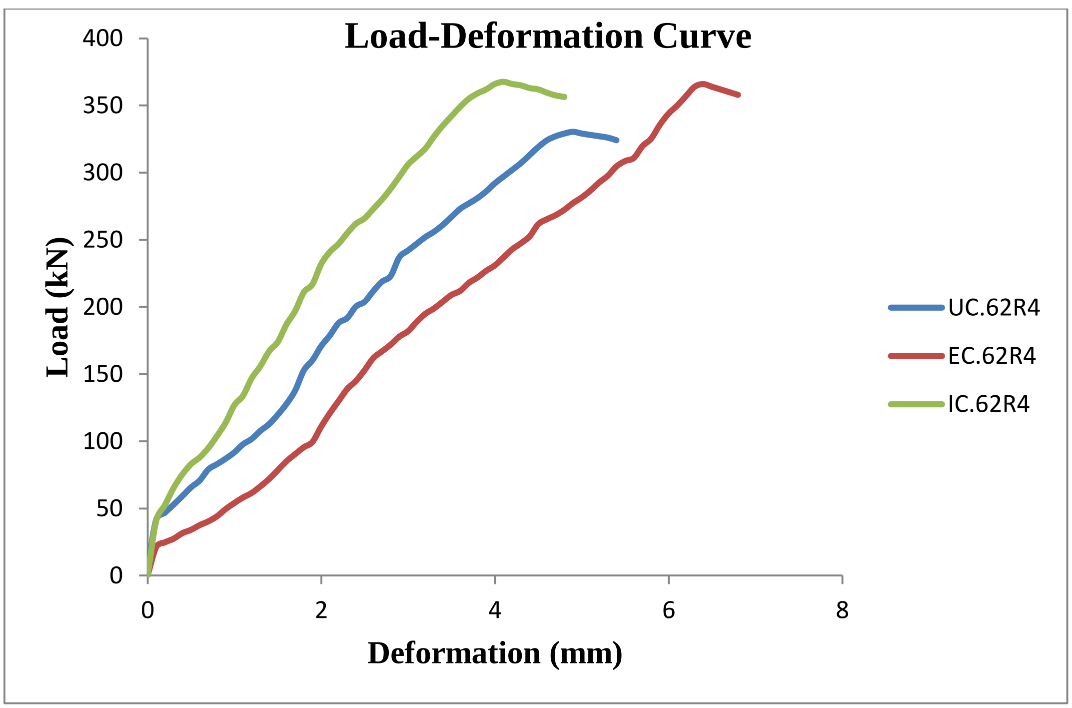

Figure4.1 Load deformation curve for Group 1 having 4 lateral ties

Figure 4.1 shows the load deformation curve for group 1 having 4 rings and a w/c ratio 0.62. From Fig 4.1 it can be seen that the unconfined specimen peak load was 340.3kN for

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5.3mm axial deformation. For externally confined specimen peak load was 380kN for 7.1mm axial deformation. For internally confined columns peak load was 356kN for 4.9mm axial deformation. The increase or decrease in peak load and axial deformation with respect to unconfined column are shown in table 4.1.

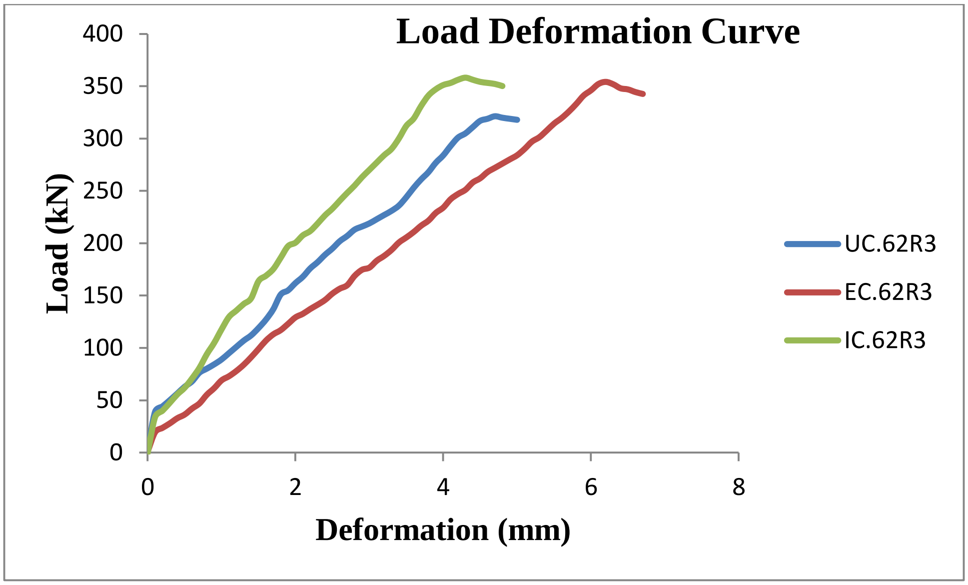

Figure4.2 Load deformation curve for Group 1 having 3 lateral ties

Figure 4.2 shows the load deformation curve for group 1 having 3 rings and a w/c ratio 0.62. From Fig 4.2 it can be seen that the unconfined specimen peak load was 311kN for 4.9mm axial deformation. For externally confined specimen peak load was 365kN for 6.4mm axial deformation. For internally confined columns peak load was 322kN for 4.1mm axial deformation. The increase or decrease in peak load and axial deformation with respect to unconfined column are shown in table 4.1.

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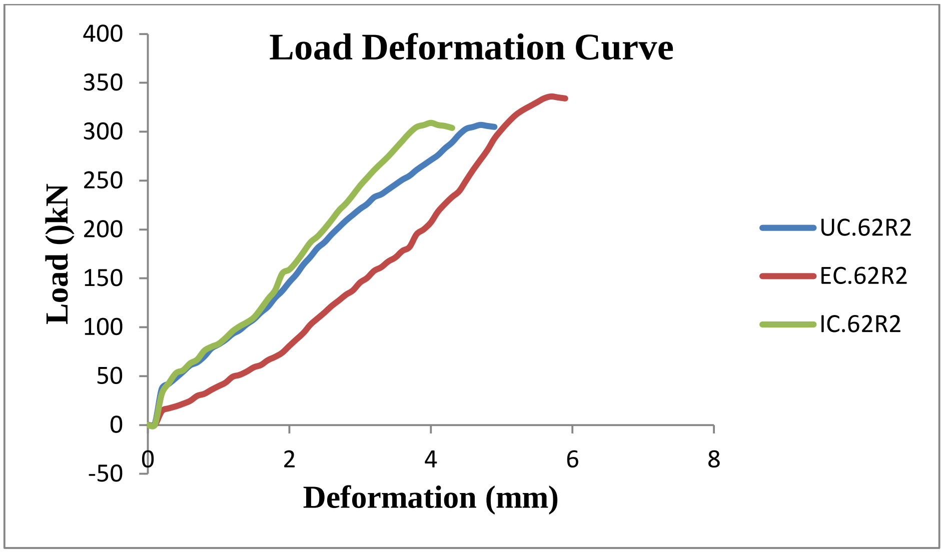

Figure4.3 Load deformation curve for Group 1 having 2 lateral ties.

Figure 4.3 shows the load deformation curve for group 1 having 2 rings and a w/c ratio 0.62. From Fig 4.3 it can be seen that the unconfined specimen peak load was 300kN for 4.7mm axial deformation. For externally confined specimen peak load was 336kN for 5.7mm axial deformation. For internally confined columns peak load was 312 kN for 4mm axial deformation. The increase or decrease in peak load and axial deformation with respect to unconfined column are shown in table 4.1

Table 4.1 Peak load and corresponding deformation for different stirrups

Number of stirrups	Deformation (mm)	**Un-Confined**	**Externally Confined**	**Internally Confined**	**Increment %**	
					Externally Confined	**Internally Confined**
4	Deformation (mm)	4.9	6.4	4.1	+30	-16
	Load (kN)	340.3	380	356	+11	4
3	Deformation (mm)	4.7	6.2	4.3	+32	-8
	Load (kN)	311	365	322	+17	3
2	Deformation (mm)	4.7	5.7	4	+21	-14
	Load (kN)	300	336	312	+12	+4

+/- shows increase and decrease in % of load capacity and deformation

4.2 LOAD-DEFORMATION CURVES FOR GROUP 2

After performing experiments results obtained are plotted in the form of graphs as shown in Figure 4.4 -4.6.

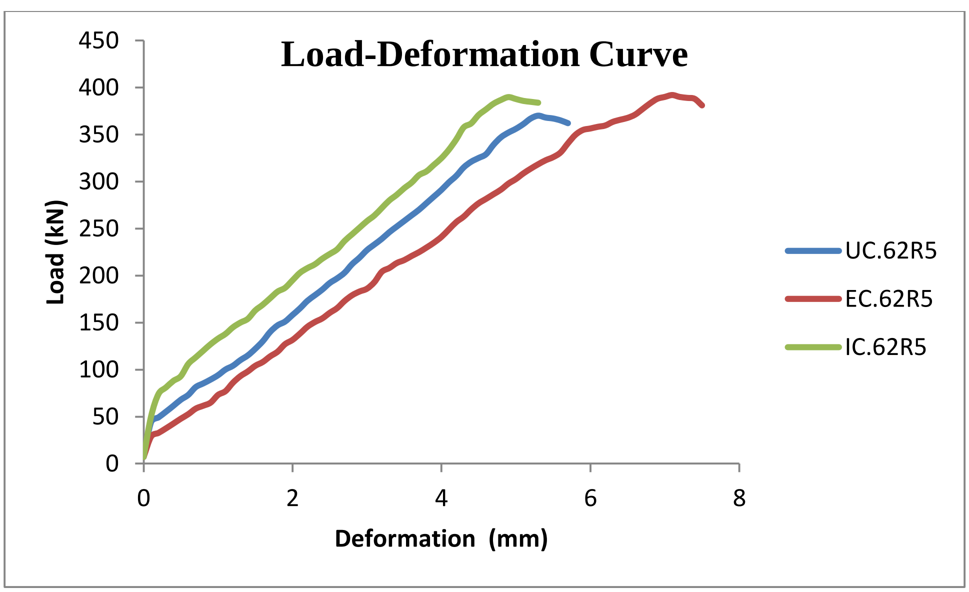

Figure 4.4 Load deformation curve for Group 2 having 0.62 w/c ratio

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Figure 4.4 shows the load deformation curve for group 2 having 5 rings and a w/c ratio 0.62. From Fig 4.4 it can be seen that the unconfined specimen peak load was 370kN for 5.3mm axial deformation. For externally confined specimen peak load was 392kN for 7.1mm axial deformation. For internally confined columns peak load was 390kN for 4.9mm axial deformation. The increase or decrease in peak load and axial deformation with respect to unconfined column are shown in table 4.2

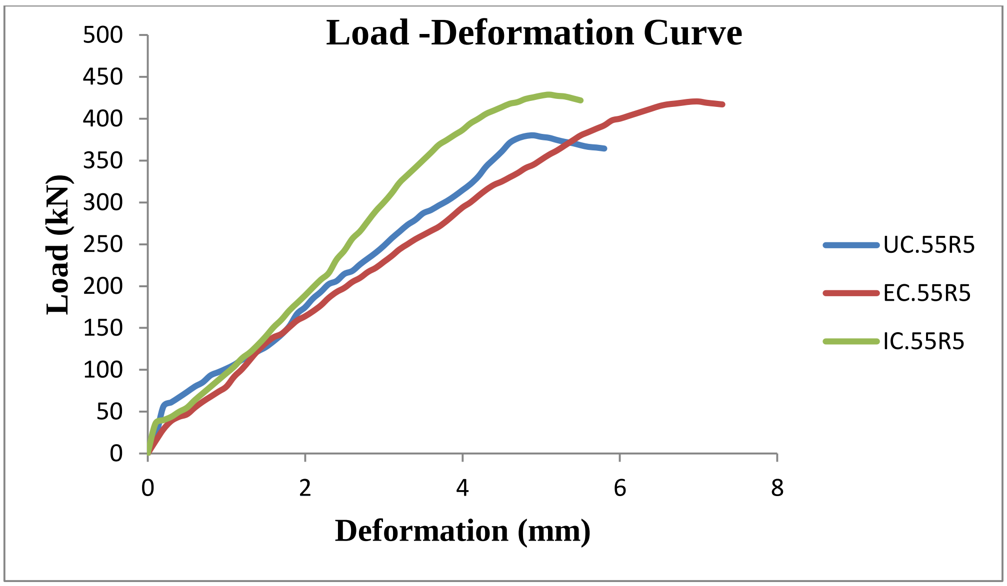

Figure 4.5 Load deformation curve for Group 2 having 0.55 w/c ratio

Figure 4.5 shows the load deformation curve for group 1 having 5 rings and a w/c ratio 0.55. From Fig 4.5 shows that unconfined specimen peak load was 384kN for 4.9mm axial deformation. For externally confined specimen peak load was 411kN for 7.1mm axial deformation. For internally confined columns peak load was 428.9kN for 5.1mm axial deformation. The increase or decrease in peak load and axial deformation with respect to unconfined column are shown in table 4.2

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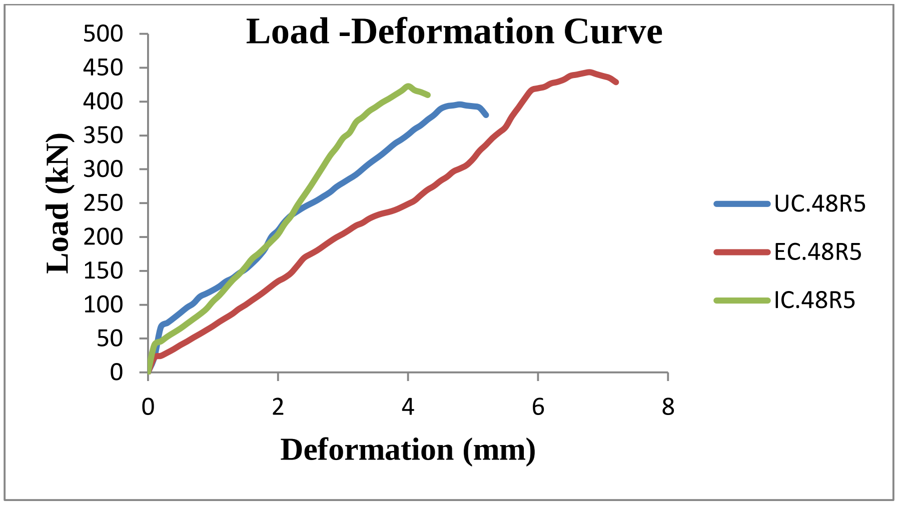

Figure 4.6 Load deformation curve for Group 2 having 0.48 w/c ratio

Figure 4.6 shows the load deformation curve for group 1 having 5 rings and a w/c ratio 0.48. From Fig 4.6 shows that unconfined specimen peak load was 405kN for 4.7mm axial deformation. For externally confined specimen peak load was 443.2kN for 6.8mm axial deformation. For internally confined columns peak load was 434kN for 4mm axial deformation.

The increase or decrease in peak load and axial deformation with respect to unconfined column are shown in table 4.2

Table 4.2 Peak load and corresponding deformation for different stirrups

W/C ratio		**Un-Confined**	**Externally Confined**	**Internally Confined**	**Increment %**	
					Externally Confined	**Internally Confined**
0.62	Deformation(mm)	5.3	7.1	4.9	+33	-7
	Load (kN)	370	392	390	+5	+5
0.55	Deformation (mm)	4.9	7	5.1	+42	+4
	Load (kN)	384	411	428.9	+7	+11
0.48	Deformation (mm)	4.7	6.8	4	+33	-7
	Load (kN)	405	443.2	434	+5	+5.
+/- shows increase and decrease in % of load capacity and deformation						

4.3 ENERGY ABSORPTION

Energy absorption of both groups were calculated and presented in table 4.3 and 4.4. It can be seen that external confinement gives high energy absorption while internal confinement gives low energy absorption as compared to unconfined ones. It can also be inferred that group 2 samples having 0.55 w/c ratio give maximum increment in energy absorption. In group 2 there is decrease in energy absorption for internally confined specimens with respect to unconfined ones.

Table 4.3 Energy absorption for group 1 samples

	Energy Absorption (Nm)				Increment %	
	Number of stirrups	**Un-Confined**	**Externally Confined**	**Internally Confined**	**Externally Confined**	**Internally Confined**
GROUP 1	4	1118	1435	899	+28	-19
	3	991	1140	876	+15	+7
	2	837	854	646	+2	-2
+/- shows increase and decrease in % of energy consumption						

Table 4.4 Energy absorption for group 2 samples

	Energy Absorption (Nm)				Increment %	
	w/c ratio	**Un-Confined**	**Externally Confined**	**Internally Confined**	**Externally Confined**	**Internally Confined**
GROUP 2	0.62	1131	1540	1227	+34	+8
	0.55	1121	1710	1174	+52	+4
	0.48	1105	1537	1077	+39	-2
+/- shows increase and decrease in % of energy consumption						

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CHAPTER 5

CONCLUSIONS

5.1 GENERAL

The columns were divided into two groups. Eighteen columns were casted for each group. In group 1 there were varying lateral reinforcements and group 2 there were casted by varying mix. Load displacements curve and energy absorption were calculated and comparisons were made. The following conclusions are drawn after the experimental investigation of confined circular column under uniaxial load testing in UTM.

5.2 CONCLUSION

- External confinement gives more axial deformation for same load capacity
- For group 1 external confinement increases the load taking capacity as it can be observed that maximum increase in peak load was for columns with 3 rings (17%).
- In group 1 by using external confinement occurrence of peak load was delayed with respect to unconfined specimens. The increment was maximum for columns with 3 rings (32%).
- In group 1 peak was obtained earlier in comparisons to unconfined ones and very low percentage increase in load taking ability.
- For group 2 maximum increases in load capacity was for w/c 0.55 when confined internally (11%).
- For group 2 with w/c 0.55 shows increase in axial deformation at peak load (42%).
- External confinement provided more ductility.

- In group 1 it was also observed that external confined column with 3 and 2 rings have similar ultimate load capacity as compared to unconfined 3 and 2 rings columns respectively.
- High increase in energy absorption for group 2 column having w/c 0.55 (52%).

5.3 FUTURE SCOPE

To enhance ultimate load capacity in large scale columns can be confined by using double or triple layer of WWM. Also diameter of wire can be increased and orientation of mesh opening can be changed i.e. using diagonal openings. Increasing the proportion of aggregate with nominal size 10mm increases concrete homogeneity which assists in achieving high increments in ultimate load capacity.

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