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Effect of Corner Radius on Compressive Response of Steel Confined Concrete

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ABSTRACT

Strengthening of Reinforced concrete structures results in much greater capacity to sustain loads. This research investigates the effect of corner radius on the compressive strength of concrete columns using steel jacket technique. Three parameters considered were the cross- sectional shape (i.e., circular, square, and rectangular), the corner radius in case of square and rectangular specimens and gauge of steel which is to be confined. Behavior and failure load of the strengthened columns were experimentally investigated on thirty specimens divided into six un-strengthened specimens and twenty-four strengthened ones. The results also indicate that the effectiveness of steel confinement decreases with an increase in sectional aspect ratio and increases with an increase in corner radius. All the confined specimens display extremely ductile behavior because of the concrete's high yielding strength, and noncircular columns effectively withstand the knife action of sharp edges. The results show that while the average ultimate axial strain is significantly underestimated by all twenty-four models, the average compressive strength of steel confined circular, square, and rectangular concrete columns is predicted correctly.

Keywords: *Circular; Compression; Confinement; Corner Radius; Steel Confined; Rectangular; Square.*

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UNDERTAKING

We, both the group members, solemnly profess that the current research work under the title "Effect of Corner Radius on Compressive Response of Steel Confined Concrete" is our own. Neither we took the already published work of someone else nor have attempted to plagiarize data from relevant sources at any stage. Whenever and wherever the relevant data is taken, it is added with required citation and proper references. This work is a result of our toiling and laborious efforts; we confidently owe all this written work.

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Before proceeding further, Firstly I praise and applause the Almighty Allah, the Most Gracious, the Omniscient, the Omnipresent, and the Sustainer, for His countless blessings and bounties.

We pay homage and feelings of gratitude, from the core of our hearts, with due respect, to Dr. Shahzad Saleem, our project mentor, supervisor, for his sincere dealings and guidance. He helped us from every possible aspect to deepen our interests and broadening our minds for the new ideas and creative thinking by making us realize our capabilities along with the desired knowledge of tackling the impending problems from different directions by using our technical as well as non-technical skills. We were remained in continuous contact with him, and every time we were guided like a caressing guardian. Each time, during the FYP tenure, whenever we were confronted with some sort of issue, we had got our problems solved right that time. The knowledge we attained, the experience we gained, and the time we spent in the journey of FYP, will always be a treasure for both of us.

Finally, we extend our chain of acclamation by adding our parents in this ambit for the continuous moral, technical, and financial support without which nothing was practicable.

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18-CE-51

DEDICATIONS

First, all our praises and dedications belong to Allah Almighty; by the will of Allah, we have completed the required milestone in our graduation. I put forward my feelings of reverence for all the teachers, my parents, my siblings, and relatives who helped us in our journey toward completion of the final year project since the very start of the work.

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CHAPTER ONE
INTRODUCTION

➢ *Background*

Strengthening of Reinforced concrete structures results in much greater capacity to sustain loads. It may be necessary to strengthen existing structures due to change in use that resulted in additional live loads (for example, change in use of the facility from residential to public or storage), construction problems during erection, deterioration of the load carrying elements, aging of structure itself or upgrading to confirm to current code requirements (seismic for example), design errors etc. Additional concrete elements may be required for these kinds of situations or to strengthen, repair and retrofit the entire structures. There are three methods of strengthening the columns include fiber reinforced polymer (FRP) jacketing, concrete jacketing and steel jacketing. It has been observed that axial capacity of the columns has been effectively increased by using the above three methods.

Results of series of experimental tests on full-scale specimens strengthened with steel caging including simulation of the beam-column joint under combined bending and axial loads was presented by Julio Garzón-Rocaet et al. Capitals were applied to every one of the examples to associate the confining with the beam-column joint either by compound anchors or steel bars. It was observed that both the failure load and ductility of the strengthened columns is increased by steel jacketing.

An experimental and theoretical study on 20 square reinforced concrete columns retrofitted with steel jacket technique was performed by Khair Al-Deen Isam Bsisu. Concentric axial loading was applied on all the tested specimens. Khair Al-Deen Isam Bsisu observed that compressive strength of the specimen was increased two times by using this technique (steel jacketing). The ductility of the column was also increased by steel jacketing of concrete specimens.

A rational design method to proportion the steel cage considering its confinement effect on the concrete column was presented by Pasala Nagaprasad et al. A trial study was done to confirm the adequacy of the proposed plan strategy and itemizing of steel confine secures inside potential plastic pivot areas. Under combined cyclic and axial loads, the compressive strength of the specimens was increased by steel caging techniques without using any binder material in the gap between concrete column and steel angles. This method gave more effective and accurate results.

Rosario Montuori et al. introduced a hypothetical model to foresee the second bend conduct of RC sections bound by points and secures and the approval of the proposed model by results from test testing on 13 examples tried under hub force. It was inferred that hypothetical model showed a decent capacity to anticipate the conduct of segments reinforced with points and secures as far as both disfigurement and obstruction.

It has been finished up from different exploration concentrates on that confinement of fiber built up polymers FRP composites can essentially work on the strength and flexibility of plain and supported substantial segments. Different exploratory examinations have been directed for the assurance of compressive conduct of substantial segments by utilizing various techniques for confinement, for example, steel jacketing and fiber reinforced polymers (FRP) repression which incorporates CFRP, GFRP and AFRP controls and so on. In the beginning phases of retrofitting, steel and cement jacketing was broadly utilized for confinement of substantial sections. Be that as it may, these repression materials had a few major issues including their actual properties, for example, significant burden and so on, erosion issues, augmenting the section sizes and long projecting period because of their relieving prerequisites. With the progression of time, these materials were supplanted by FRP which around settled the above examined issues of steel and cement jacketing. A portion of these FRP is being clarified further. Carbon fiber supported polymers (CFRP) composites were utilized since the mid-1980s. In the field of retrofitting, CFRP composites have shown high proficiency in the confinement of cement because of their high modulus of flexibility, lighter weight and simple method of establishment. Test review was additionally led for the assurance of impacts of glass fiber supported polymers (GFRP) composites imprisonment on compressive conduct of pivotally stacked substantial segments by utilizing angle proportion, calculation of cross area and number of layers of GFRP as examination boundaries. From the review, it was reasoned that the heap conveying limit of segments diminished by expanding the viewpoint proportion and expanded by expanding the quantity of layers. Exploratory outcomes were additionally gotten with regards to the pressure strain conduct of round and non-roundabout substantial sections polyethylene terephthalate (PET) fiber supported polymer (FRP). The boundary considered in this study were cross sectional shape, the corner span in the event of rectangular and square segment and the quantity of FRP layers. PET for FRP showed high proficiency in the improvement of compressive strength and strain of segments by expanding either the sectional perspective proportion or the corner span. Dissimilar to the next FRP material, the PET FRP gave trilinear connection between compressive anxiety of substantial segments.

➢ *Comparison Between FRP and Steel Jacketing*

The selection of a particular type of retrofitting technique depends upon the availability of the materials used for retrofitting, ductility, cost, and the weight increased by retrofitting materials.

Nowadays, the FRP is widely used across the world. But we work on steel jacketing because for our condition it is suitable for the following reasons.

- Materials for steel jacketing are locally available as compared to FRP.
- Due to the local availability of steel, steel jacketing is more economical than FRP.
- Steel is more ductile than FRP. So steel is preferred because it gives warning before failure.
- We used light weight steel jackets, so the dead weight of the structure does not increase too much.

➢ *Problem Statement*

Despite of all the advantages of FRP, FRP is not locally available in developing countries. Therefore, FRP have more cost as compared to steel confinement materials. We chose steel confinement over FRP due to less research available on it and the most important reason is economy. In our research, our prime focus is to observe the effects of cross-sectional shape, corner radius and steel gauge on steel confined concrete.

➢ *Objectives of the study*

Following are the main objectives of the study:

- To study the effect of steel confined concrete on compressive strength.
- To study the effect of corner radius, cross-sectional shape, and ductility on steel confined concrete.
- To study the failure modes of steel confined concrete.

➢ *Research Methodology*

An efficient philosophy, from choice of materials to the research center execution, has been created which is important for moving toward the most OK outcomes for any of the trial program. This part is isolated into three stages: In the absolute First Phase literature, review will be the super concerned region, in the Second Phase sample preparation and testing will be the practicable region, Third Phase is about data collection and compilation.

- *Phase I: Literature Review*

In the very first phase, we will overview of the previously published works on effect of corner radius on compressive strength of steel confined concrete. A literature review also includes a critical evaluation of the material; therefore, it is called a literature review.

- *Phase II: Sample Preparation and Testing*

The second phase of the study comprises of sample preparation, experimental program, and the testing details. Material which has selected is now be utilized in the preparation of samples; afterward, different tests will be performed by using these prepared samples. We test the specimens by using universal testing machine (UTM).

- *Phase III: Data Collection and Compilation*

This piece of the examination for the most part manages the assortment of information and accumulation of the information into a methodical structure. When every one of the experiments gets played out, the following stage is to gather the mathematical and hypothetical information from these trials, at last, the outcomes are extricated from these mathematical and hypothetical discoveries. Initially, the experiments were performed then the information is gathered from a different spectator.

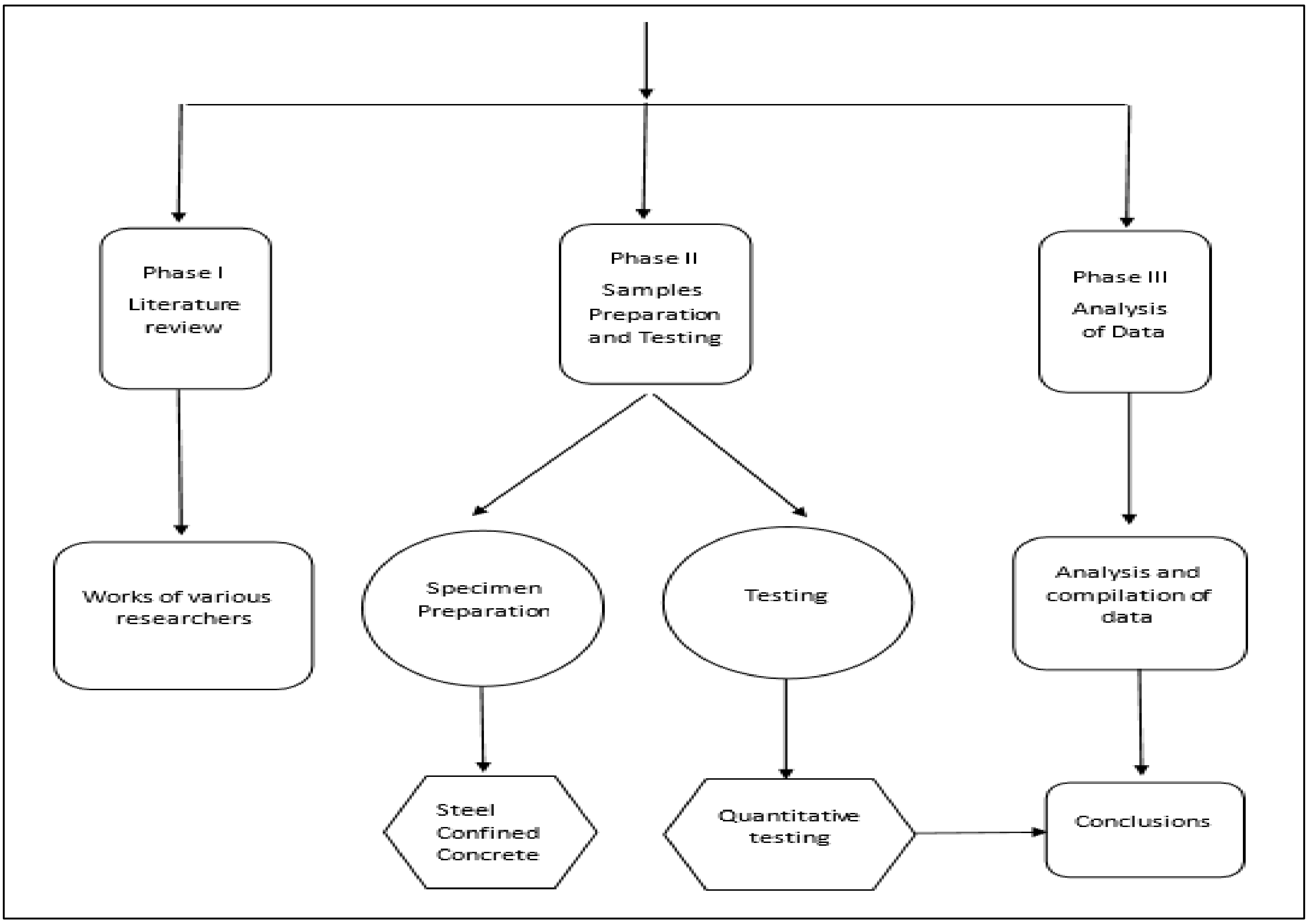

Fig 1 Research Methodology

CHAPTER TWO
LITERATURE REVIEW

➢ *Research Work by Ali Hameed Naser Almamoori, Fatimah H. Naser, Mohammed K. Dhahir (1)*

They have checked the effect of section shape on the behavior of thin-walled steel columns filled with light weight aggregate concrete.

- *Experimental Program*

The specimens consisted of 19 CFST (Concrete filled steel tubular columns) columns, 16 of which had special shape cross-sections such as triangle, elliptical, rectangular round-ended, hexagon, octagon, L-shape, square with round corners, rhombic, T-shape, plus-shaped, pentagram, semi-circular, 1/4 circular, D-shaped, hexagonal asymmetric, and fan-shaped, and the remaining 3 were circular, square, and rectangular for comparison purposes Because all pieces were made of mild steel plate with a thickness of 2 mm, they were planned to have roughly the same outside perimeter (P), and hence roughly the same cross-sectional area. However, each portion will have a varied cross-sectional area of concrete because of this.

The axial compressive loads from the loading chamber were transferred to the specimen via a 20 mm thick steel plate at the bottom. One longitudinal dial gauge and two transverse dial gauges were mounted at the bottom plate to acquire the axial and lateral deformations of the CFST column.

- *Results*

The results revealed that all the CFST columns collapsed owing to outward local buckling around the mid-height of the column due to the crushing of the light-weight concrete core, with further local buckling near the extremities of the column during the last phases of loading. Furthermore, the findings revealed that when the number of steel plates welded together to create the section grows, the section becomes more stable and may accomplish greater confinement. In general, the load–lateral deformation relationship was unaffected by the shape of the cross section.

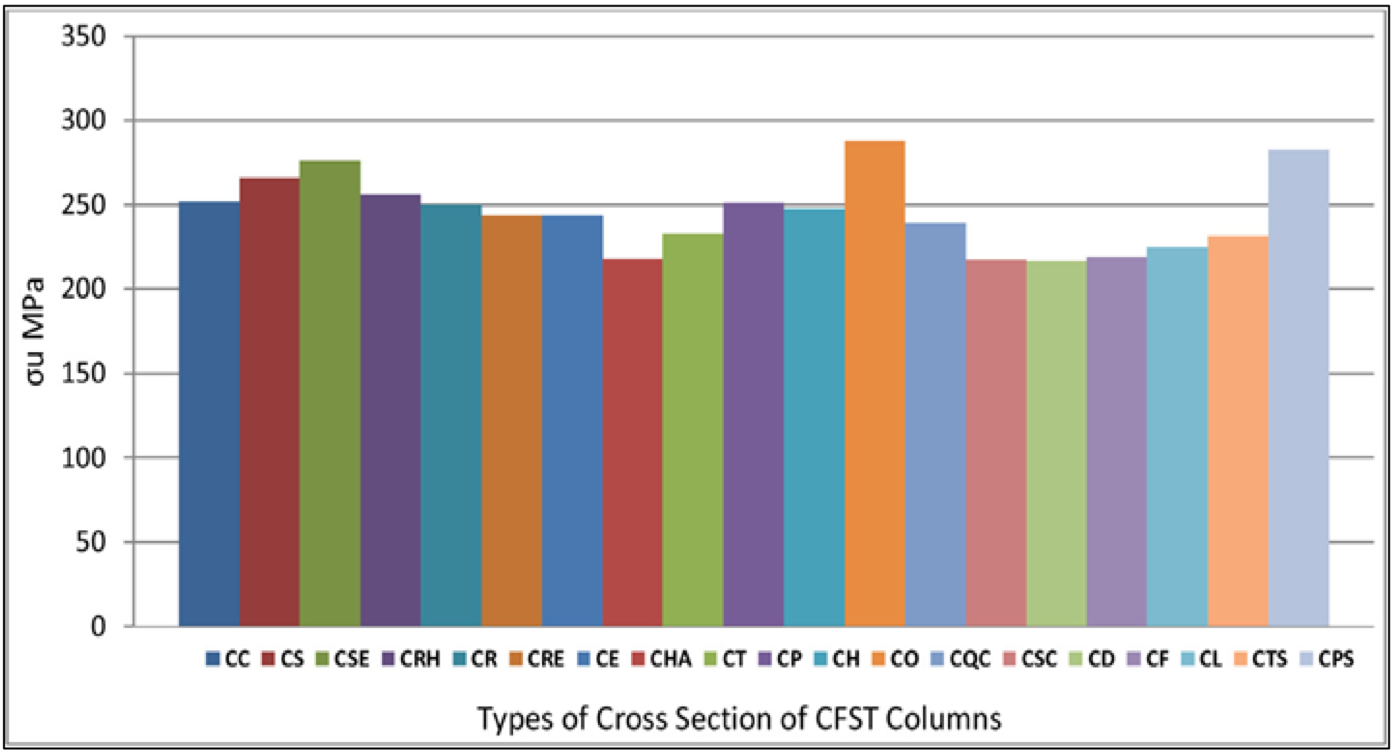

Fig 2 Ultimate Stress of Different-Shaped CFST Columns

➢ *Research Work by H Farooq, M Usman, K Mehmood, M S Malik, A Hanif (2)*

H Farooq, M Usman, K Mehmood, M S Malik, A Hanif worked on steel strips as well as steel jackets as retrofitted material.

- *Experimental Program*

The laboratory testing of strengthened short columns with the shape of 152.4 x 152.4 x 355.6 mm with 4#3 longitudinal bars and 3#2 ties @ 100 mm c/c with 25 mm cover is the focus of this research. In the laboratory, specimen columns were prepared for compression testing using a universal testing machine. Six short columns were created in all. Two examples were reference specimens, two were fortified with steel strips, and two were strengthened with steel jackets out of a total of six specimens.

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The examples were made with a 1:2:4 cement-sand-aggregate mixture with a w/c ratio of 0.55, and the mechanical parameters of the material are listed in table 2. A vibratory compactor was utilised to accomplish uniform compaction to the best possible level. After a 28-day moist curing period, samples were removed from the curing tank and placed in the laboratory under normal temperature and moisture conditions until their surfaces dried. The materials were put to the test in the concrete lab of Pakistan's Military College of Engineering Risalpur. The jacketing of the columns was done using galvanised steel sheet. Steel strips and steel jackets were made from the same 17-gauge steel with a thickness of 1.41 mm for both categories. Steel strips had a cross-sectional dimension of 50.8 x 1.41 mm. Hilti-Impact Anchors were used to secure the steel strips all around the columns. Each anchor was capable of withstanding a force of 0.25 KN. These anchors measured 45mm in length and 6mm in diameter. Six columns with the same aspect ratio and a height of 355.6 mm were created.

- *Results*

Steel strip restricted columns failed at a 54 percent higher rate than un-strengthened columns, and jacket strengthened columns at a 138 percent higher rate.

The proportion of the increase in strength with the degree of confinement illustrates that increasing the amount of confinement has a considerable impact on load carrying capability. The cracking stress (the stress at which the first crack in the masonry emerged during loading) and strain for reinforced columns have both increased significantly. The cracking stress for strengthened columns increases by a factor of 1.5 for SSC (Strip strengthened column) and 2.66 for JSC (Steel jacket strengthened column) column specimens when compared to specimen RCC.

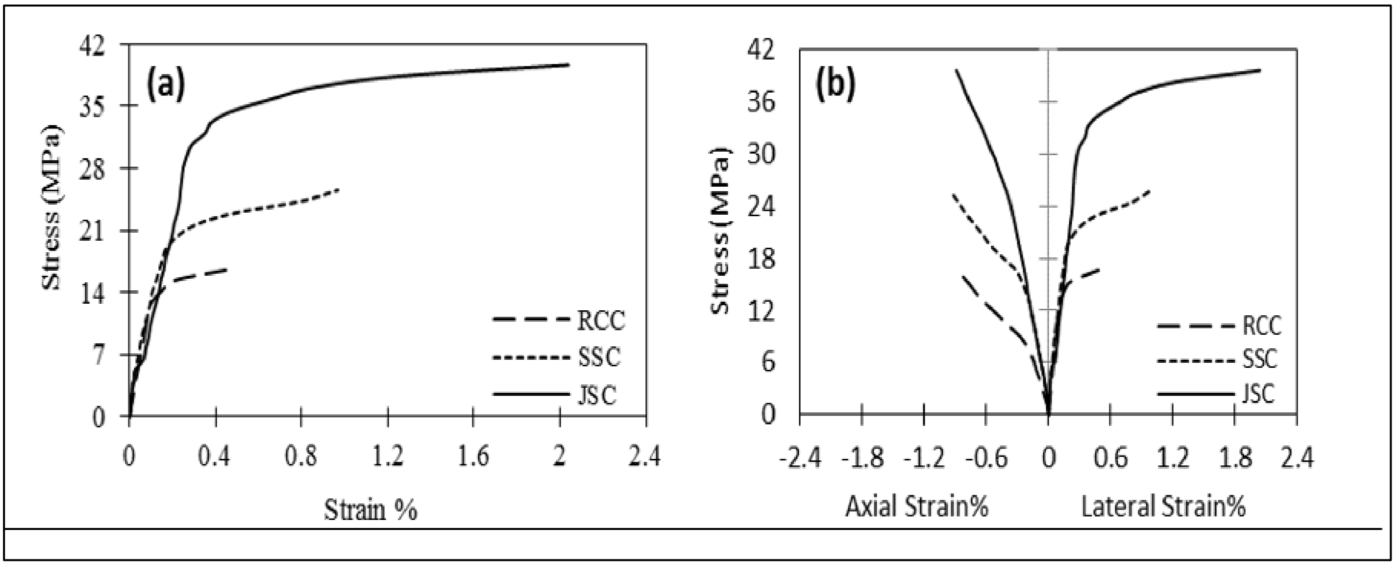

Fig 3 (A) Stress-Vertical Strain in Concrete and (B) Axial Stress Versus Axial and Lateral Strains

➢ *Research Work by Miscellaneous Researchers (3)*

Abhishek Jodawat1, Arihant Parekh, Bhushan Marathe, Ketan Pawar, Sunny Patwa, Yash Sahu1, Indrajeet Jain also worked on steel retrofitted concrete by using angles and battens as a retrofitting material.

- *Experimental Program*

When steel jacketing is employed as a retrofitting material for Reinforced Concrete Columns, Abhishek Jodawat1, Arihant Parekh, Bhushan Marathe, Ketan Pawar, Sunny Patwa, Yash Sahu1, Indrajeet Jain found better characteristics. The purpose of the study was to investigate the behavior of RC columns as well as RC columns that had been modified with steel jacketing systems, either angle batten or full plate systems. Under axial load, the performance of regular RC columns and retrofitted RC columns for various specimens. Experimental studies are used to evaluate and analyze the performance and behavior of various specimens. The strength return for undamaged and preloaded specimens was demonstrated in experimental research. 85 percent of the failure load is applied to the preloaded specimen.

The RC column is cast in four phases with correct standards, and the cubes are cast to guarantee the required or goal strength is met. During each stage, standard cubes of 150x150x150 are cast. The average strength is calculated using the three samples. The cubes are cured for 28 days in a water bath.

For the angle battening system and full plate system for the loading case of 85 percent and intact cases, as well as for original columns, the retrofitted specimens are tested under axial loading. To measure the impact of strengthening on carrying capacity, the specimens are loaded until they fail.

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- *Results*

✓ Intact specimens retrofitted with angle batten and complete plate systems increased their strength by 32% and 22%, respectively.
✓ The strength of an 85 percent loaded specimen retrofitted with an angle batten system and a full plate system is enhanced by 16 percent and 6%, respectively.
✓ The lateral deflection is enhanced by 9% and 11%, respectively, for 85 percent loaded specimens retrofitted with angle batten and full plate system.

➢ *Research Work by Samoel Mahdi Saleh (4)*

He worked on size effect on the load carrying capacity of normal and lightweight concrete filled square steel tube composite columns.

- *Experimental Program*

In this research, 9 column specimens of square Steel Hollow Sections (SHS) were constructed for axial compression testing. These column specimens were categorized into 3 groups, each with 3 specimens. The first group's specimens were filled with normal concrete, whereas the second group were filled with lightweight concrete. The third group specimens were evaluated as bare steel sections for comparison.

Under the action of incremental monotonic loading, all column specimens were evaluated with a high degree of accuracy using a universal testing machine with a capacity that can be adjusted from 20 to 200 tons.

- *Results*

During the testing, one of the most important observations was that all the column specimens displayed the same form of failure, which was local buckling at the top or bottom of the column. This observation could lead to the conclusion that the size of the specimen has no bearing on the failure manner. The load carrying capability of the concrete filled steel tubes (CFST) specimens was greatly improved as compared to that of the naked hollow steel tubes (SHS) specimens, regardless of the kind of concrete used for fill, whether normal or lightweight concrete.

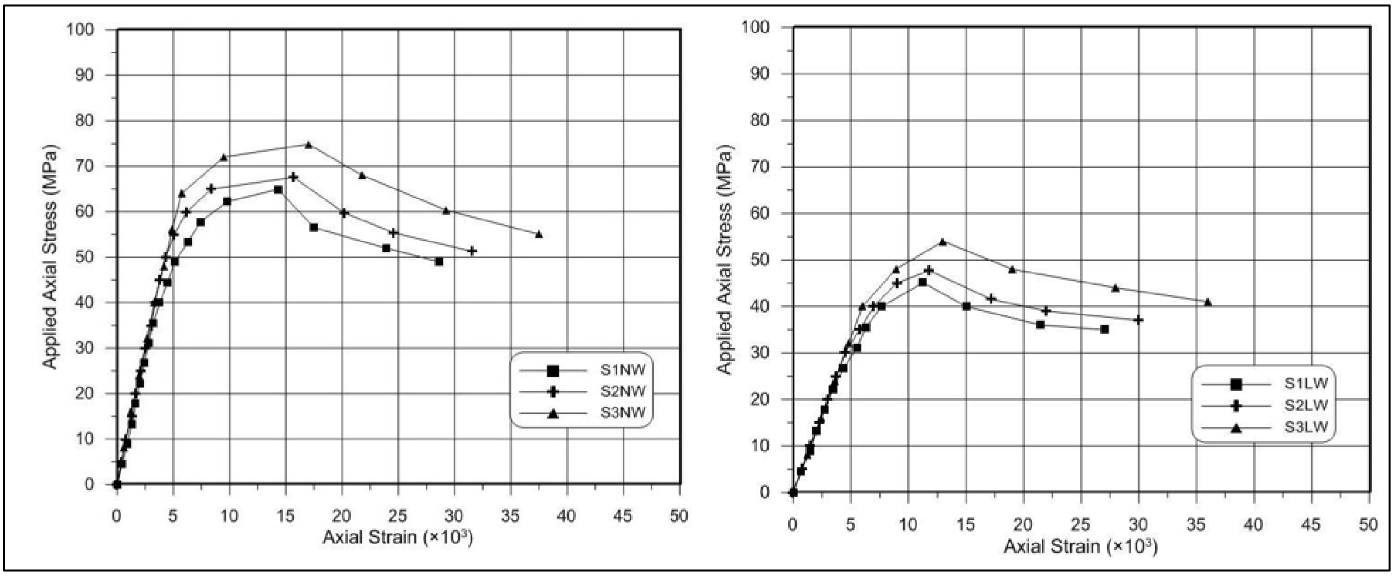

Fig 4 (A) Structural Response of Column Specimens Filled with Normal Concrete (B) Structural Response of column Specimens Filled with Lightweight Concrete

➢ *Research work by Halil Sezen, M. ASCE; and Eric A. Miller (5)*

Halil Sezen, M. ASCE; and Eric A. Miller worked on steel retrofitted concrete.

- *Experimental Program*

15 column specimens with nonseismic reinforcement features were built, strengthened, and tested as part of the experimental program. The geometrical and material features of all 15 bare or unretrofitted columns, which represented existent columns, were similar. BASE, a bare column, was used as a reference or control specimen with no strengthening. The remaining 14 naked columns were reinforced using a variety of techniques, as detailed below.

The bare or unretrofitted specimens measured 152 mm (6 in.) in diameter and 762 mm (30 in.) in height. The columns were reinforced longitudinally with six No. 10M (No. 3) deformed steel bars (ASTM 2008). As transverse spiral reinforcement, smooth 6.4

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mm (1/4 in.) diameter wire was employed. The spiral reinforcement pitch or spacing was 76 mm (3 in.), which is the ACI Code's upper limit for spiral spacing (ACI 2008). The transverse steel volumetric ratio offered is 0.013, which is somewhat higher than the ACI Code's minimum volumetric ratio for columns with nonseismic features. In addition, following ACI Code, 1.5 extra turns of spiral reinforcement were added to each column end to prevent end failure. The spiral reinforcement had an exterior diameter of 127 mm (5 in.) and a clear concrete cover of 12.7 mm (1/2 in.) for a total specimen diameter of 152 mm (6 in.).

All specimens were subjected to a monotonically increasing concentric axial load using an actuator with a capacity of 4,890 kN (1,100 kips).

Two 152 mm (6 in.) diameter bare columns were jacketed with steel tubes with an exterior diameter of 219 mm (8 5/8 in.) and a thickness of 4.95 mm (0.195 in.). The steel tube has yield and ultimate strengths of 460 MPa (66.7 ksi) and 501 MPa (72.6 ksi), respectively. Concrete was used to fill the 31 mm (1.22 in.) gap between the existing column and steel tube, which had a compressive strength of 22.5 MPa (3260 psi) on the day of testing. Inside concrete jackets, the same concrete was used.

- *Results*

Both steel-jacketed columns underwent local buckling around the specimens' midheights at very significant axial displacements, which finally led to global buckling. Steel jacketing greatly improved both columns' initial stiffness, strength, and deformation capacity. Steel jacketing was quite efficient in providing radial confinement to the concrete when the axial load was put exclusively on the base column cross section and not on the steel tube itself, though not s effective as in specimen C-CFT (in specimen CFT).

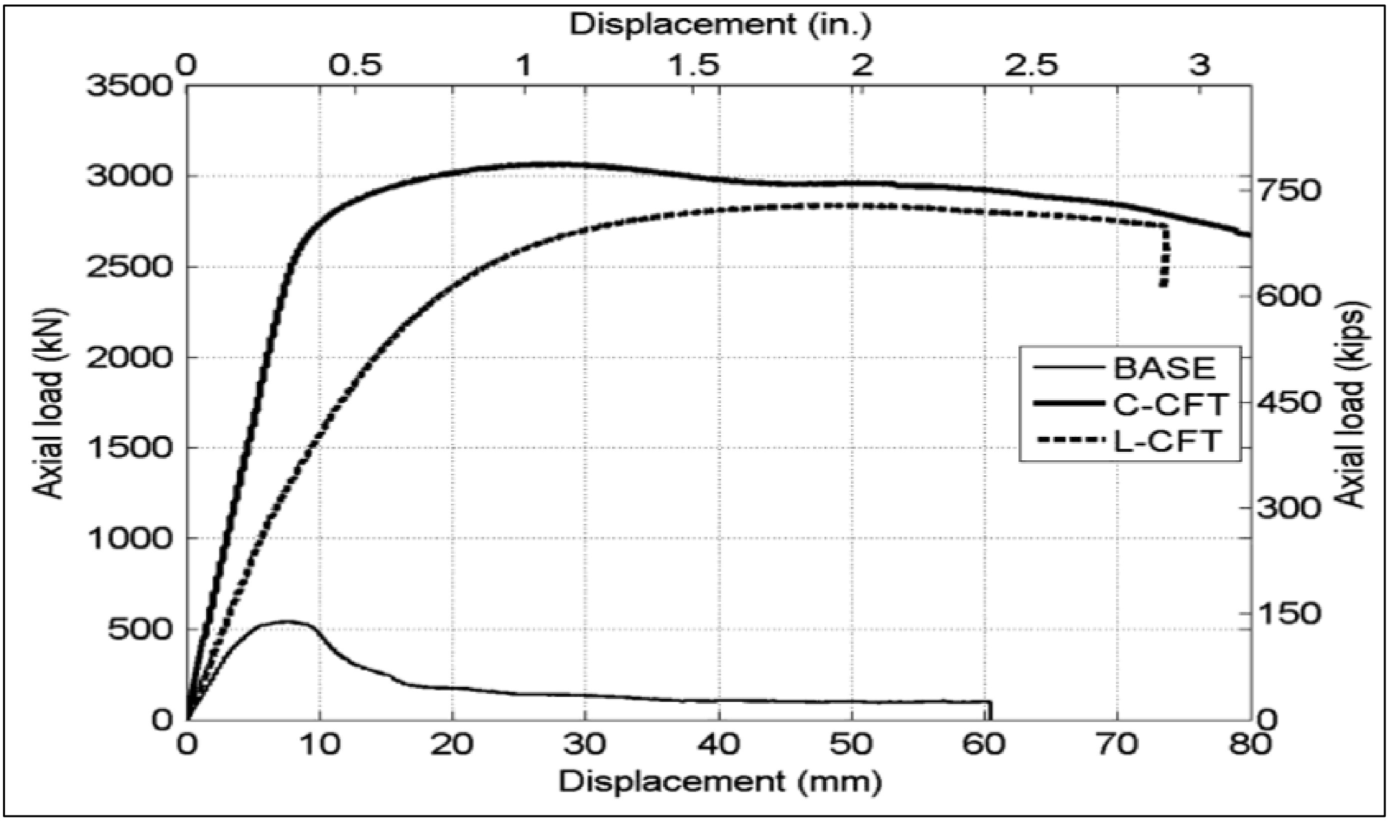

Fig 5 Axial Load-Displacement Relations for the Reference Specimen and Steel-Jacketed Specimens

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CHAPTER THREE
EXPERIMENTAL PROGRAM

- *Introduction*

In this chapter, the focus will be on the sample and material selection, sample preparation, testing, and experimentation. Keeping in view the different tests that will have to be performed, within the circumference of the undergoing study. Selection of a material is defined as picking up the material, which complies with all the specifications and requirements, needed to be fulfilled for testing purposes.

- *Preparation of Specimens*

The specimens were collected from batch plant. Ready mix concrete is used to prepare the specimens. Ready-mix concrete is concrete that is manufactured in a batch plant, according to each specific job requirement, then delivered to the job site "ready to use". The average 28-day compressive strength of concrete obtained from testing three unconfined concrete cylinders from each batch was 30 MPa. Two identical unconfined control specimens were made for each size and cross-sectional shape, and they were tested alongside their confined counterparts to determine their unconfined compressive strength.

Fig 6 Preparation of Specimens

The steel gauge used to confine the specimens were gauge no. 16 and 20. Gauge no. 16 steel have a thickness of 1.6 mm and gauge no. 20 steel have a thickness of 0.9 mm. 16- and 20- gauge steel are A36 mild carbon steel alloys. Common structural steel in U.S.A. Minimum yield of 250 MPa and ultimate tensile strength of 400-550 MPa.

Fig 7 Steel Casing

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➢ *Experimental Program*

In this study, 30 specimens were tested under monotonic axial compression, of which 24 specimens were confined. The variables of this study were the cross-sectional shape (i.e., circular, square, and rectangular), corner radius (0 and 21 mm) in case of square and rectangular (aspect ratio 1.5 and 2) specimens, and the gauge of steel (16 and 21). The details of the specimens are shown in Fig. 3.3 and Table 3.1. The height of all specimens was 300mm. For each column, two identical specimens were prepared. For square and rectangular specimens, the cross-sectional area was kept almost constant to study better the effect of cross-sectional aspect ratio. For rectangular specimens, an aspect ratio of 1.5 and 2 is selected. The square and rectangular specimens were cast in molds made of plywood sheets with 0- and 21-mm corner radius in the cross section, in which 0 mm represents no corner rounding and 21 mm represents a well-rounded corner.

The specimens are labeled as XaYbZc, in which "X" is the aspect ratio (R for aspect ratio), with the subscript "a" showing the numerical value of the aspect ratio (i.e., 1, 1.5 and 2); "Y" represents the gauge of steel (G for gauge), with the subscript "b" showing gauge no. of steel (i.e., 0, 16, and 20); and "Z" represents the corner radius (C for radius), with the subscript "c" value of corner radius (i.e. 0 and 21 mm). For example, R1G16C21 indicates that it is a square column with 16 no. gauge steel wrapped and a corner radius of 21 mm.

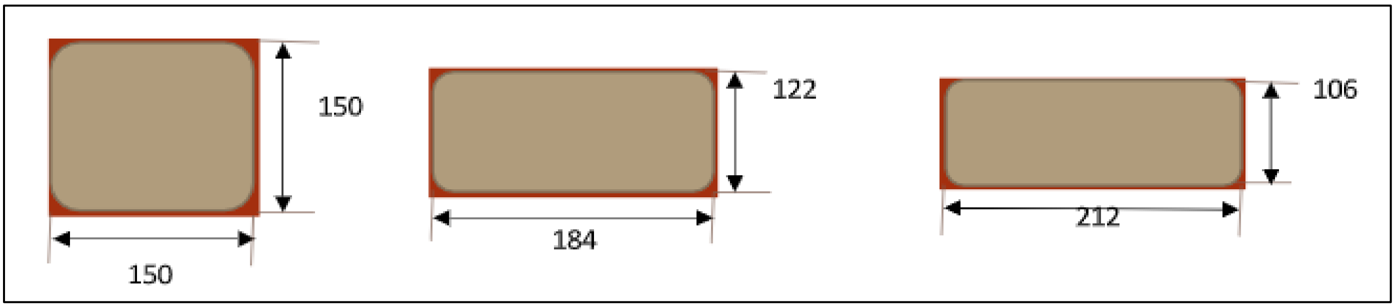

Fig 8 Details of Cross-Sectional Dimensions (all Dimensions are in Millimeters)

Table 1 Details of Test Specimens

Specimen	Dimension (mm)	Aspect Ratio	Corner Radius (mm)	Steel Gauge No
R1G0C0	150 X 150 X 300	1	0	0
R1.5G0C0	184 X 122 X 300	1.5	-	-
R2G0C0	212 X 106 X 300	2	-	-
R1G20C0	150 X 150 X 300	1	0	20
R1G20C21	-	-	21	-
R1G16C0	-	-	0	16
R1G16C21	-	-	21	-
R1.5G20C0	184 X 122 X 300	1.5	0	20
R1.5G20C21	-	-	21	-
R1.5G16C0	-	-	0	16
R1.5G16C21	-	-	21	-
R2G20C0	212 X 106 X 300	2	0	20
R2G20C21	-	-	21	-
R2G16C0	-	-	0	16
R2G16C21	-	-	21	-

Fig 9 Pictures of Specimens

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- ***Testing***

In this study, all the specimens were instrumented with linear variable differential transducer (LVDT) to measure the axial displacement. The LVDT can measure displacement up to 20mm. We connected the LVDT to universal testing machine (UTM). MCC8 module was used in computer. Different inputs like displacement rate, sensitivity, target displacement etc. were provided to MCC8 module. To apply the load on concrete core only, rectangular steel plates were placed at both the top and bottom ends of the specimens. The loading was applied at a constant displacement rate of 0.5 mm/min for unconfined specimens, whereas confined specimens were subjected to a displacement rate of 1 mm/min, owing to the higher expected axial deformations. This difference in loading rates has a negligible effect on the response of confined concrete. The specimens were loaded until the final rupture failure in case of unconfined concrete whereas in case of confined specimens, the specimens were tested 2 times both times they were loaded up to 20 mm axial displacement. Data from the LVDT and load cell were recorded in computer. Graph between load and displacement were also drawn in MCC8 module.

Fig 10 Universal Testing Machine (UTM)

Fig 11 Testing of Specimen

- ***Summary***

In chapter 3, firstly, the specimens were prepared for testing phase. Then testing was performed. Results were gathered in tabular form so that the behavior can easily be predicted by just having a gentle look at these tables.

CHAPTER FOUR
RESULTS AND DISCUSSION

In this chapter we have presented the experimental results which includes the peak, post strength and failure mode of the specimens. We have discussed the reasons of the failure mode of the specimens.

Table 2 Results of Test Specimens

Specimen	Unconfined Strength (kN)	Peak Strength (kN)	Failure Load (kN)
R1G0C0	671	-	-
R1.5G0C0	576	-	-
R2G0C0	563	-	-
R1G20C0	-	793	525
R1G20C21	-	918	605
R1G16C0	-	881	588
R1G16C21	-	1037	749
R1.5G20C0	-	877	403
R1.5G20C21	-	848	493
R1.5G16C0	-	816	575
R1.5G16C21	-	1036	647
R2G20C0	-	815	584
R2G20C21	-	912	505
R2G16C0	-	875	637
R2G16C21	-	974	672

➢ *Effect of Steel Gauge on Compressive Behavior of Steel Confined Concrete*

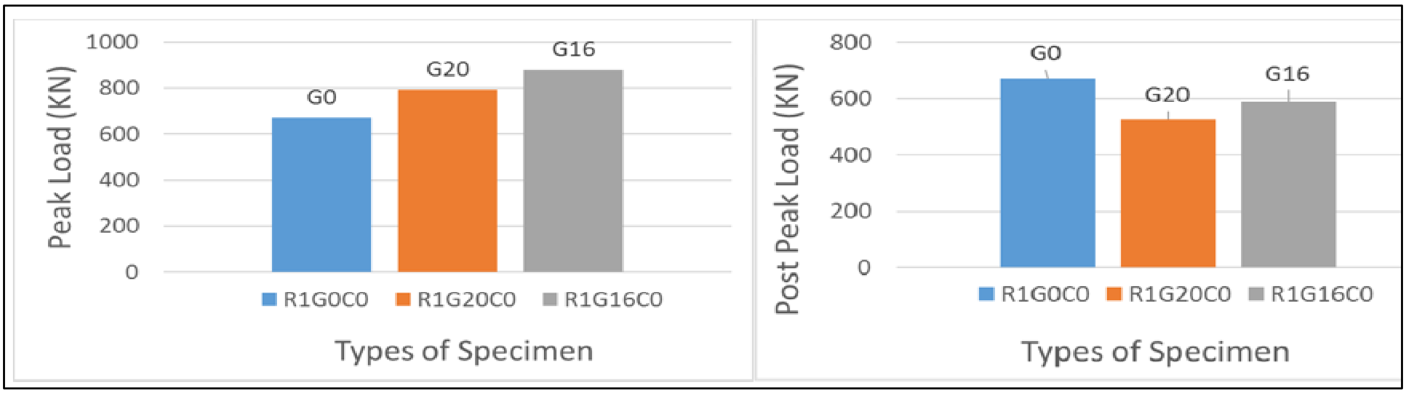

Fig 12 Comparison of Peak and Post Peak Load of Specimens Having Aspect Ratio (R) =1 with no Chamfered Edges

Graph 12 is showing the effect of steel gauge on compressive response by keeping all other parameters (Corner radius, Aspect ratio) same. The results showed that the peak and failure load is increased by decreasing the gauge number. The peak strength of G16 and G20 confined specimens is increased by 31% and 18% of the unconfined specimen strength respectively. Whereas the failure load of G16 and G20 confined specimens is decreased by 12% and 22% of the unconfined strength respectively.

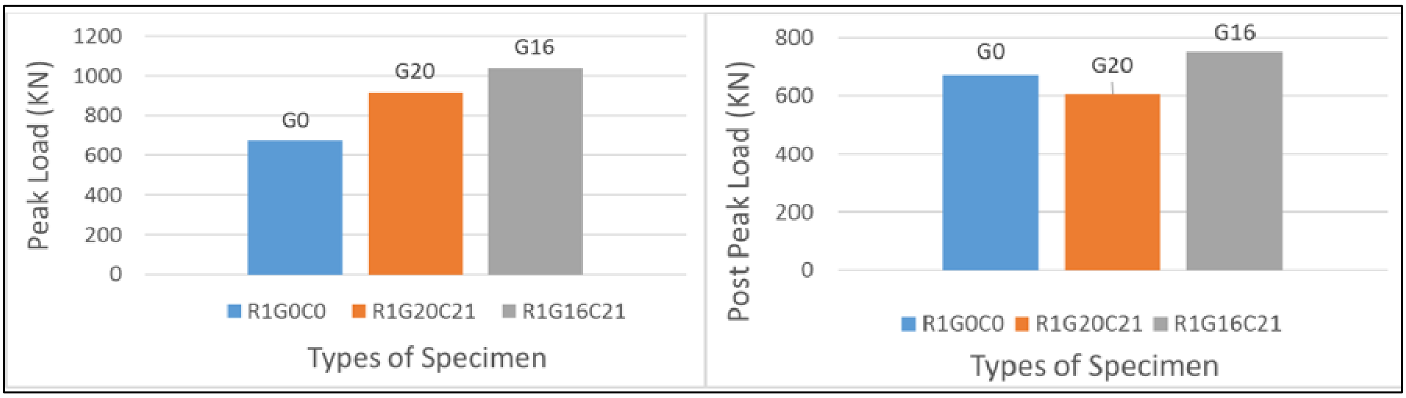

Fig 13 Comparison of Peak and Post Peak Load of Specimens Having Aspect Ratio (R) =1 with Chamfered Edges

Graph 13 is showing the effect of steel gauge on compressive response by keeping all other parameters (Corner radius, Aspect ratio) same. The results showed that the peak and failure load is increased by decreasing the gauge number. The peak strength of G16 and G20 confined specimens is increased by 55% and 37% of the unconfined specimen strength respectively. Whereas the failure load of G16 and G20 confined specimens is 12% increased and 10% decreased of the unconfined strength respectively.

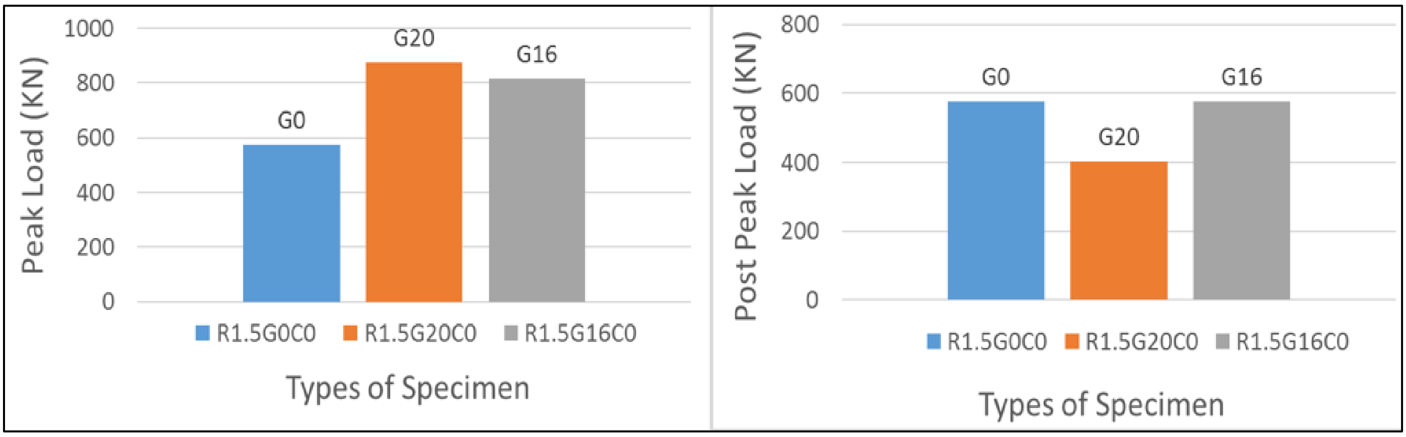

Fig 14 Comparison of Peak and Post Peak Load of Specimens Having Aspect Ratio (R) =1.5 with no Chamfered Edges

Graph 14 is showing the effect of steel gauge on compressive response by keeping all other parameters (Corner radius, Aspect ratio) same. The results showed that the peak and failure load is increased by decreasing the gauge number. The peak strength of G16 and G20 confined specimens is increased by 42% and 52% of the unconfined specimen strength respectively. This is violating the general trend, the possible reasons for this behavior could be good compaction of concrete or grouting is not properly done. Whereas the failure load of G16 and G20 confined specimens is decreased by 0.17% and 30% of the unconfined strength respectively.

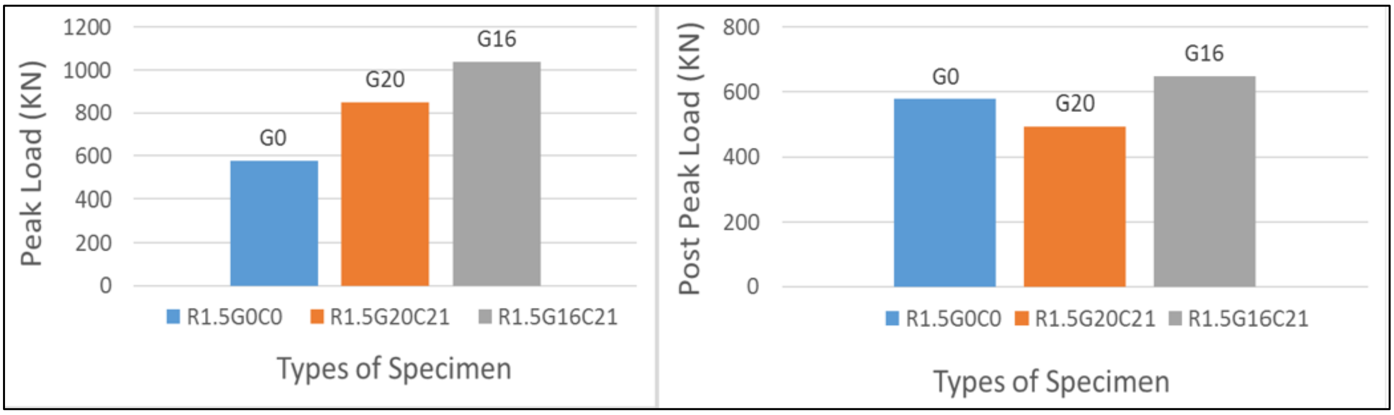

Fig 15 Comparison of Peak and Post Peak Load of Specimens Having Aspect Ratio (R) =1.5 with Chamfered Edges

Graph 15 is showing the effect of steel gauge on compressive response by keeping all other parameters (Corner radius, Aspect ratio) same. The results showed that the peak and failure load is increased by decreasing the gauge number. The peak strength of G16 and G20 confined specimens is increased by 80% and 47% of the unconfined specimen strength respectively. Whereas the failure load of G16 and G20 confined specimens is 12% increased and 14% decreased of the unconfined strength respectively.

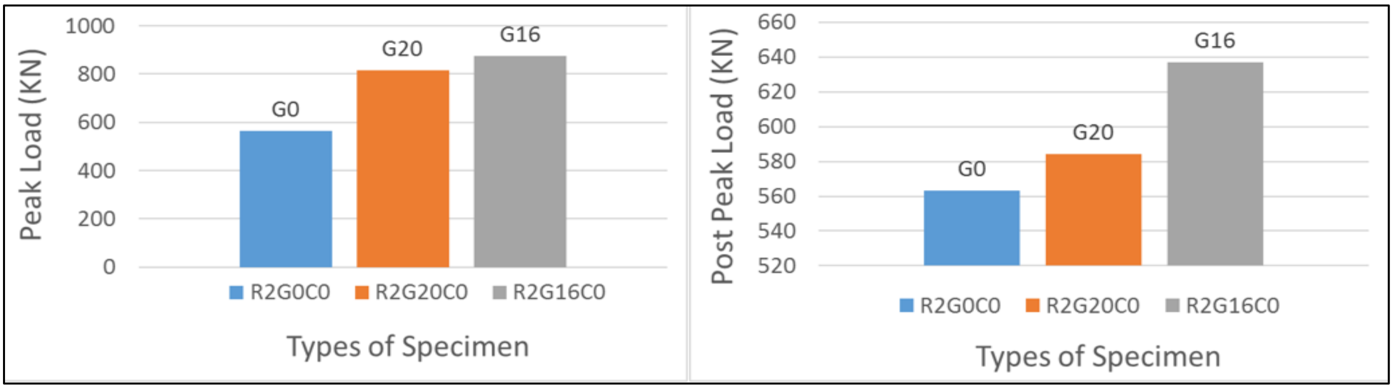

Fig 16 Comparison of Peak and Post Peak Load of Specimens Having Aspect Ratio (R) =2 with no Chamfered Edge

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Graph 16 is showing the effect of steel gauge on compressive response by keeping all other parameters (Corner radius, Aspect ratio) same. The results showed that the peak and failure load is increased by decreasing the gauge number. The peak strength of G16 and G20 confined specimens is increased by 55% and 45% of the unconfined specimen strength respectively. Whereas the failure load of G16 and G20 confined specimens is increased by 13% and 4% of the unconfined strength respectively.

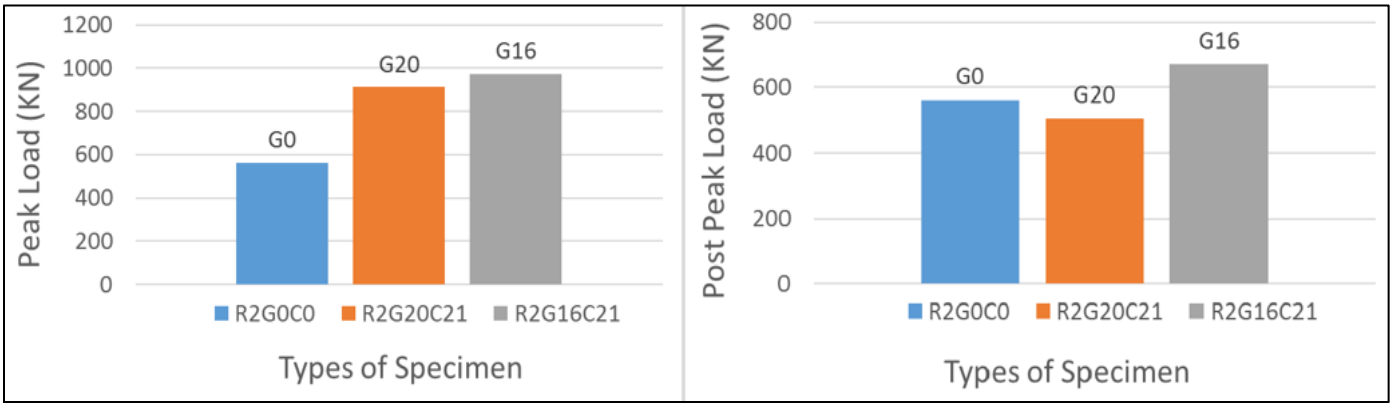

Fig 17 Comparison of Peak and Post Peak Load of Specimens Having Aspect Ratio (R) =2 with Chamfered Edges

Graph 17 is showing the effect of steel gauge on compressive response by keeping all other parameters (Corner radius, Aspect ratio) same. The results showed that the peak and failure load is increased by decreasing the gauge number. The peak strength of G16 and G20 confined specimens is increased by 73% and 62% of the unconfined specimen strength respectively. Whereas the failure load of G16 and G20 confined specimens is 19% increased and 10% decreased of the unconfined strength respectively.

Fig 18 Effect of Different Steel Gauges on Specimens After Loading

In unconfined specimens, the tensile microcracks parallel to the path of loading was observed which did not have an impact on reducing strength. Then shear fractures begin at the corners and connect with tensile cracks caused macrocracks and a loss in strength. Then the specimens deformed laterally, and following macrocracks, the specimens separated into two crashed and two bearing zones. Whereas in confined specimens, the initiation of cracks was at corner due to stress concentration and buckling of steel jacket was observed.

- *Effect of Aspect Ratio on Compressive Behavior of Steel Confined Concrete*

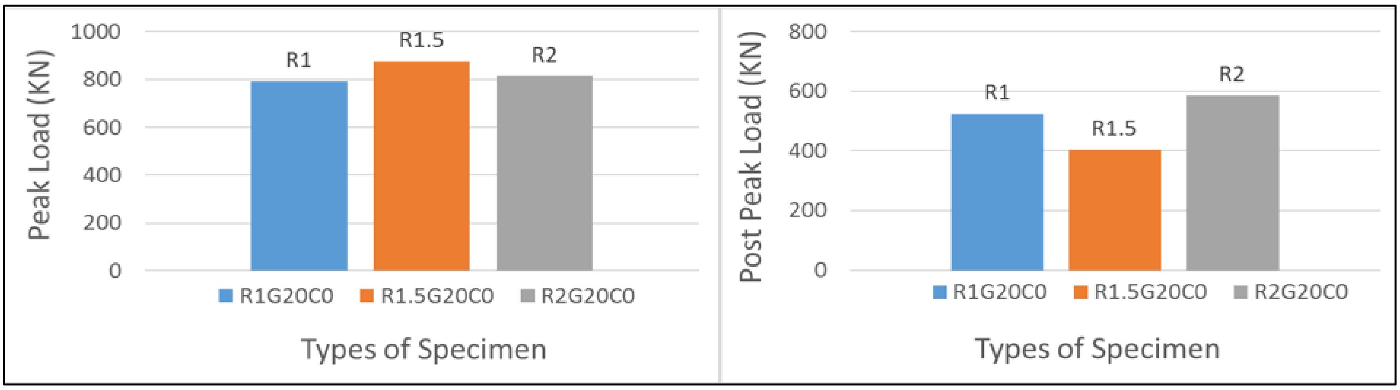

Fig 19 Comparison of Peak and Post Peak Load of Specimens Confined with Gauge 20 Steel Plate and Have no Chamfered Edges

Graph 19 is showing the effect of aspect ratio on compressive response of concrete by keeping all other parameters (Gauge, Corner radius) same. General trend is that the peak strength and failure load are decreased with the increase in aspect ratio. The peak strength of R1.5 and R2 confined specimens is increased by 11% and 3% of the R1 confined specimens' peak strength respectively. Whereas the failure load of R1.5 and R2 confined specimens is 23% decreased and 11% increased of the R1 confined specimens' post peak strength respectively.

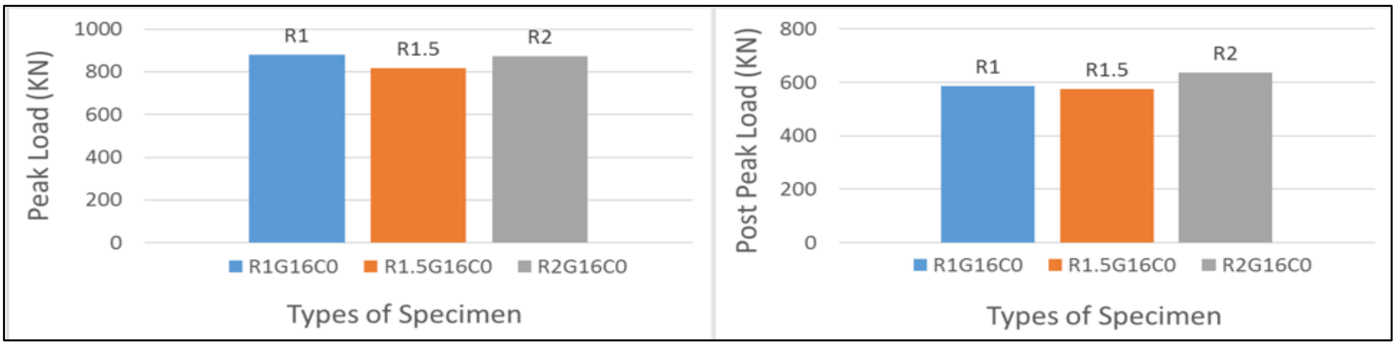

Fig 20 Comparison of Peak and Post Peak Load of Specimens Confined with Gauge 16 Steel Plate and Have no Chamfered Edges

Graph 20 is showing the effect of aspect ratio on compressive response of concrete by keeping all other parameters (Gauge, Corner radius) same. From the results we observed that the peak strength and failure load are decreased with the increase in aspect ratio. The peak strength of R1.5 and R2 confined specimens is decreased by 7% and 1% of the R1 confined specimens' peak strength respectively. Whereas the failure load of R1.5 and R2 confined specimens is 2% decreased and 8% increased of the R1 confined specimens' post peak strength respectively.

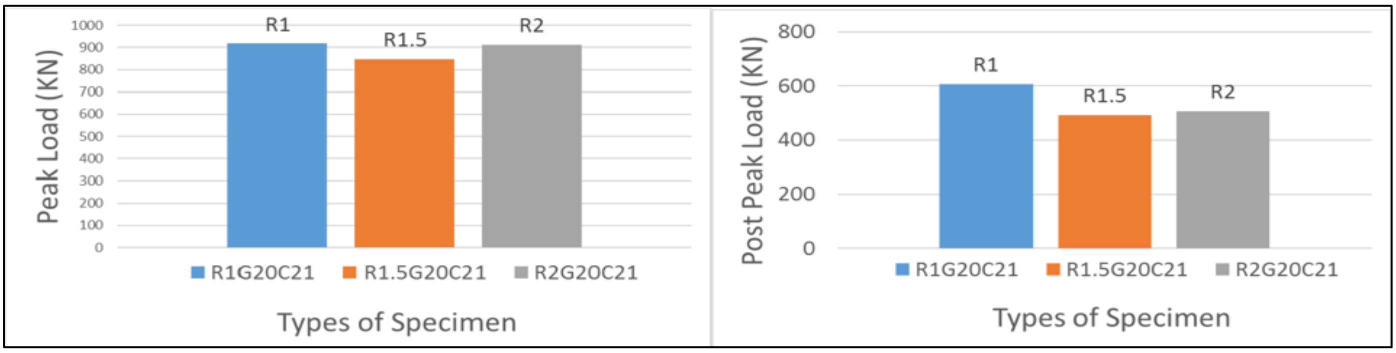

Fig 21 Comparison of Peak and Post Peak Load of Specimens Confined with Gauge 20 Steel Plate and Have Chamfered Edges

Graph 21 is showing the effect of aspect ratio on compressive response of concrete by keeping all other parameters (Gauge, Corner radius) same. From the results we observed that the peak strength and failure load are decreased with the increase in aspect ratio. The peak strength of R1.5 and R2 confined specimens is decreased by 7% and 1% of the R1 confined specimens' peak strength respectively. Whereas the failure load of R1.5 and R2 confined specimens is decreased by 19% and 17% of the R1 confined specimens' post peak strength respectively.

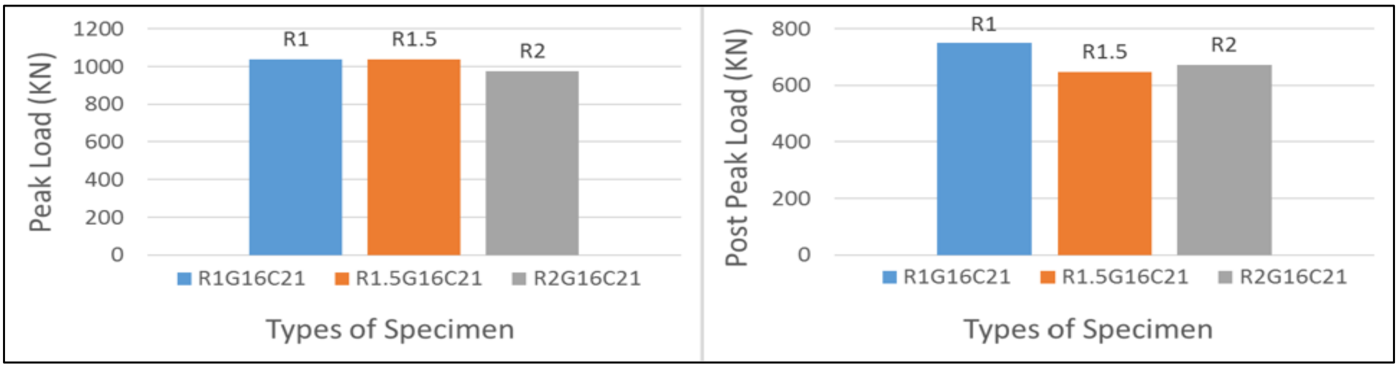

Fig 22 Comparison of Peak and Post Peak Load of Specimens Confined with Gauge 16 Steel Plate and Have Chamfered Edges

Graph 22 is showing the effect of aspect ratio on compressive response of concrete by keeping all other parameters (Gauge, Corner radius) same. From the results we observed that the peak strength and failure load are decreased with the increase in aspect ratio. The peak strength of R1.5 and R2 confined specimens is decreased by 0.1% and 6% of the R1 confined specimens' peak

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strength respectively. Whereas the failure load of R1.5 and R2 confined specimens is decreased by 14% and 10% of the R1 confined specimens' post peak strength respectively.

Fig 23 Effect of Different Aspect Ratio on Specimens After Loading

In confined specimens, stresses are concentrated at corners so the initially cracks occur at corners. In R1 and R1.5 confined specimens, the stresses from the concrete transferred to the steel plate and first yielding was observed and then buckling. In R2 specimens, warping was observed.

- *Effect of Corner Radius on Compressive Behavior of Steel Confined Concrete*

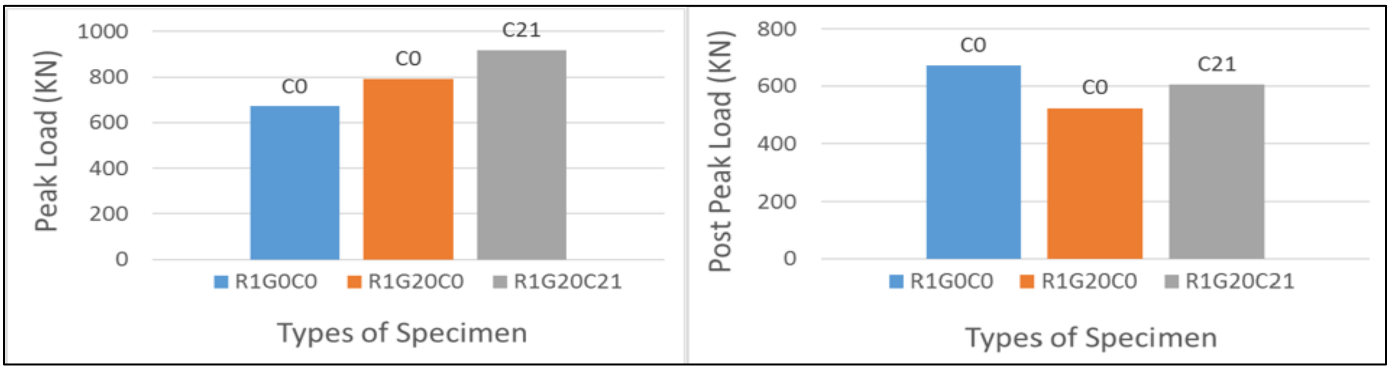

Fig 24 Comparison of Peak and Post Peak Load of Specimens Having Aspect Ratio (R)=1 and Confined with Gauge 20 Steel Plate

Graph 24 is showing the effect of corner radius on compressive response of concrete by keeping all other parameters (Gauge, Aspect ratio) same. From the results it was observed that the peak and failure load of chamfered corner specimens are greater than the sharp corner specimens. The peak strength of C0 and C21 confined specimens is increased by 18% and 37% of unconfined specimen strength respectively. Whereas the failure load of C0 and C21 confined specimens is decreased by 22% and 12% of unconfined specimen strength respectively.

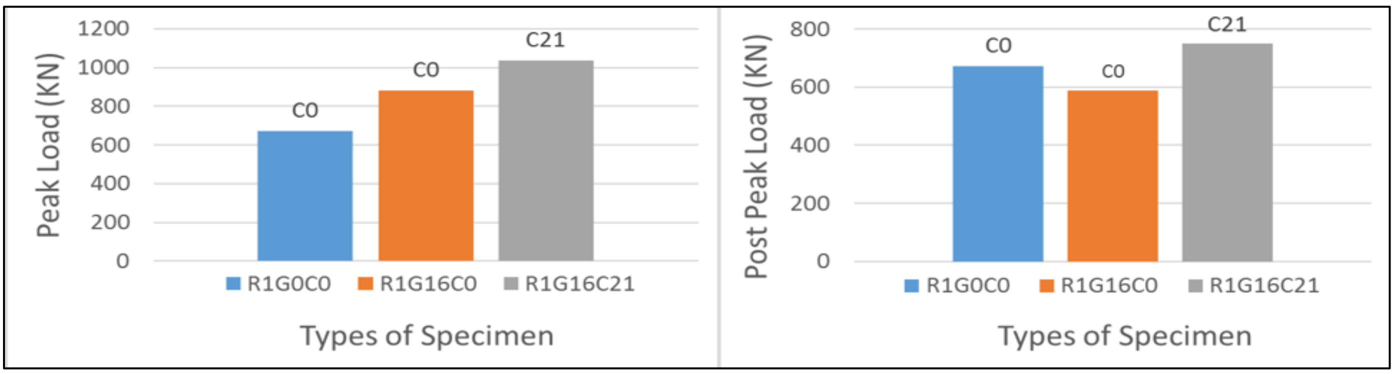

Fig 25 Comparison of Peak and Post Peak Load of Specimens having Aspect Ratio (R)=1 and confined with Gauge 16 steel plate

Graph 25 is showing the effect of corner radius on compressive response of concrete by keeping all other parameters (Gauge,

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Aspect ratio) same. From the results it was observed that the peak and failure load of chamfered corner specimens are greater than the sharp corner specimens. The peak strength of C0 and C21 confined specimens is increased by 31% and 55% of unconfined specimen strength respectively. Whereas the failure load of C0 and C21 confined specimens is 12% decreased and 12% increased of unconfined specimen strength respectively.

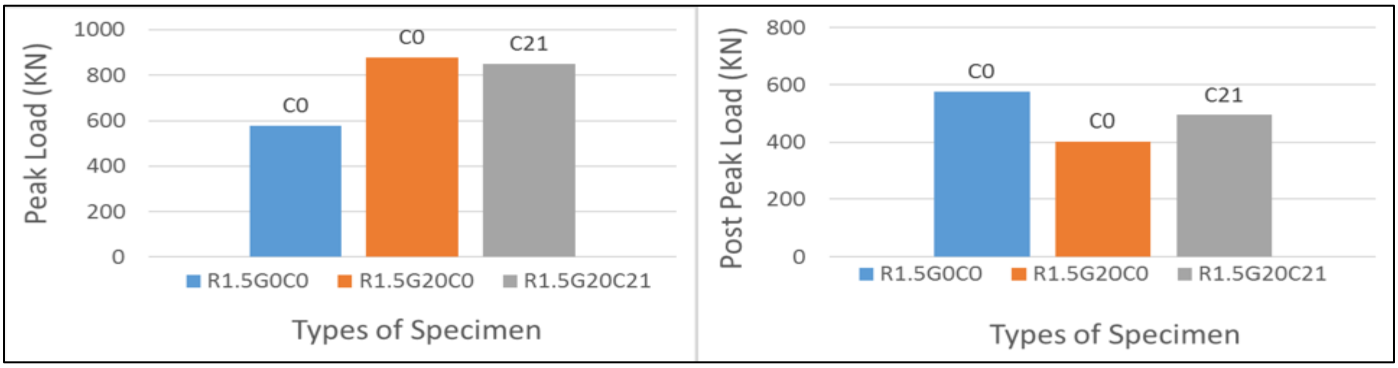

Fig 26 Comparison of Peak and Post Peak Load of Specimens Having Aspect Ratio (R)=1.5 and Confined with Gauge 20 Steel Plate

Graph 26 is showing the effect of corner radius on compressive response of concrete by keeping all other parameters (Gauge, Aspect ratio) same. From the results it was observed that the peak and failure load of chamfered corner specimens are greater than the sharp corner specimens. The peak strength of C0 and C21 confined specimens is increased by 51% and 47% of unconfined specimen strength respectively. This is violating the general trend, the possible reasons for this behavior could be good compaction of concrete or grouting is not properly done. Whereas the failure load of C0 and C21 confined specimens is decreased by 30% and 14% of unconfined specimen strength respectively.

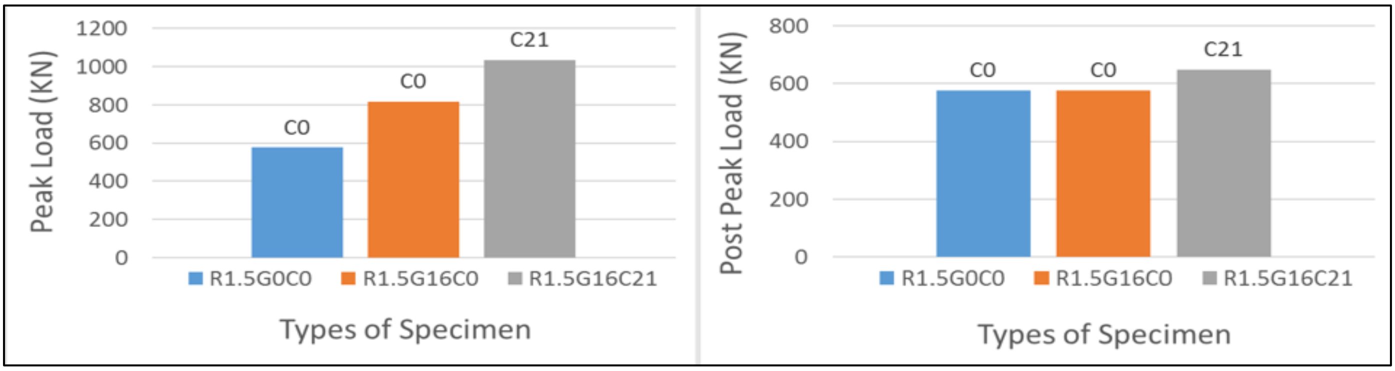

Fig 27 Comparison of Peak and Post Peak Load of Specimens Having Aspect Ratio (R)=1.5 and Confined with Gauge 16 Steel Plate

Graph 4.14 is showing the effect of corner radius on compressive response of concrete by keeping all other parameters (Gauge, Aspect ratio) same. From the results it was observed that the peak and failure load of chamfered corner specimens are greater than the sharp corner specimens. The peak strength of C0 and C21 confined specimens is increased by 42% and 80% of unconfined specimen strength respectively. Whereas the failure load of C0 and C21 confined specimens is 2% decreased and 12% increased of unconfined specimen strength respectively.

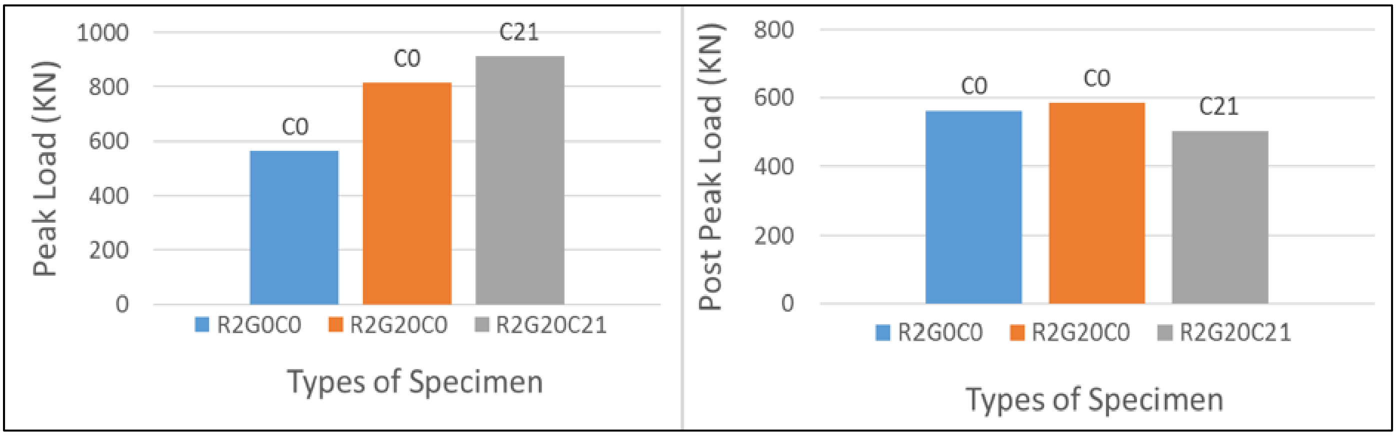

Fig 28 Comparison of Peak and Post Peak Load of Specimens Having Aspect Ratio (R)=2 and Confined with Gauge 20 Steel Plate

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Graph 4.15 is showing the effect of corner radius on compressive response of concrete by keeping all other parameters (Gauge, Aspect ratio) same. From the results it was observed that the peak and failure load of chamfered corner specimens are greater than the sharp corner specimens. The peak strength of C0 and C21 confined specimens is increased by 45% and 62% of unconfined specimen strength respectively. Whereas the failure load of C0 and C21 confined specimens is 4% increased and 10% decreased of unconfined specimen strength respectively.

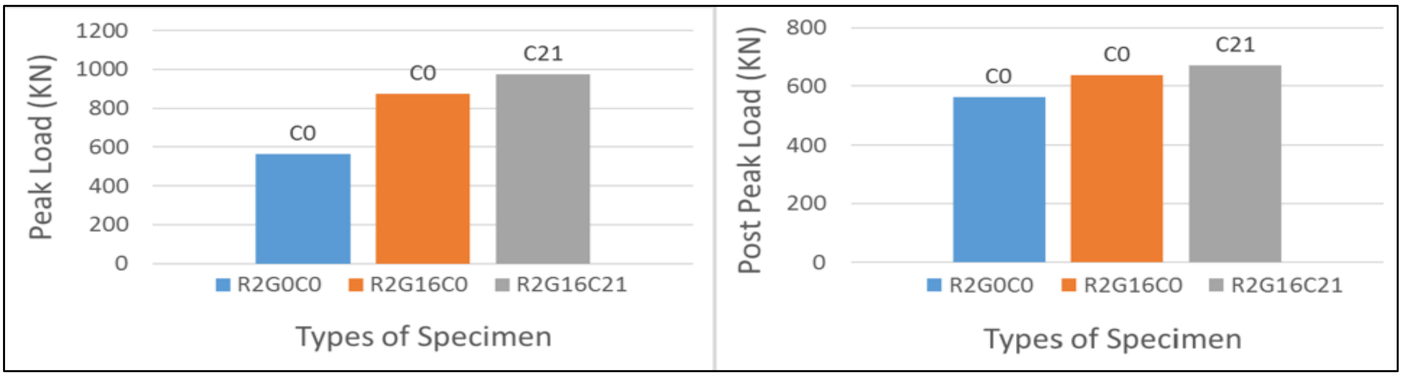

Fig 29 Comparison of Peak and Post Peak Load of Specimens Having Aspect Ratio (R)=2 and Confined with Gauge 16 Steel Plate

Graph 4.16 is showing the effect of corner radius on compressive response of concrete by keeping all other parameters (Gauge, Aspect ratio) same. From the results it was observed that the peak and failure load of chamfered corner specimens are greater than the sharp corner specimens. The peak strength of C0 and C21 confined specimens is increased by 55% and 73% of unconfined specimen strength respectively. Whereas the failure load of C0 and C21 confined specimens is increased by 13% and 19% of unconfined specimen strength respectively.

Fig 30 Effect of Corner Radius on Specimens After Loading

In unconfined specimens, the tensile microcracks parallel to the path of loading was observed which did not have an impact on reducing strength. Then shear fractures begin at the corners and connect with tensile cracks caused macrocracks and a loss in strength. Then the specimens deformed laterally, and following macrocracks, the specimens separated into two crashed and two bearing zones. Whereas in confined specimens, stresses are concentrated at corner due to less effective confinement area. By chamfering of corner of specimens, the effective confinement area was increased which in turn reduced the stresses at the corner of the specimens.

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CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

➢ *The Conclusions are Drawn, and Observations Made from the Study of Confinement of Concrete Specimens are as Follows:*

- Axial strength of concrete columns is greatly enhanced by using steel jackets.
- The significant increase in axial strain with respect to lateral strain shows increased ductility and when coupled with high compressive strength, it justifies the used of additional confinement in retrofitting and new construction.
- By decreasing the gauge number of steel, compressive strength of confined concrete can be increased.
- If aspect ratio is more, the compressive strength of concrete will be less. The concrete specimens with aspect ratio 1 will have the most compressive strength.
- The specimens with corner radius have greater compressive strength as compared to the specimens with sharp corners.

➢ *Recommendations*

- This technique is recommended where the economy is a main concern. So, it is the better technique for developing countries as compared to FRP which requires high initial budget.
- This technique is recommended where you want to considerably increase the ductility along with strength of structural members.
- This technique is recommended where retrofitting is required on large areas and the clear spans are critical.
- This technique is recommended where steel is locally made and available.

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