CYCLIC RESPONSE OF STEEL-STRIP CONFINED REINFORCED CONCRETE BEAM-COLUMN JOINTS

AMIR JAMSHED

(NUST201464388MMCE16014F)

Supervisor

DR. MUHAMMAD RIZWAN

MILITARY COLLEGE OF ENGINEERING

NATIONAL UNIVERSITY OF SCIENCES AND TECHNOLOGY RISALPUR

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This is certified that following thesis

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Submitted by

AMIR JAMSHED

(NUST201464388MMCE16014F)

has been accepted for the completion of degree requirements for

MASTER OF SCIENCE

In

STRUCTURAL ENGINEERING

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Dr. Muhammad Rizwan

Military College of Engineering

National University of Sciences and Technology

Declaration

It is certified that the research work titled "***Cyclic Response of Steel-Strip Confined Reinforced Concrete Beam-Column Joints***" is my genuine work. This work has not been presented anywhere else for evaluation. The contents that have been obtained from other sources have been appropriately acknowledged and referred.

Amir Jamshed

(NUST201464388MMCE16014F)

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Amir Jamshed

(NUST201464388MMCE16014F)

Supervisor's Signature

Dr. Muhammad Rizwan

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This thesis work is dedicated to

MY FAMILY AND INSTRUCTORS

who blessed me with courage,

and

moral support to accomplish this significant

event of my life

ACKNOWLEDGEMENTS

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Words can't express and no actions can return the affection, friendly attitude, sacrifices, advices, continuous prayers, help, and motivation that my Father and my wife rendered in me during the achievement of this important milestone of my engineering career and life.

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(Amir Jamshed)

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ABSTRACT

Confinement introduces deformability in reinforced concrete structural elements. The relationship of stress and strain in confined concrete is appreciably affected by the yield strength, arrangement of reinforcement and confining/ transverse reinforcement spacing. Performance of confined reinforced concrete components can be studied through their load-displacement response curves. Parameters such as yield strength, peak load, ultimate displacement, stiffness degradation and ductility can all be evaluated from these curves. The hinge zones of beam and columns, in reinforced concrete frames, are often well confined. However, higher ductility requirements of the system can only be met if the stress path of moment reversals occurring at the face of supports exists through the joint. The joints are often congested. An interior joint, of intermediate floor, is required to accommodate reinforcement of at least six structural components. Due to congestion it is difficult to add confining reinforcement in the joints. In this project, a proposed technique to confine beam-column joints using steel strips will be implemented and examined. The technique uses contact area of steel strips to provide confinement pressure and economize on the overall volume of confining reinforcement provided in the joints. The behavior of steel-strip-confined beam-column joints will be studied in the form of load-displacement curves. The response of joints confined with steel strips will be compared with those confined by stirrups. The comparison will be used to quantify the effect of proposed confining reinforcement. The study will be helpful in understanding the response of beam-column joints. The study of steel strip confined and stirrup confined beam-column joints will be available for additional application in assessment of the performance of reinforced concrete structures. Such analysis will be helpful to estimate the improvement in the response of building structures containing joints confined by proposed technique.

The idea here is to explore whether the proposed confinement gives better results or at par results, in case of better performance of steel strip confined joints considerable amount of steel can be saved in quantity (keeping strength and ductility same) or higher strength and ductility may be achieved, henceforth the introduction of new confinement technique in the market will be proposed basing on research results.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Earthquake is one of the well-known phenomenons recorded and experienced by the mankind since the inception of human life on the planet Earth. Seismic activities/ earthquakes have caused an intense level of devastation. The exposure of building structures to earthquake has remained an important region for the researchers in order to curtail the hazards of earthquake as much as possible. As the buildings/ structures have to resist huge lateral load reversals through an event of earthquake, appropriate reinforced concrete beam column joint detailing in structures is of great importance. Confinement introduces deformability in reinforced concrete structural elements. The yield strength, configuration and spacing of transverse reinforcement have considerable influence on the stress strain relationship of confined concrete members.

Performance of confined reinforced concrete components can be studied through their load-displacement curves. Parameters such as yield strength, max load, ultimate displacement, stiffness degradation and ductility can be calculated and analyzed from the mentioned curves. The hinge zones of beam and columns, in reinforced concrete frames, are often well confined. However, higher ductility requirements of the system can only be met if the stress path of moment reversals occurring at the face of supports exists through the joint. The joints are often congested. An interior joint, of intermediate floor, is required to accommodate reinforcement of at least six structural components. Due to congestion it is difficult to add confining reinforcement in the joints. In this project, a proposed technique to confine beam-column joints using steel strips will be implemented and examined. The technique uses contact area of steel strips to provide confinement and economize on the overall volume of confining reinforcement provided in the joints. The behavior of steel-strip-confined beam-column joints will be studied in the form of load-displacement curves.

Concrete structural components exist in buildings in different forms. Beam-column joint is one of the structural components to transfer loads to soil through foundations. Considering the response of this element during loading is essential to the development of an overall efficient, safe and sound building/ structure.

1.2 Background

Reinforced concrete beam column joint's correct detailing in structures is of importance because they have to resist lateral load reversals during an event of earthquake. Studies conducted after occurrence of earthquakes indicate that almost all of the structural failures are initiated from the beam column joints, this is indicative of the structure's weak zone.

The beam column joint is a zone of weakness because of joint's improper detailing. Weakness at joint is as a result of insufficient confining reinforcement and meager concrete strength. Lesser shear capacity and brittleness is due to inadequate detailing of joint. Reinforced Concrete (RC) structures constructed before 1970s, which were not designed and detailed as per latest seismic codes collapsed during earthquakes because of failure of exterior beam column joints. Improving the strength of beam column joint is the most viable solution to avoid structural failures because of localized defects. Various techniques can be used to rehabilitate already constructed weak beam column joints. Alcocer and Jirsa used Reinforced Concrete jackets and steel jackets for improving the strength of RC joints. However, this technique is labor demanding, more costly and requires highly skilled workers. This method increases the dead load and dimensions of the joint. Steel pates fixed with epoxy or bolts is another method to increase the strength and ductility of concrete. Alternatively fiber-reinforced polymers (FRP) can be used in RC members at critical locations. These polymers act as external reinforcement which is attached on to the members. FRP is also a good strengthening technique.

1.3 New confining technique

We have used a new technique to strengthen the beam column joint. We introduced varied arrangement of stirrups and used steel plates/ strips of same area as that of steel stirrups for confinement. We have used two types of strips with different thickness i.e. gauge 18 (1.3mm thick) and gauge 14 (2mm thick). We have made our control specimen from steel stirrups (#3) and compared the strength properties of control specimen with that of beam column joint specimen with steel strips as confinement.

1.4 Problem Statement

The northern area of Pakistan is covered by World's three largest mountain ranges that are Hindu Kush, Himalayan and Karakoram ranges and these ranges are located over the tectonic plate boundaries. Large region of Pakistan is seismically active. Numbers of earthquakes are recorded each year. These earthquakes cause large damages to property/ infrastructure and loss of lives. Design of structures which can achieve desired performance levels as required by prevailing building codes is necessary. Therefore, such projects aimed in the area of performance based seismic design are important and will help in mitigating the effects of earthquakes.

Thus a requirement arises to compare the variation in ductility and ultimate strength under cyclic loading of steel strips confined joints with joints confined by steel stirrups as transverse reinforcements.

1.5 Aims and objectives

To compare steel strips and steel strips confined RC beam column joints with a view to analyze their ultimate strength and ductility.

1.6 Types of Analysis

1.6.1 Static Analysis

It is used to determine displacements, stresses, etc. under static loading conditions. it is further divided into linear and nonlinear static analyses. Nonlinearities can include plasticity, stress stiffening, large deflection, large strain, hyper-elasticity, contact surfaces, and creep.

1.6.2 Modal Analysis

Modal analysis is used to calculate the natural frequencies and mode shapes of a structure. Different mode extraction methods are available but are not relevant to our experimental study and therefore will not be discussed.

1.6.3 Harmonic Analysis

This type of analysis is used to determine the response of a structure to harmonically time-varying loads. It is usually based on geometrical functions.

1.6.4 Transient Dynamic Analysis

Transient Dynamic Analysis is used for determination of the response of a structure to arbitrarily time-varying loads. All nonlinearities mentioned under Static Analysis above are allowed.

1.6.5 Spectrum Analysis

It is an extension of the modal analysis, it is used to calculate stresses and strains due to response spectrum or a PSD input (random vibrations).

1.6.6 Buckling Analysis

This type of analysis is used to calculate the buckling loads and determine the buckling mode shape. It is further classified into linear (eigen value) buckling and nonlinear buckling analyses.

The above discussed 'structural analyses' are general in nature. The scope of our study is limited to 'Quasi-static cyclic analyses.

METHODOLOGY

The methodology I followed consists of construction/ fabrication of Reinforced Concrete Beam Column joints samples with steel stirrups and steel strips as transverse reinforcement. These samples were tested and analyzed under cyclic loading. The responses of joints confined with steel strips were compared with those confined by steel stirrups. The comparison was used to identify the effect of proposed confining reinforcement. The methodology was as under:

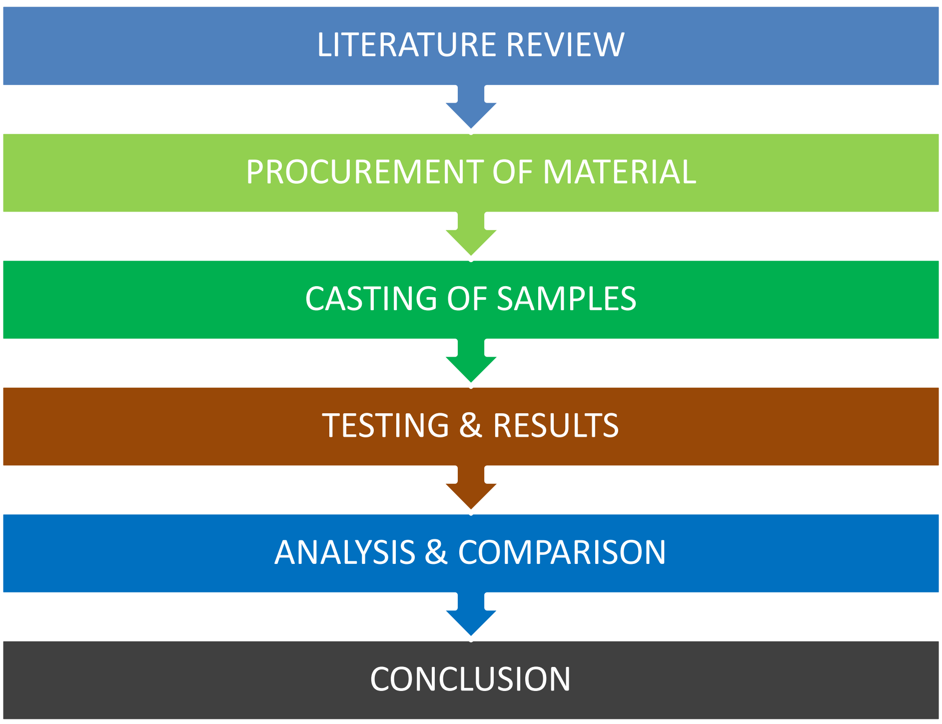


Figure 1: Methodology

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Natural calamities have caused destruction of property and loss of lives since inception of mankind. Major earthquakes are one of the most devastating natural phenomena that are relatively unexpected, unpredicted and whose impact is sudden due to the almost immediate destruction. Every earthquake is unique in its properties i.e. magnitude, intensity, location, epicenter etc. The devastating effect of 2005 earthquake is well known (Figure 2).

Figure 2: Earthquake Destruction in Muzaffarabad - 2005

The severity of ground shaking at a given location during an earthquake can be minor, moderate and strong which relatively speaking occur frequently, occasionally and rarely respectively. Design life of buildings is kept 50 - 100 years, but they are designed and detailed to withstand major earthquakes which may occur in 100 – 1000 years. This is because the damages caused are intense and too expensive. Hence, the major requirement is to construct earthquake resistant buildings/ structures, which can withstand the enormous force of an earthquake. During earthquake buildings are designed not to collapse, however severe damage is expected. Thus, the safety of people and contents is assured in earthquake resistant buildings. Seismic provisions and codes are used in world to achieve this objective.

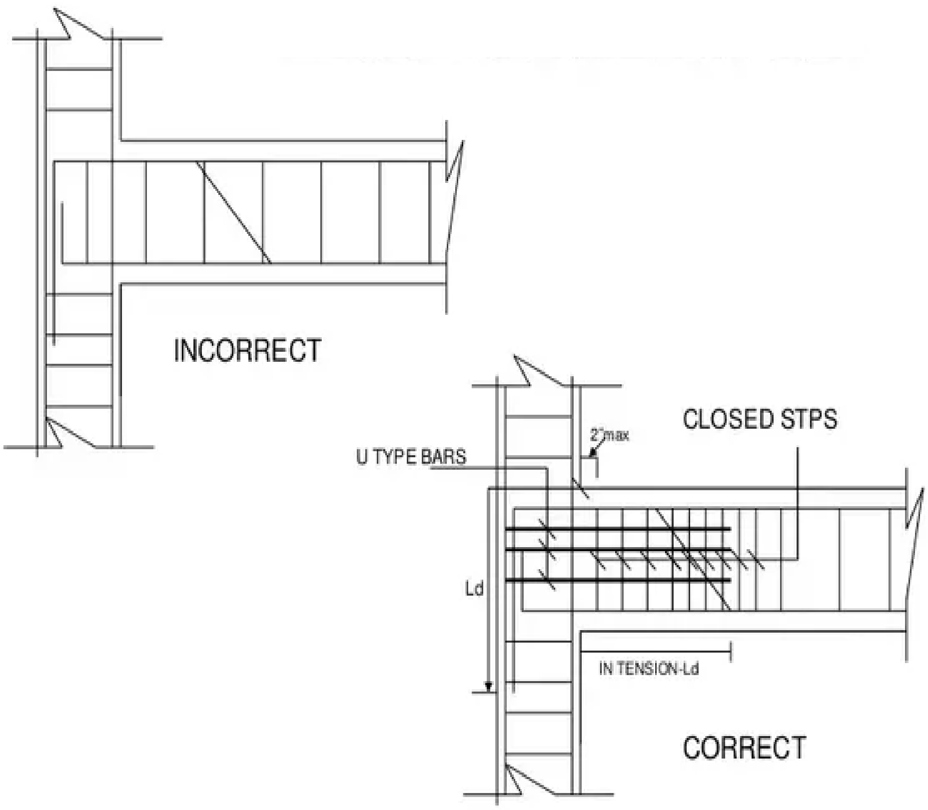


Figure 3: A typical beam-column joint (exterior)

Beam Column Joints is defined as the portion of the column which is within the beam. The design of monolithic joints was limited to providing adequate anchorage for the main reinforcement. The design of joints have become more important with the increasing use of high strength concrete, this resulted in reduction of member dimensions and increase in the area of steel reinforcement.

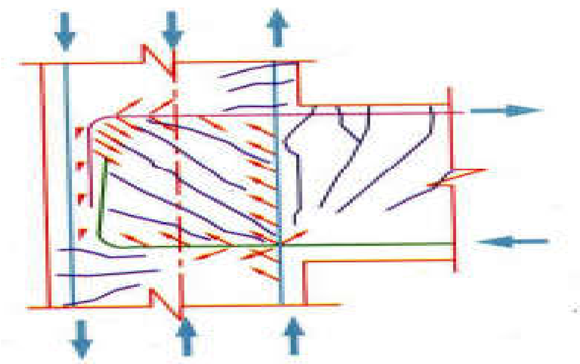


Figure 4: Free body diagram of loads acting on a typical joint

The poor design practice of RC beam-column joint is compounded by the high demand imposed by the adjourning flexural members (beam and columns) in the event of mobilizing their inelastic capacities to dissipate seismic energy. Numerous researches have been carried out over the past few decades, which are described in literatures to understand the complex mechanism and to study the behavior of joints under seismic loadings experimentally and analytically.

The detailing of beam–column joints of RC frame structures in regions of seismic activity is normally governed by code provisions that require a considerable amount of transverse reinforcement to resist the lateral joint shear forces. In recent years, a lot of non-conventional methods have been developed to improve the performance of RC beam-column joints under seismic loading, such as the joints reinforced with steel jackets and fiber-reinforced polymer (FRP). The failure of structure during an earthquake is normally subjected to the failure of joints.

Figure 5: A typical failure of Beam-Column joint

The major objective of the ACI code is to design structures with adequate strength and ductility. Ductility is the ability of a member to endure large deformations without rupture during failure. Ductile member may bend or deform excessively under load but it remains by and large intact. This capability prevents total structure collapse and provides protection/ reaction time to the occupants of the building. Ductile structures undergo large deformations before collapse and provide visible evidences of impending failure and give opportunity to relieve the distress by reducing loads. Brittle members fail explosively or suddenly, completely and without warning thus not allowing any remedial measures to be taken. When a brittle member fails it usually disintegrates and may damage adjacent portion of the structure or overload the member bringing an additional failure. A collapse in which the effect of local failure is spread to the entire structure or to a significant portion of the structure is known as progressive collapse.

2.2 Literature Review

2.2.1 Dr Muhammad Rizwan (2015) - Modeling steel-strip-confined reinforced concrete columns. In reinforced concrete columns deformability is introduced by use of confinement. In confined concrete the area, placing and spacing of confining steel has a direct effect on the stress strain relationship of the reinforced concrete. The overall compressive strength of concrete is also influenced with the use of confining reinforcement. The analysis of confined columns is done with the help of hysteresis response. The hysteresis data is used to plot the backbone curves of the samples, which are of great importance. Parameters such as peak load, yield strength, ultimate displacement, stiffness degradation and ductility can all be calculated and from these curves. Further evaluation is possible from these backbone curves. Hysteresis response and backbone curves are used in this study to analyze the behaviour. The backbone curves are achieved experimentally and are modeled in Drain-3DX through simple calibration procedure. The hysteresis data of samples confined with steel stirrups and strips is modeled and compared. The comparison indicates improvement in the response of columns confined with steel strip transverse reinforcement. The study will be helpful in understanding the modeling in Drain-3DX of the hysteresis response. The column models after calibration will be accessible for further application and assessment of the performance of building structures confined with steel strips or typical steel stirrups.

2.2.2 Eythor Thorhallsson (2011) - Test Of Rectangular Confined Concrete Columns For Strength And Ductility. This research test the ductility and strength of reinforced concrete columns casted by using Icelandic cement and aggregate. Icelandic aggregate has a high porosity. Pour water in Icelandic aggregate is about 3–8% while pore water in an aggregate in North-Europe is about 0.5%. The question of the ductility is specially interesting in Earthquake Engineering design. For Iceland this information's is valuable as part of the country has high earthquake risk. The test program consisted of reinforced concrete columns with different longitudinal reinforcement and hoops spacing. The large scale columns were tested under compressive concentric loading after 28 days of curing at the Structural Engineering and Composites Laboratory at Reykjavík University (SEL). The test specimens were loaded on a hydraulic press with load controlled capabilities. The test results showed that ductility capacity of Icelandic concrete is quite lower than compared with tests from Europe and USA. This result indicates that it is necessary to establish specially formulas for Icelandic confined concrete.

2.2.3 Pasala Nagaprasad (2009) - Seismic strengthening of RC columns using external steel cage.

Steel caging technique is commonly used for the seismic strengthening of reinforced concrete (RC) columns of rectangular cross-section. The steel cage consists of angle sections placed at corners and held together by battens at intervals along the height. In the present study, a rational design method is developed to proportion the steel cage considering its confinement effect on the column concrete. An experimental study was carried out to verify the effectiveness of the proposed design method and detailing of steel cage battens within potential plastic hinge regions. One ordinary RC column and two strengthened columns were investigated experimentally under constant axial compressive load and gradually increasing reversed cyclic lateral displacements. Both strengthened columns showed excellent behavior in terms of flexural strength, lateral stiffness, energy dissipation and ductility due to the external confinement of the column concrete. The proposed model for confinement effect due to steel cage reasonably predicted moment capacities of the strengthened sections, which matched with the observed experimental values. Copyright 2009 John Wiley & Sons, Ltd.

2.2.4 Dr Muhammad Fiaz Tahir (2015) - Response of Seismically Detailed Beam Column Joints Repaired with CFRP Under Cyclic Loading.

6 x beam column joints were fabricated and tested in this experimental study. Quasi-static monotonic loading was applied on the casted samples. The samples

were tested up till failure point, the damaged samples were retrofitted with carbon fiber reinforced polymer/ laminates. The retrofitted samples are again subjected to the same type of loading. The experiment results indicated an increase of 8.6, 6.7% in the ultimate strength of sample 1 and 2 and an increase of 54.6, 51.2% in the ultimate deflection. However, a reduction of 49, 48; 24.8, 25.6; 60.6, 51.7 % was observed in the ductility, ductility factor and stiffness of retrofitted specimens respectively.

2.2.5 Giuseppe Campione (2012) - Strength and ductility of R.C. columns strengthened with steel angles and battens.

This paper consists of analysis of strengthening of Reinforced Concrete members with steel angles and battens. An axial force and moment is applied on the samples of columns. On the basis of stress strain curves of the constituent materials (concrete, battens and steel angles) moment curvature curves of members are made. The induced effects of confinement are because of the use of longitudinal (bars and steel angles) and transverse (stirrups and battens) steel reinforcements which were utilized for stress strain curves of the concrete samples subjected to compression. Initial calibration of columns loaded axially was done by use of compressive laws of steel bars and steel angles for confined concrete. The experimental data available in the literature was used for derivation of the bending moment diagram, axial force diagram and the moment curvature diagram. The use of steel angles along with their spacing, arrangement and characteristics is studied. The influence of the main parameters effecting the problem (strip and angle shape and properties of component material) were finally subjected to a parametric analysis showing the results as axial force diagram and moment curvature diagram diagrams. The strength and ductility of reinforced concrete columns was effectively improved by the use of the reinforcing technique and was proved after the analysis.

2.2.6 G. Campione (2012) – Reinforced Concrete columns externally strengthened with RC jackets. In this study the reinforced concrete columns were strengthened by the use of external concrete jackets. These columns were subjected to compressive load and their behaviour was analyzed. The jacketed members under axial load was further used to develop its bending moment for its cross sectional analysis. The effect of confinement of concrete jacket on concrete column was the aim of this study. The buckling effect of bars in compression was also studied. There are few other important parameters as well, such as shrinkage, bondage slip, creep etc. but these are not considered\ in this study because: the study was conducted by the use of thick non shrinkable grout jacket and a well roughened surface of old concrete was developed before the application of new concrete. Long term effects were included though corrective coefficients for monolithic behaviour proposed in the literature. An initial confirmation of the model adopted was made referring to the short term experimental data available in the literature on the compressive behaviour of Reinforced Concrete columns fitted with concrete jackets to increase the strength. A conclusion was reached with the data available in the form of moment diagram, axial force diagram and moment curvature diagrams. This reinforcing technique was found effective for increasing the ductility and strength of the column samples. This study emphasizes the importance of a precise choice of strengthening materials, such as concrete strength, spacing and arrangements of stirrups, thickness and shape of jackets etc. which will definitely affect the overall test results.

2.2.7 Hasan Moghaddam (2010) - Axial compressive behavior of concrete actively confined by metal strips; part A: experimental study.

In this experimental study the concrete specimens were retrofitted by use of a strapping technique to enhance their compressive strength. In this technique, standard strapping devices, which are normally used in the packaging industry were used. The high strength metal strips were post tensioned around the concrete columns. Experimental investigation consisted of 72 cylindrical and prismatic compressive specimens for axial compressive tests, these samples were dynamically confined by metal strips and these strips were post tensioned, thus increasing confining pressure. The influence of various parameters on ductility and strength of confined concrete were studied. This includes the compressive strength of concrete, properties of confining strips (volumetric ratio etc.), post tensioning force applied to the strip, quantity of strip layers wrapped around the specimens and details of strip joint. The effects of strength and ductility of confining strips on the behavior of confined specimens were also studied. Longitudinal and lateral strains of concrete and strain of the strips were monitored. Test results showed significant increase in the strength and ductility of specimens due to active confinement by metal strips. It was noted that ductility of confining material plays the most important role in increasing the ductility of concrete. The increase in strength is mainly dependent to the effective mechanical volumetric ratio of confining strips. It was also observed that the active confinement of concrete by post tensioning the confining element results in stiffer pre peak response of concrete specimens than the usual passive confinement.

2.2.8 Richart, F. E., Brandzaeg, A. and Brown, R. L. (1928) - "A study of the failure of concrete under Combined Compressive Stresses". The study reflects that the performance of Reinforced Concrete columns improved by confinement. During start of 20th century, in nearly all of the conducted researches, the compressive strength of concrete was estimated by adding the confinement response of an equivalent fluid pressure [2, 3]. This study resulted in the realization of effect of different parameters like form/ shape, center to center distance and yield strength of transverse/ confining and main/ longitudinal reinforcement on performance of RC columns confined with this technique. Experimentally studied behaviour of confined columns indicated the importance of configuration and spacing of confining reinforcement, thus, adjustment of confinement models was recommended.

The significance of properties of confining reinforcement on the stress strain behavior of confined concrete is well realized from the sequential advance in the above referred study. The effect of configuration and yield strength of transverse reinforcement is included in the confinement models with the help of an efficiency coefficient. Considering different confining configuration and material strengths, estimation of the stress strain curves of confined concrete, indicates that they have important role in inelastic seismic response of Reinforced Concrete structures. As a result economy is achieved in seismic design. The accuracy of estimation models is improved through the experimental data. A large data bank of such data is available. In this paper back bone curves of RC beam column joints confined with transverse reinforcement of steel stirrups and strips is presented and comparison is made. The back bone curves of the studied hysteresis response are used to determine yield, peak and ultimate loads. During yield, peak and ultimate loading cycles the response of the RC beam column joints and their lateral load capacity, which includes ductility, residual displacement, degradation of stiffness and energy dissipation are compared. The comparison presented of the studied experimental response will be helpful to researchers and designers working in the field of seismic performance of RC structures to understand the effect of kind of transverse steel on the RC beam column joints under cyclic loading.

2.3 Previous Study

It's a sequel of a previous study that was carried out by Dr. Muhammad Fiaz Tahir in which a total of 6 samples were casted. These samples were coded as A-1 to A-6. The dimensions of beam and column used are marked on the figure. The length of beam was 800 mm from the column face. Formwork detail is shown in Figure.

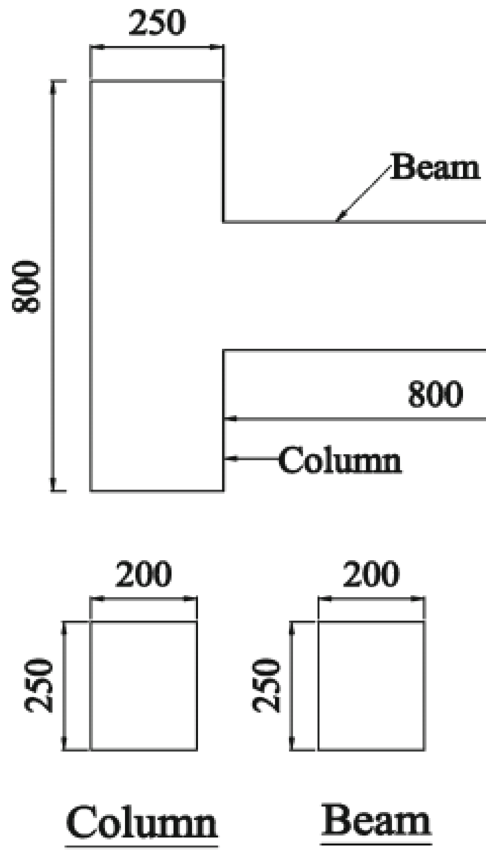


Figure 6: Details of Beam Column joint Specimen

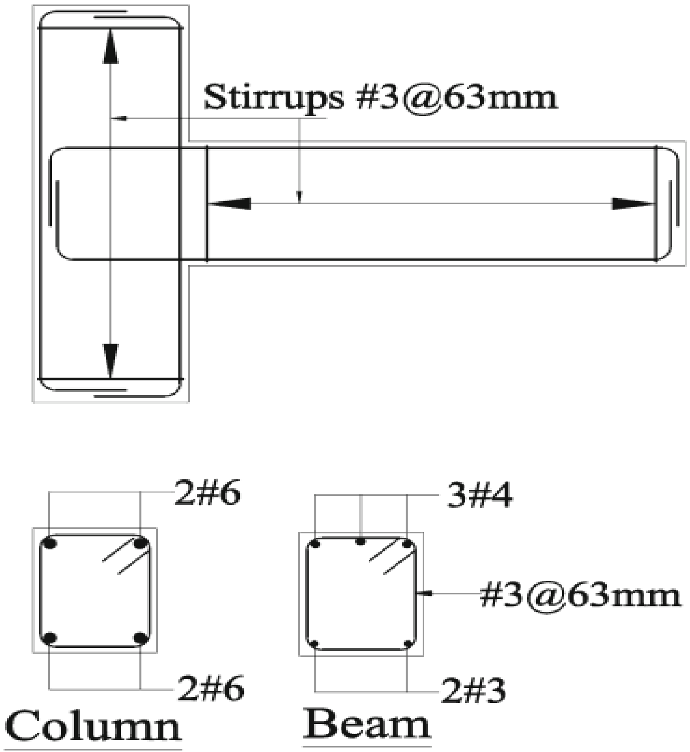


Figure 7: Reinforcement Details

ACI detailing guidelines were used for beam column joint's structural detailing. Transverse reinforcement of steel stirrups was provided in beam and column at 63 mm spacing. 135^0 seismic hooks were given for the transverse reinforcement. Beam column joint was also provided with stirrups. Main reinforcement in column was 4#6 bars, whereas the main/ longitudinal reinforcement in beam was 3#4 bars on the tension side and 2#3 bars on the compression side. The details of the joint are shown in figure. Strength of concrete was 31 Mpa before the conduct of test. Coarse aggregate of maximum size of 9.5 mm was used. Specific gravity of Coarse aggregates was calculated as 2.67 (ASTM-C-127). Specific gravity of Fine aggregate used was calculated as 2.71. Locally available Ordinary Portland cement of 3.15 Specific gravity was used as a binding agent. Water/ cement ratio of 0.45 was used with mix ratio of 1:1.25:2.5. During preparation of mix no admixture was used.

Six reinforced concrete beam column joints seismically detailed were casted and tested for this investigation. Quasi static monotonic loading was applied to all specimens. Two arrangements were used for the retrofitting of damaged samples with carbon fiber reinforced polymer (CFRP). Quasi static monotonic loading was again applied to repaired specimens. This study indicated an increase of 8.6, 6.7% in ultimate strength of 1 & 2 samples and an increase of 54.6, 51.2% in the ultimate deflection. However, decrease of 49, 48; 24.8, 25.6; 60.6, 51.7 % was recorded in ductility, ductility factor and stiffness of repaired specimens, respectively.

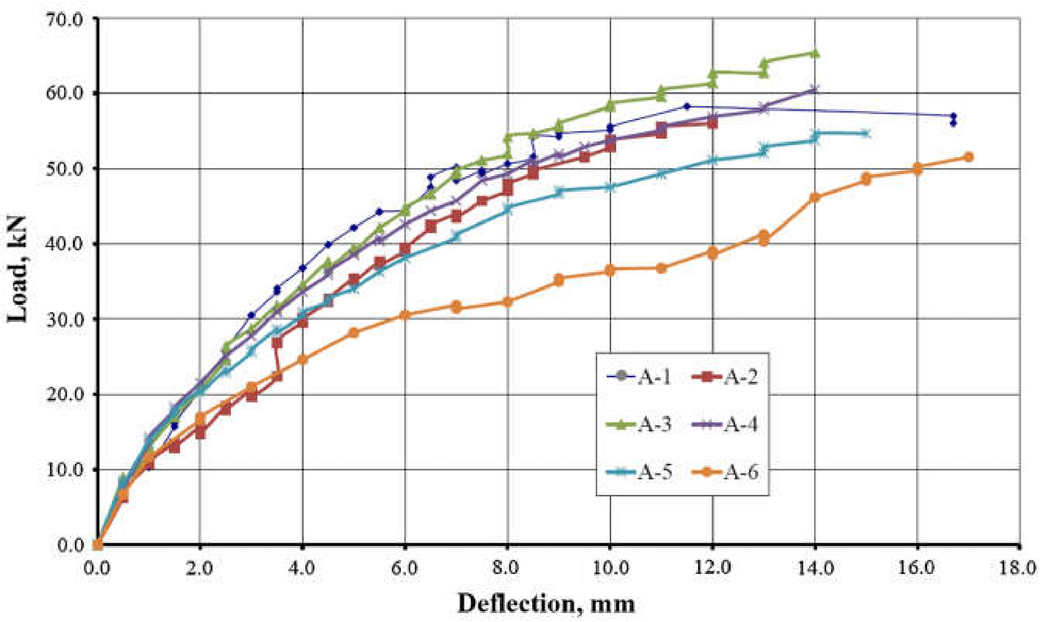


Figure 8: Load Deflection curves of 6 specimens

The joints were tested and load vs. deflection curves for the specimens were obtained. The curves shown above are of 6 x specimens that indicate a similar response as the composition is same in all the specimens.

2.4 Relevance to our project

In our project the detailing design and concrete mix ratio (less transverse reinforcements) has been kept same for comparison purposes. The only thing in variation is use of steel strips which is of same cross sectional area as of #3 bars. The spacing has been kept same in all the specimens.

CHAPTER 3

FABRICATION AND CASTING OF SPECIMEN

The volume of transverse steel is conserved in case of strips. Having same area of cross section for transverse reinforcement, thus the number of steel stirrups and steel strips is kept the same. Normal/ main Reinforcement is kept same for all three types of specimen i.e. control specimens with #3 bars, specimens of 14 gauge and 18 gauge transverse reinforcement. This chapter focuses on all the important details regarding the fabrication and construction of Specimen for testing. The main components of this chapter are described as under:

1. Material Used.
2. Preparation of Steel Strips and Stirrups.
3. Construction of Steel cages.
4. Casting of Steel cages with Concrete.
5. Curing of Specimen.

3.1 Material Used

The material required for the casting of samples is as under:

a. Steel

b. Steel strips (locally fabricated)

c. Formwork (for casting of Specimens).

d. Cement

e. Sand

f. Course Aggregate

g. Water

Further details of the above mentioned materials are discussed below:

3.1.1 Steel.

Steel of different sizes and arrangement were procured from local market (Nomee Steel located in Hathar Industrial Estate) of Taxila. The details are given in the table below:

S.No	TYPE	CUT LENGTH	NO. OF BARS	GRADE
1	#3 Deformed	40 in	120	40
2	#3 Deformed	27.5 in	48	60
3	#6 Deformed	30.5 in	48	60
4	#4 Deformed	30.5 in	36	60

Table 1: Specification and Cut length of bars required

3.1.2 Steel strips (locally fabricated)

Special purpose steel sheets of desired gauge were cut into strips of the required dimensions at Gujjar Gari located in the outskirts of Mardan. The afore-mentioned place is known for its Steel industry. The steel strips used were of grade 40 and were verified after testing at UET Taxila. Two different types of Steel strips were used, having dimensions and other specifications as under:

S. NO	STRIP TYPE	LENGTH	THICKNESS (mm)	THICKNESS (in)	WIDTH (mm)	AREA (in)
1	A	40 in	2 (14 gauge)	0.07875	36	0.11
2	B	40 in	1.3 (18 gauge)	0.0512	54	0.11

Table 2: Strip details

Figure 9: Fabrication of steel strips

3.1.3 Formwork

Formwork of required dimensions was made from chip board sheets at UET Taxila. Specially fabricated for the simulation of the beam column connection/ joints. Steel frames/cages were placed and casted in the formwork. Figures below show the formwork and its dimensions.

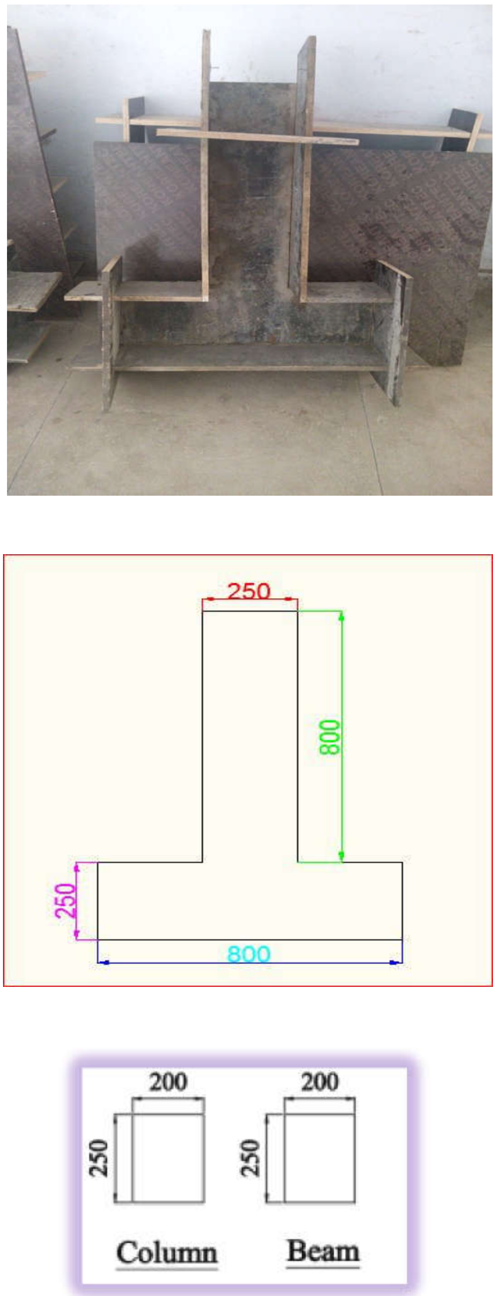


Figure 10: Formwork (dimension in mm)

3.1.4 Cement

Ordinary Portland cement manufactured by Askari Cement was used, which is one of the leading manufacturers of Cement in Pakistan. Cement of the required quantity was purchased from Taxila local market. Total of 11 bags of cement were purchased, out of which 12 specimens were casted, more over 3 Cylinders were also casted for checking the concrete's compressive strength. The cement used was uniform in color (mainly grey with a light greenish shade) and the cement was free of hard lumps and moisture.

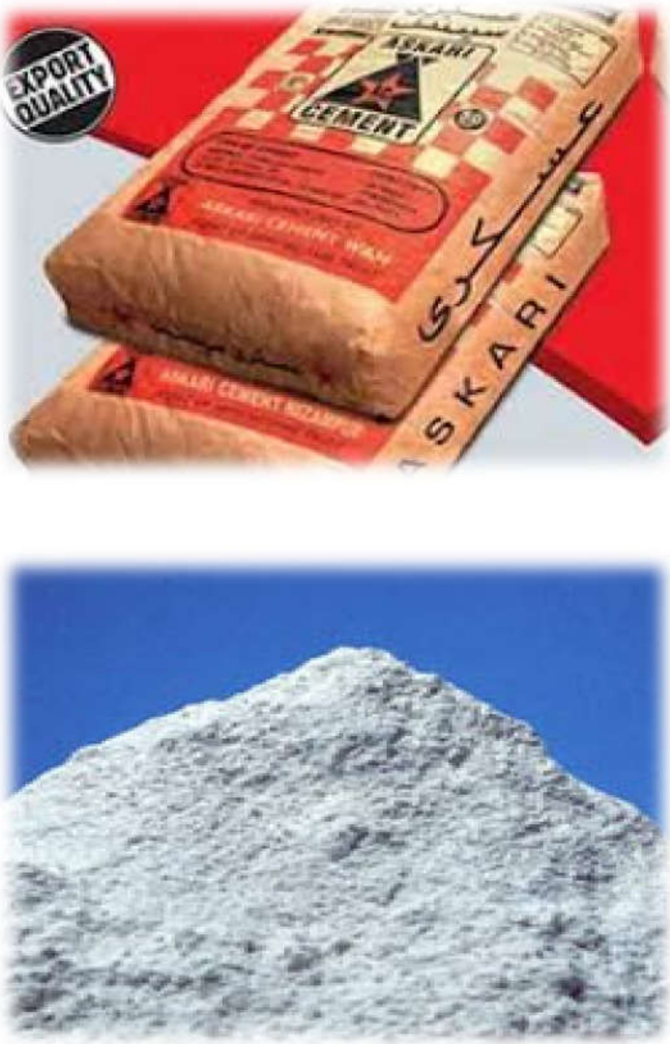


Figure 11: Askari Cement

3.1.5 Fine Aggregate/ Sand

Sand of calculated amount about 36 ft^3 was purchased locally from Taxila. Sand play an important role from bonding point of view and it also contributes in strength and workability. Fine aggregate grading within the limits of ASTM C 33 (AASHTO M 6) is considered satisfactory for most of the concretes. Various properties of sand were worked out after sieve analysis.

SER NO.	PROPERTIES	RESULTS
1	Type of Sand	Natural
2	Specific Gravity	2.67
3	Water Absorption	1.05%
4	Fineness Modulus of Sand	2.39

Table 3: Sand Properties

SIEVE SIZE	TOTAL WEIGHT (gm)	RETAINED %	PASSING %	CUMULATIVE % RETAINED
4	2.0	0.4	99.6	0.4
8	20.0	4.2	94.4	4.7
16	70.0	14.2	80.2	18.7
30	187.0	37.6	42.6	56.3
50	146.0	28.4	14.2	85.7
100	51.04	9.4	3.8	96.1
Fineness Modulus of sand (261.2/100) = 2.61				Total 261.2

Table 4: Sieve Analysis of Sand

3.1.6 Coarse Aggregate

Coarse aggregate of wide range is permitted by ASTM C 33 (AASHTO M 80). Well Graded, well-shaped coarse aggregate of 18 ft^3 was purchased locally from Taxila. It was washed and cleaned before use. Tests were conducted to check its various properties including gradation.

SER NO.	PROPERTIES	RESULTS
1	Type of Aggregate	Crushed
2	Specific Gravity	2.79
3	Water Absorption	3.38%
4	Fineness Modulus of Aggregate	7.47
5	Crushing Value	28
6	Density	3.14

Table 5: Properties of Coarse Aggregate

3.1.7 Water

As per ACI standards, pure drinkable water was used during making of concrete. The water used was free of contamination, odor and sediments. Source of water was from UET Taxila.

3.2 Preparation of Steel Strips and Stirrups

This involved the following tasks:

3.2.1 Fabrication of stirrups and bending of bars

The work included bending of 120 #3 bars into required dimensions as well as optimal bending of other steel bars in order to make it useable for the construction of steel cages/ frame.

3.2.2 Bending of Strips

The steel strips that were to be used as an alternate arrangement of transverse reinforcement were bent according to our requirement at a local Denting shop in Afghan market located in Taxila on National Highway. Image is shown below:

Figure 12: Bending of strips

3.3 Construction of Steel Cages

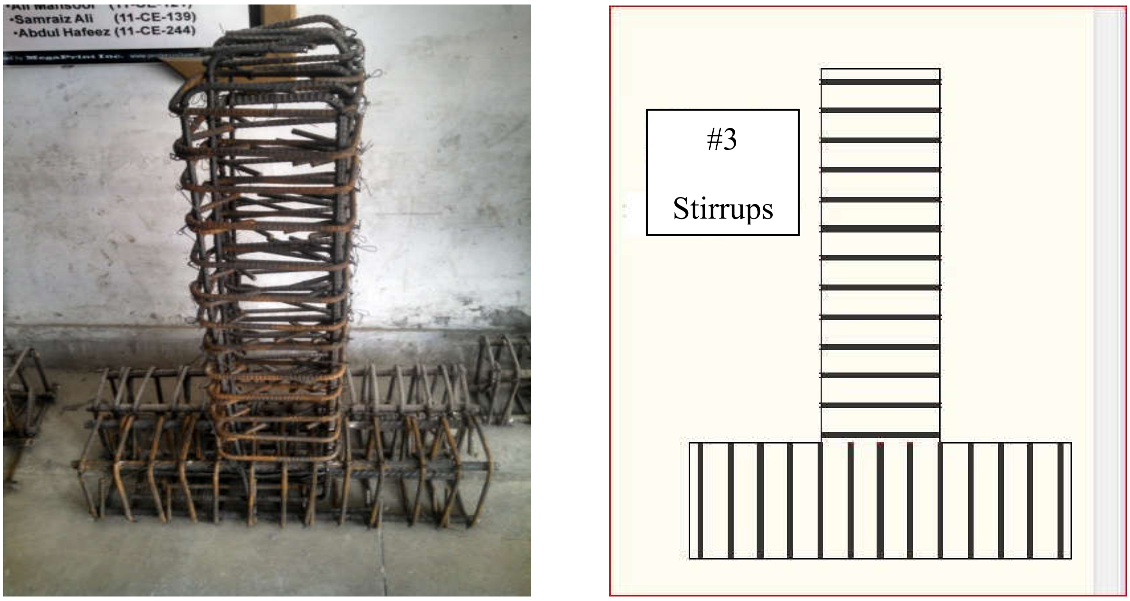
The steel cages were constructed by me along with expert workers according to specific arrangement of work. 3 x groups of frames/ Cages were made. The detail of groups of frames is given below in table.

GROUP TYPE	TRANSVERSE REINFORCEMENT	NO. OF SPECIMENS	NO. OF TRANSVERSE RFT		MAIN REINFORCEMENT
			BEAM	COLUMN	
#3	#3 Stirrups	4	13	13	2#3,3#4(in beams) 4#6 (in columns)
14 Gauge	2mm thick strip(36mm wide)	4	13	13	2#3,3#4(in beams) 4#6 (in columns)
18 Gauge	1.3mm Thick strip (54mm wide)	4	13	13	2#3,3#4(in beams) 4#6 (in columns)

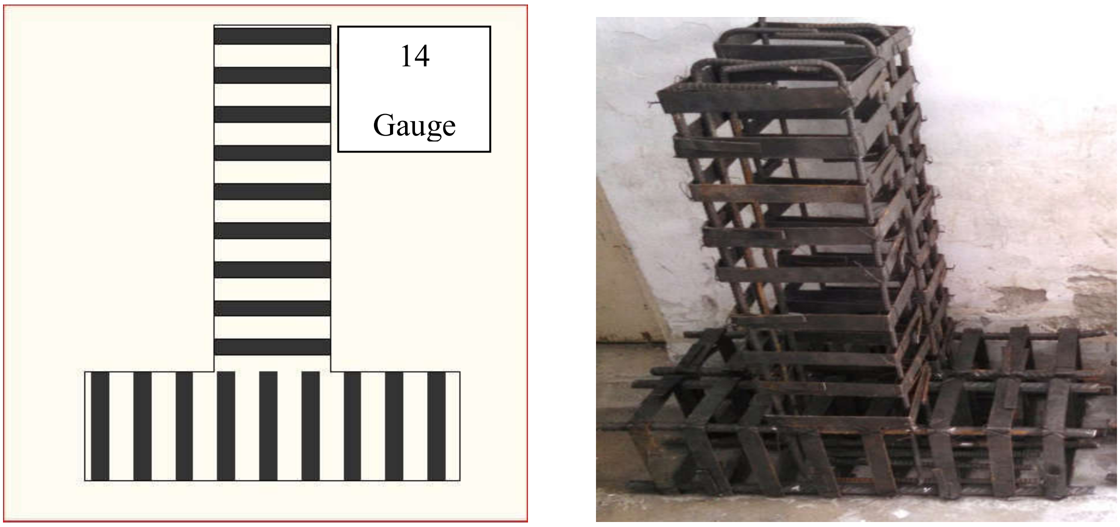
Table 6: Reinforcement Details

The steel cages were fabricated in such a way that the transverse reinforcement had same center to center distance between them. There center to center distance was kept 63 mm. The figure below shows the transverse reinforcement:

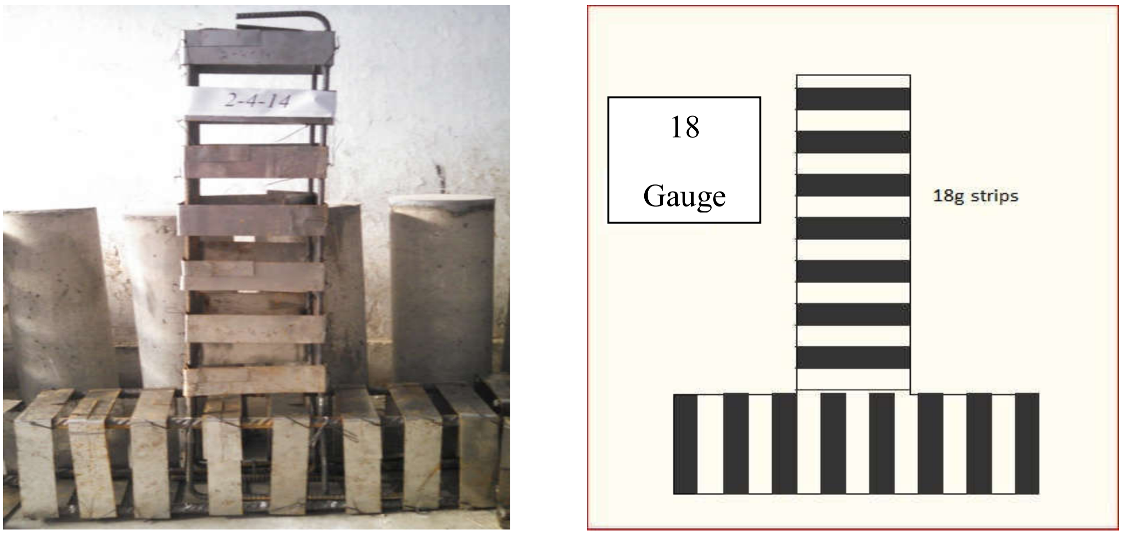
(a) Construction of steel cages



(b) #3 stirrups model



(c) 14 gauge strip model (2 mm)



(d) 18 guage strip model (1.3 mm)

Figure 13: Fabrication of Steel Cages

I calculated area of one stirrup which is found to be 0.11 in^2. I used two different types of strips (14 and 18 gauge) of same area i.e. 0.11 in^2. Volume of steel actually means the number of stirrups and strips used in each beam column joint. The number of stirrups used in each column and beam according to design is 13 with 63 mm center to center spacing. Strips of 1.3mm thickness are used in beams and columns specimens confined with 18 gauge and strips of 2mm strips are used in specimens confined with 14 gauge. Thus the area of stirrups and strips used are same.

Area of one stirrup = 0.11in^2

Area of one strips (14 gauge) = 0.11 in^2

Area of one strips (18 gauge) = 0.11in^2

3.4 Casting of Beam Column Joints

Properties of concrete can be concluded after proper testing as per ASTM standards. On the basis of tests conducted, results are compiled and suggestions are made. Keeping in view our requirements for the experimental study I have casted 12 x beam column joint samples along with 3 cylinders at UET Taxila. Proper curing was ensured at all places. I casted samples in 2 groups of 6 specimens each of 4 ksi and 3 ksi strength keeping the aggregate-cement ratio as 1:1.25:3. The water-cement ratio was kept 0.45 as per ACI Code. Two Specimens of each previous mentioned group were made and the code for the specimens was engraved on samples after initial setting time. The same coding was done on paper tape so the specimens can be counter checked. The engraved coding was done in such a way that they can easily be decoded during testing and compilation of results. Following coded specimen were made on the first day. A total of 12 specimens were casted and the following tables show details of specimen and coding:

GROUP/ SET	RATIO	LONG RFT (BEAM/ COLUMN)	TRANSVERSE RFT	NAME	NO OF SPECIMEN
1	1:1.25:3	3#4 + 2#3/ 4#6	#3@ 63mm c/c	Control Specimen	2
1	1:1.25:3	3#4 + 2#3/ 4#6	1.3mm x 54mm @ 63mm c/c	18 Gauge Specimen	2
1	1:1.25:3	3#4 + 2#3/ 4#6	2.0mm x 36 mm @ 63mm c/c	14 Gauge Specimen	2
2	1:2:4	3#4 + 2#3/ 4#6	#3@ 54mm @ 63mm c/c	Control Specimen	2
2	1:2:4	3#4 + 2#3/ 4#6	1.3mm x 54mm @ 63mm c/c	18 Gauge Specimen	2
2	1:2:4	3#4 + 2#3/ 4#6	2.0mm x 36 mm @ 63mm c/c	14 Gauge Specimen	2
Total					12 Specimens

c/c = center to center distance

Table 7: Specimen Details

CODED NAME	TYPE	CODE DESCRIPTION
CRCJ	1-4-#3	Specimen no.1 having 28 MPa (4ksi) strength with #3 stirrups as transverse reinforcement
	2-4-#3	Specimen no.2 having 28 MPa (4ksi) strength with #3 stirrups as transverse reinforcement
SSCJ-02	1-4-14	Specimen no.1 having 28 MPa (4ksi) strength with transverse reinforcement as 2mm thick strip (14 gauge)
	2-4-14	Specimen no.2 having 28 MPa (4ksi) strength with transverse reinforcement as 2mm thick strip (14 gauge)
SSCJ-1.3	1-4-18	Specimen no.1 having 28 MPa (4ksi) strength with transverse reinforcement as 1.3mm thick strips (18 gauge)
	2-4-18	Specimen no.2 having 28 MPa (4ksi) strength with transverse reinforcement as 1.3mm thick strips (18 gauge)
CRCJ	1-3-#3	Specimen no.1 having 21 MPa (3ksi) strength with #3 stirrups as transverse reinforcement
	2-3-#3	Specimen no.2 having 21 MPa (3ksi) strength with #3 stirrups as transverse reinforcement
SSCJ-02	1-3-14	Specimen no.1 having 21 MPa (3ksi) strength with transverse reinforcement as 2mm thick strip (14 gauge)
	2-3-14	Specimen no.2 having 21 MPa (3ksi) strength with transverse reinforcement as 2mm thick strip (14 gauge)
SSCJ-1.3	1-3-18	Specimen no.1 having 21 MPa (3ksi) strength with transverse reinforcement as 1.3mm thick strips (18 gauge)
	2-3-18	Specimen no.2 having 21 MPa (3ksi) strength with transverse reinforcement as 1.3mm thick strips (18 gauge)

CRCJ = Conventionally Reinforced Concrete joint

SSCJ-02 = Steel Strip Confined Joint-2 mm thick

SSCJ-1.3 = Steel Strip Confined Joint-1.3 mm thick

Table 8: Nomenclatures of Joints

Figure 14: Joints before Casting

Figure 15: Casting of Specimen

Cohesiveness and consistency of fresh concrete was tested to ensure the preparation of concrete of desired/ appropriate properties. Two tests were conducted in this regards namely slump and compacting factor test.

3.4.1 Slump

Slump is simply the measure of wetness of concrete. Wetness of concrete is directly proportional to the value of slump with in specified set of materials used in concrete mixture.

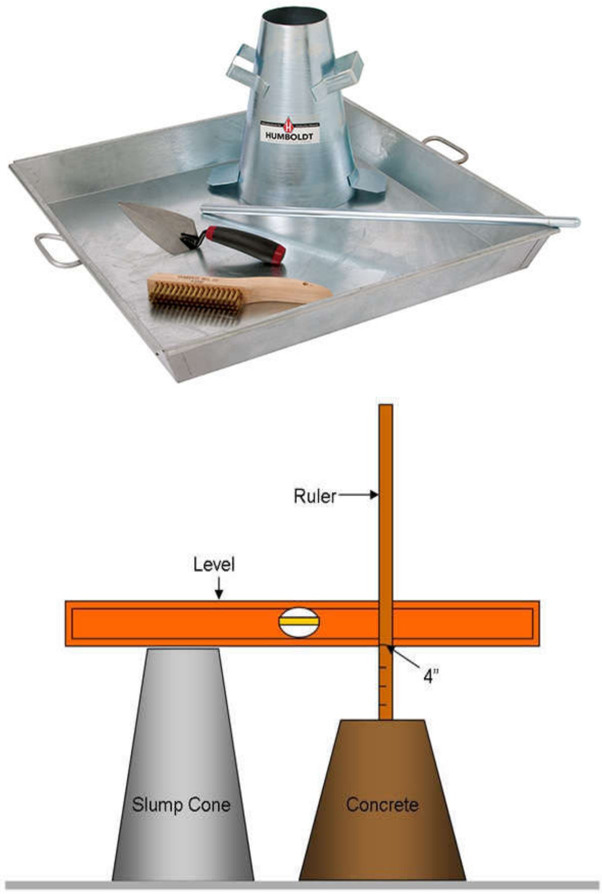


Figure 16: Slump Test

Freshly mixed concrete is poured in the slump test cone in three layers. Each layer of concrete is compacted with the help of rod which is dropped from 6 inches, this procedure is repeated 25 times. After compaction of all the layers, surface of cone is leveled with a blade. Than the cone is slowly pulled upward and removed. The concrete will slowly settle down depending on its wetness and workability. If more water is used in concrete slump will be more and vice versa. Reduction in water requirement for a desired slump is possible by increasing the maximum size of aggregate, reducing the percentage of rough textured aggregate, increasing air entrainment and by partially replacing cement with fly ash.

3.4.2 Test for Compaction Factor

This test is a simple test and is conducted to find out the workability of fresh concrete , it is conducted as per IS: 1199 – 1959. In Compacting factor test the apparatus used is as shown. Procedure to determine workability of fresh concrete by compacting factor test:

The sample of concrete is placed in the upper hopper up to the brim. The trap-door is opened so that the concrete falls into the lower hopper. The trap-door of the lower hopper is opened and the concrete is allowed to fall into the cylinder. The excess concrete remaining above the top level of the cylinder is then cut off with the help of plane blades. The concrete in the cylinder is weighed. This is known as weight of partially compacted concrete. The cylinder is filled with a fresh sample of concrete and vibrated to obtain full compaction. The concrete in the cylinder is weighed again. This weight is known as the weight of fully compacted concrete.

Compacting factor = (Weight of partially compacted concrete)/(Weight of fully compacted concrete)

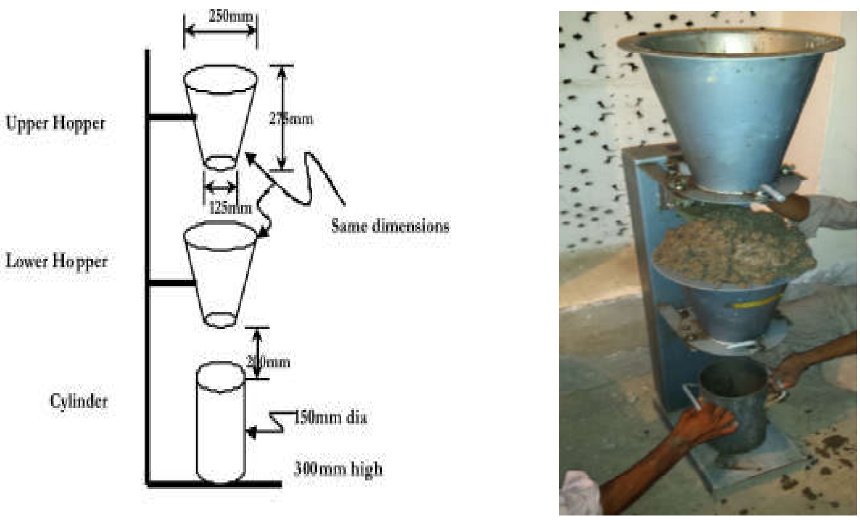


Figure 17: Compaction Factor Test

WORKABILITY	SLUMP (MM)	COMPACTION FACTOR	SUITABILITY
High range	100-175	0.95	Congested/ high reinforcement
Medium range	50-100	0.92	Normal reinforcement
Low range	25-50	0.85	Rigid Pavements Manual casted
Very Low range	0-25	0.78	Rigid Pavements Machine casted

Table 9: Fresh Concrete Tests

3.5 Curing of specimens

Curing is one of the key factors in strength gain and durability of concrete. 12 specimens and 3 concrete cylinders were curved for 28 days. Haze cloth was used for effective curing. More over a dedicated local worker from UET Taxila was hired to ensure proper curing of the specimens.

CHAPTER 4

TESTING AND RESULTS

4.1 Background

Ultimate load and deflection are two parameters that define or explain the concept of Strength. Strength can be explained in terms of Ductility. The structure is said to be more ductile if its load carrying capacity and deformability is higher. Load carrying capacity itself is related to the concrete and steel fundamental properties and the way in which the structure is made. Confinement is another parameter that is related to Strength and Deformability of structure. Moreover, it also plays an important part when shear stress acts on a structure. Therefore, ultimate aim of an engineer while designing a structure should be that it is safe in every aspect.

After an Earthquake in 2005, many reports suggested that most of the lives were lost due to the inappropriate design of Beam column joint. One of the most critical parts in any structure is the Beam column joint, because when this region is weak due to development of Plastic hinges, there is likely a chance of failure of the roofs that may be adequately designed. One of the main reasons of beam column joint failure is that its ability to sustain shear stress from various agents such as Earthquakes etc. is low. Thus, it is implicit to increase the shear strength of this structural element through confinement. One important point should be noted that a building or structure is considered to be safe against earthquakes etc when its can at least provide a better response time so that people can evacuate the building and no lives are lost. In the light of above discussion we present the following conclusions which were aimed at increasing the strength and ductility through increase in confinement strength/ pressure.

4.2 Specimen and Loading Arrangement

Cross sectional dimensions of beam and column were 250 × 200 mm each. The height of column was kept as 800 mm. The beam was fabricated at the midpoint of column with an 800 mm cantilever. The details of formwork are shown in figure. The test specimen consisted of 200 mm x 250 mm beam section having 800 mm projection and columns of 200 mm x 250 mm section and 800 mm height. The longitudinal reinforcement consists of 415 Mpa yield strength, detail is shown in Figure. ACI detailing guidelines were used for the structural detailing of the beam column joint. The transverse/ confining reinforcement was spaced at 63 mm in both beam and column. 135^0 seismic hooks were provided for all reinforcements. The beam column joint was also provided with transverse reinforcement. The longitudinal reinforcement in column comprised of 4#6 bars, whereas the main reinforcement in beam comprised of 3#4 bars on the tension side and 2#3 bars were used for the compression side. Transverse reinforcement details for the beam column joint are shown in Figure. Strength of concrete at the time of testing was 28 MPa and 21 Mpa for 2 types/ groups of samples.

Coarse aggregate of maximum 9.5 mm size was used for the concrete. Coarse aggregate of 2.67 specific gravity was used (ASTM-C-127). Fine aggregate of specific gravity 2.71 was used in the test. The binding agent was ordinary Portland cement which was available locally with a specific gravity of 3.15. Constituent materials for concrete were mixed in a ratio of 1:1.25:3 and water cement ratio of 0.45 was maintained. No admixture was used in preparing the mix. Details of specimen and dimensions are shown in figure. Two sets of samples were casted, one having 21 Mpa concrete and other with 28 Mpa concrete. Each set of samples consists of 6 test samples confined with steel stirrups of #3, 14 gauge steel strips and 18 gauge steel strips. The area of transverse reinforcement comprising of steel stirrups and strips is kept the same, details are shown in Table. The arrangement of transverse reinforcement was provided according to provision of ACI-318-08. Steel band around column ends were used in order to ensure that there is no damage/ crushing to the ends of the column. The column was applied with axial compressive force so that no movement of column occurs. The reinforcement has been provided at 63 mm c/c. The test was carried out by applying cyclic load on the beam end and displacement was measured. Drifts levels for the first cycle were 0.25% and second at 0.5%. A 0.5% increment in drift levels was used up till 5% drift level, after that the reduction in increment was to 0.25%. The concluding drift level of 5.5% was kept repetitive until we achieved 20% degradation in strength.

During the conduct of test the compressive load was kept constant on the column, thus nullifying any chance of column movement. The nomenclature assigned to beam column joints is discussed above. CRCJ represents Conventionally Reinforced Concrete Joints and SSCJ represents Steel Strip Confined Joints. A load cell was placed over a hydraulic jack and this arrangement was placed under the free end of the beam. Load on beam was then applied through the jack.

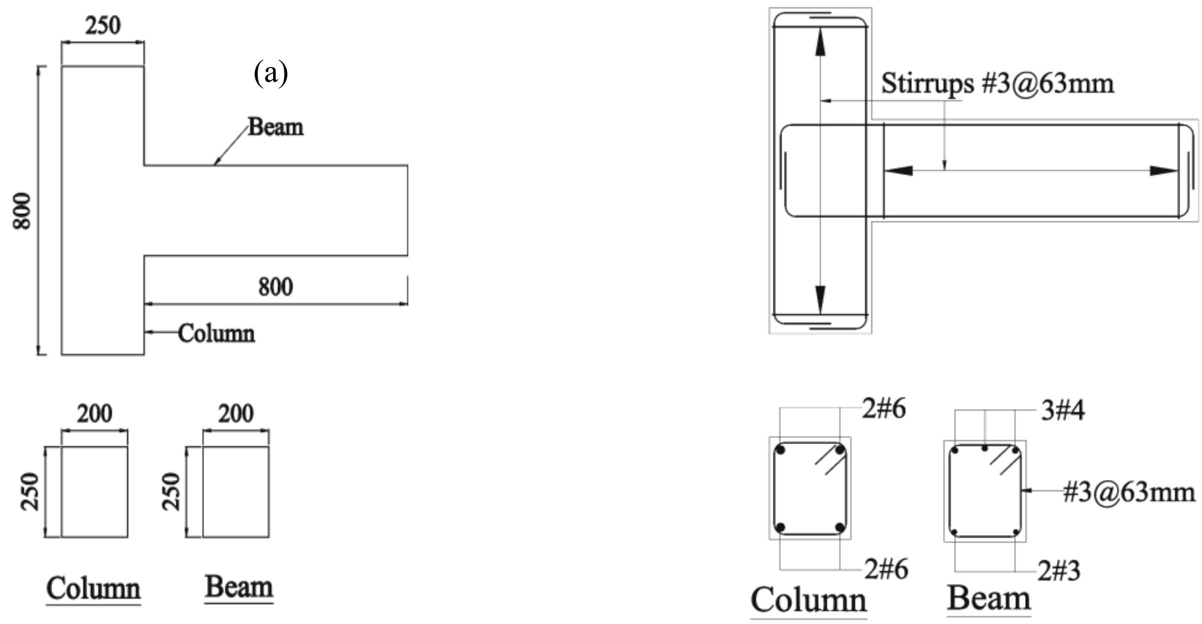


Figure 18: Specimen Dimensions and Longitudinal Steel

4.3 Instrumentation

The displacements were measured by means of Deflection gauge installed at free end of the beam, where there is maximum deflection. A hydraulic jack was used for load application and was placed under the free end of the beam. A load cell placed between the hydraulic jack and the beam was used to measure the load applied. The displacement caused due to load was measured by use of deflection gauge. The details of instrumentation are shown in Figure 19 and Table 10.

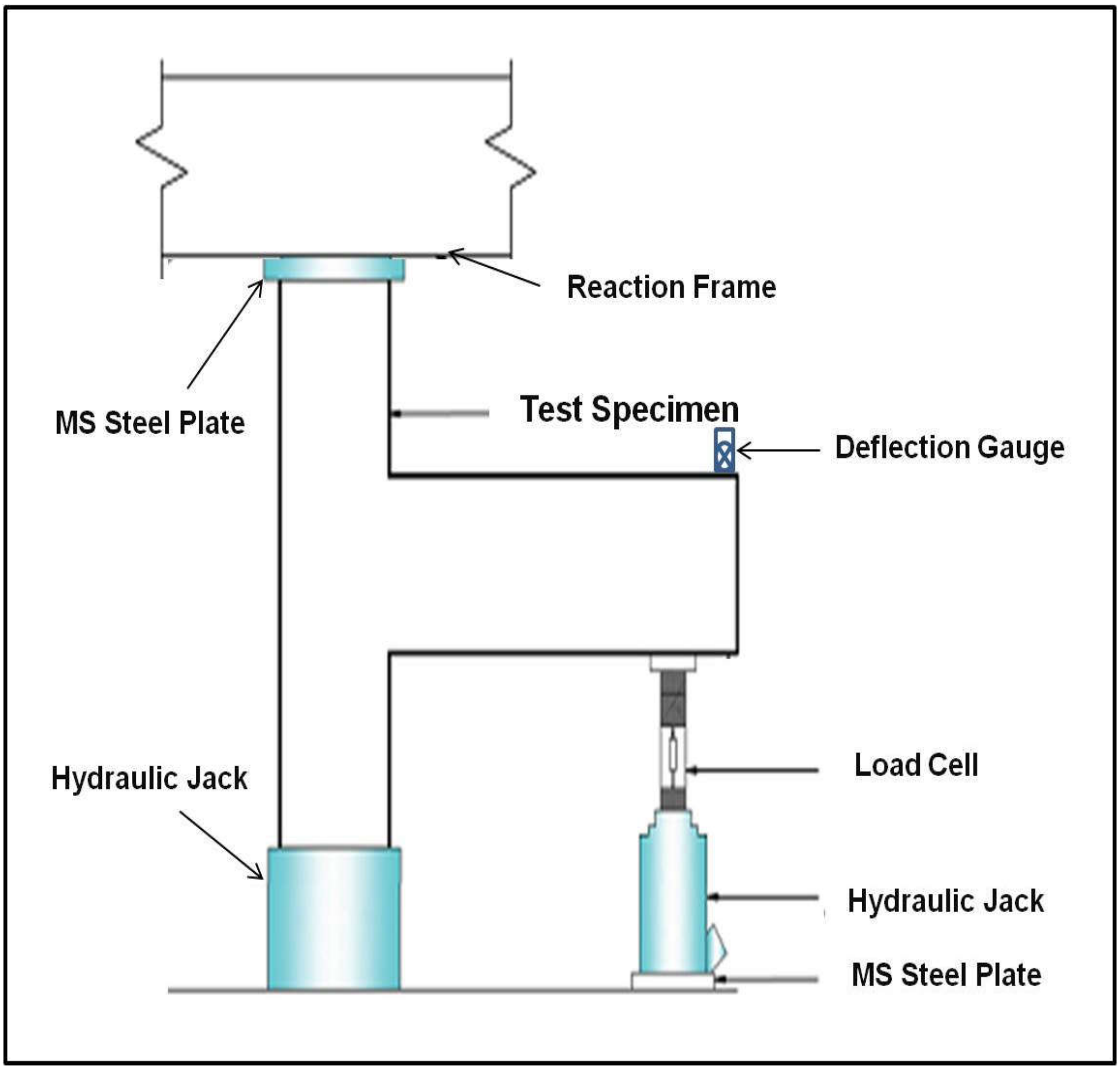


Figure 19: Line Diagram of Test Setup

SER	INSTRUMENTS
1	Hydraulic jack for column axial compressive loading
2	Hydraulic jack for loading of beam
3	Deflection gauge at top, free end of beam to measure displacement
4	Load cell to measure the load in positive and negative direction on beam
5	Load lifter

Table 10: Detail of instrumentation

4.4 Testing Setup

Standard test assembly was used with arrangements for static cyclic loading. The shear block was properly fixed to the floor. Load was applied axially with the help of hydraulic jack assembly to ensure no movement of column. Column ends were fitted with steel collars and steel plates were used at column ends to ensure uniform compressive load. The test setup is shown in Figure 20**.**

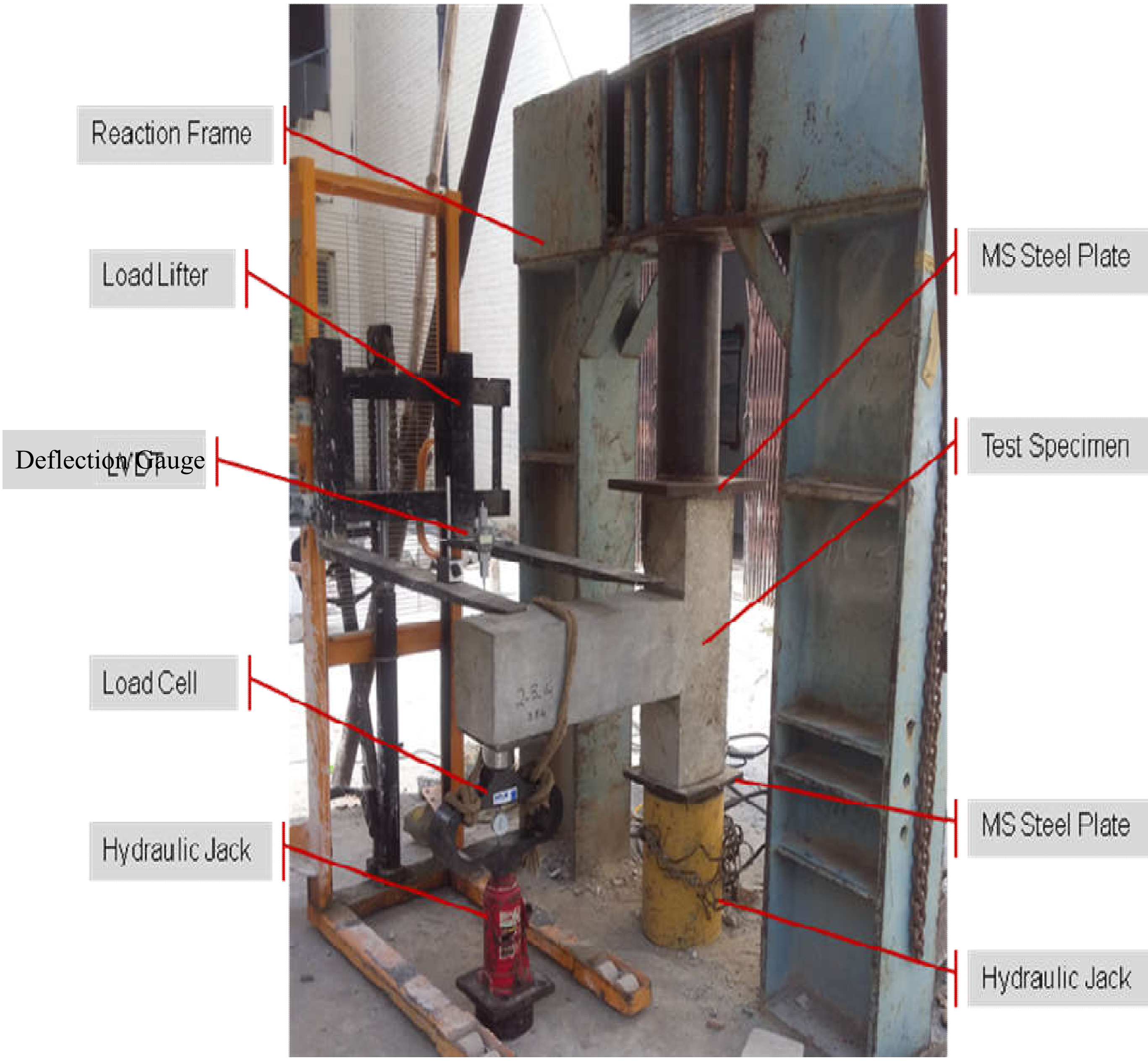


Figure 20: General layout of the test

Figure 21: Placing of Specimen for Test

Figure 22: Collars Installed at Column Ends

Figure 23: Steel plate at Column Ends

The procedure followed for conduct of test is as under:

a. The specimens were placed near the shear frame after identification of specimen markings/ coding. They were checked for any visual imperfections.
b. The steel collars were installed on column ends, thus nullifying any chance of column crushing at the ends.
c. The lifter was used to lift the specimen to the required position on the shear frame.
d. The specimen was than fixed inside the shear frame and compressive load was applied on column with the help of hydraulic jack, this ensures vertical stability of the sample. Moreover steel plates were placed on column ends for even distribution of load.
e. Deflection gauge was fixed at free end of beam on the top face in vertical position to measure the upward deflection as shown.

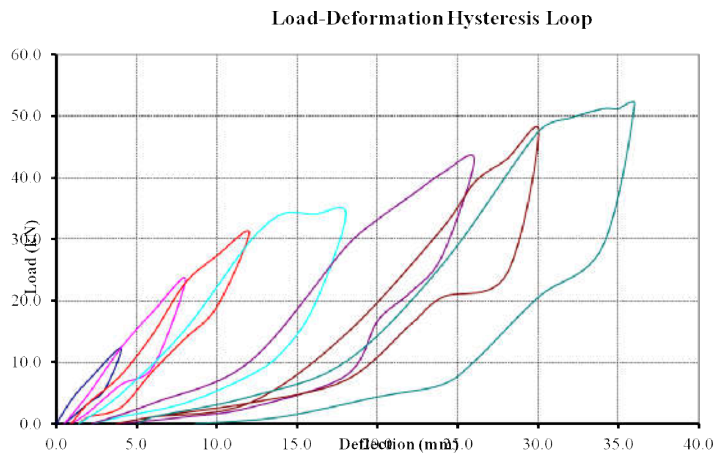
f. Another hydraulic jack was placed below the beam at its free end, this arrangement can apply load on the beam.
g. Between the hydraulic Jack and beam a load cell was placed to measure the magnitude of load being applied on the sample.
h. The load cell and the deflection gauge were calibrated before the start of test.
i. Load was then applied on the beam and the deflection was measured. The cyclic load was applied very slowly keeping the deflections at 1mm, 2mm, 4mm and so on. After every cycle load was released and the residual displacement was measured.
j. This procedure was repeated until failure of the joint was achieved (20 % degradation)
k. The cracks were observed and marked against the corresponding load/ deflections.
l. After testing the samples were again marked and placed near Concrete Laboratory at UET Taxila.
m. These samples will be used for retrofitting by another MS student for his MS thesis work.

4.5 Testing of specimen

12 x beam column joints were tested using the test setup. The test was conducted up till 20% degradation level. Data of deflection gauges fixed at top of beam near it's the free end and the load cell was recorded. The deflection was measured in mm and the load was measured in KN (after necessary conversion of load cell readings to KN). The data recorded was used to make the backbone curves and the hysteresis loops (using Excel). This data will be presented and analyzed in this paper.

4.5.1 Testing of CRCJ (1-4-#3)

In 7th cycle of loading 20% degradation was achieved. The deformation in the joint started at 12.5 KN load during the 1st cycle and achieved a displacement of 4 mm, with the appearance of a hair line crack at a distance of 2 mm from joint. In the 7th cycle peak load of 52 KN was recorded. The response of the sample in the form of hysteresis curve is plotted in Figure 24. The residual displacements became significant after 4th cycle. The residual displacement was 8.6 mm at the completion of test. The hysteresis response and backbone curve are shown below.



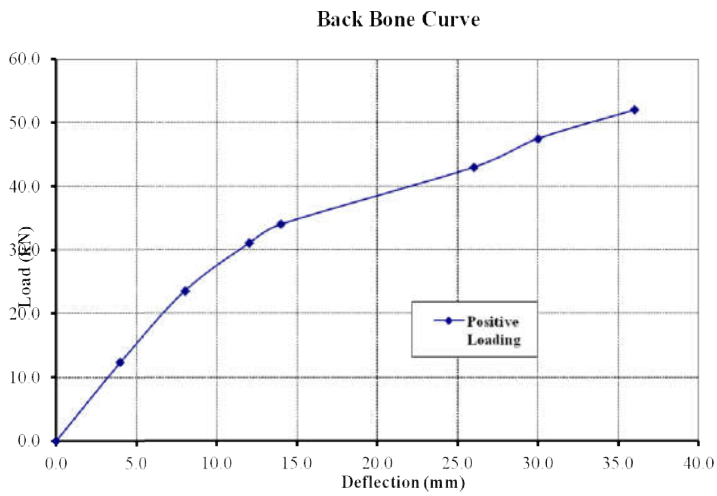
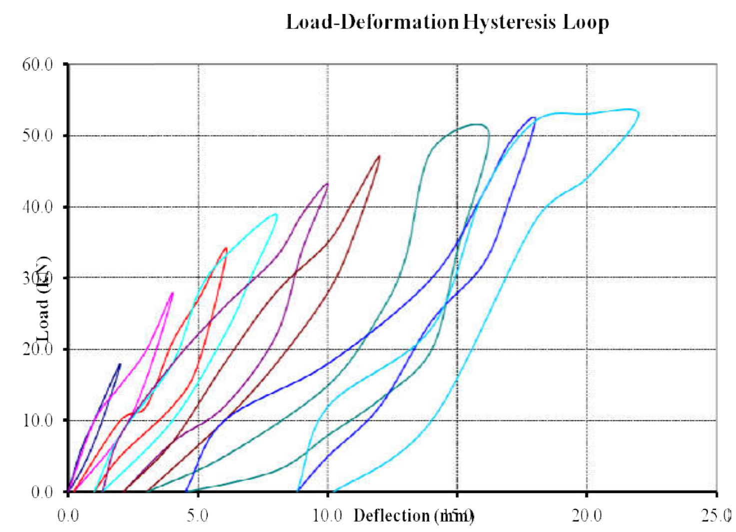


Figure 24: CRCJ (1-4-#3) Curves

4.5.2 Testing of CRCJ (2-4-#3)

In 9th cycle of loading 20% degradation was achieved. The deformation in the joint started at 18 KN load during the 1st cycle and achieved a displacement of 2 mm, with the appearance of a hair line crack at a distance of 6 mm from joint. In the 9th cycle peak load of 53 KN was recorded. The response of the sample in the form of hysteresis curve is plotted in Figure 25. The residual displacements became significant after 4th cycle. The residual displacement was 10.2 mm at the completion of test. The hysteresis response and backbone curve are shown below.



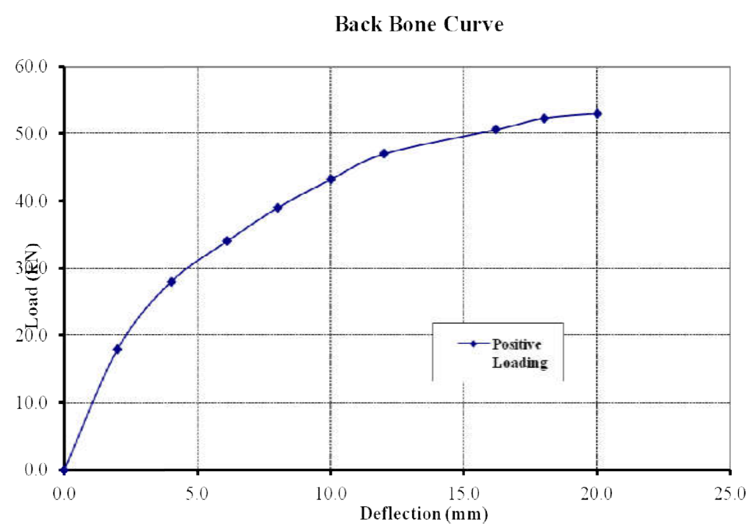


Figure 25: CRCJ (2-4-#3) Curves

4.5.3 Testing of SSCJ 02 (1-4-14)

In 9th cycle of loading 20% degradation was achieved. The deformation in the joint started at 18 KN load during the 1st cycle and achieved a displacement of 1 mm, with the appearance of a hair line crack at a distance of 9 mm from joint. In the 9th cycle peak load of 59 KN was recorded. The response of the sample in the form of hysteresis curve is plotted in Figure 26. The residual displacements became significant after 5th cycle. The residual displacement was 14.5 mm at the completion of test. The hysteresis response and backbone curve are shown below.

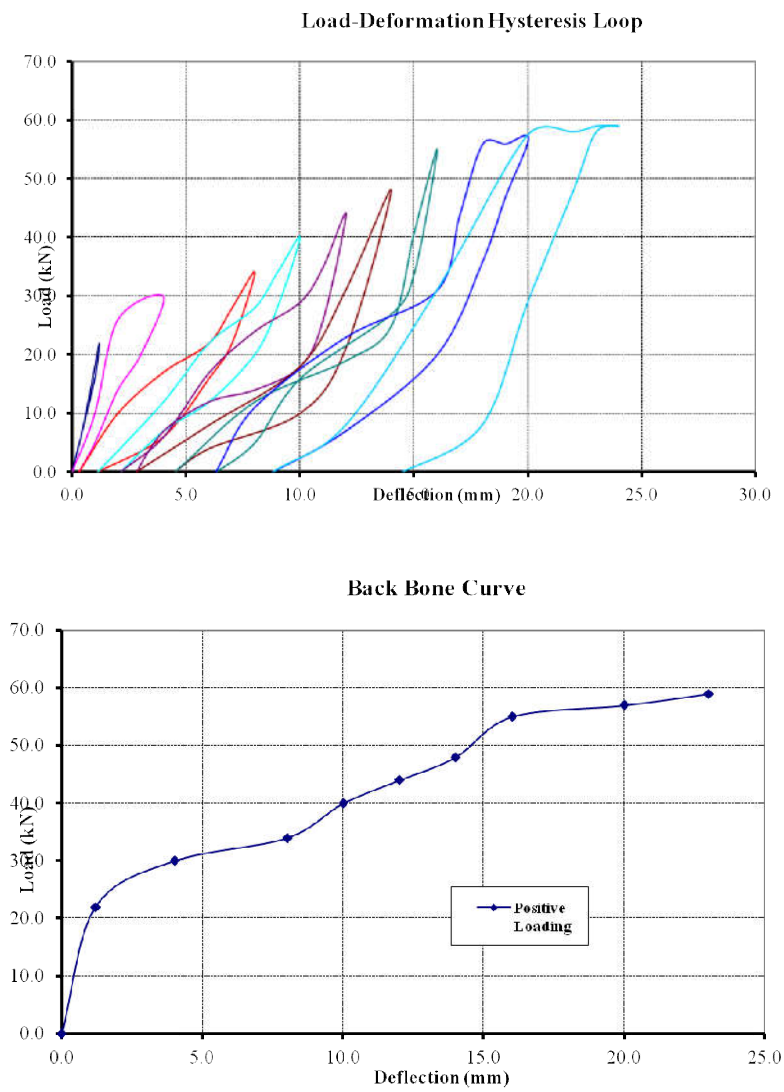
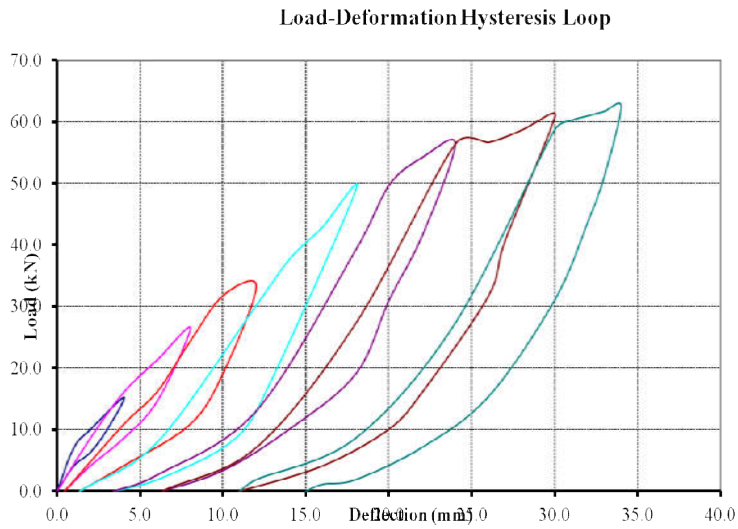


Figure 26: SSCJ 02 (1-4-14) Curves

4.5.4 Testing of SSCJ 02 (2-4-14)

In 7th cycle of loading 20% degradation was achieved. The deformation in the joint started at 16 KN load during the 1st cycle and achieved a displacement of 2 mm, with the appearance of a hair line crack at a distance of 8 mm from joint. In the 7th cycle peak load of 62 KN was recorded. The response of the sample in the form of hysteresis curve is plotted in Figure 27. The residual displacements became significant after 4th cycle. The residual displacement was 15 mm at the completion of test. The hysteresis response and backbone curve are shown below.



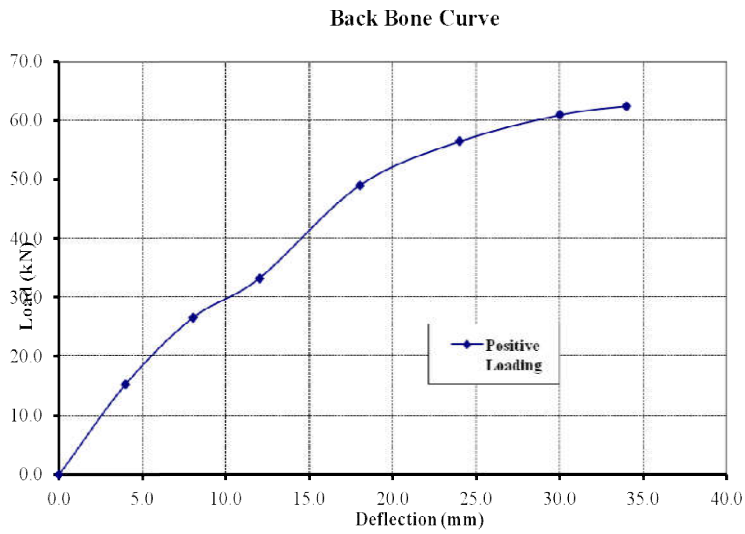
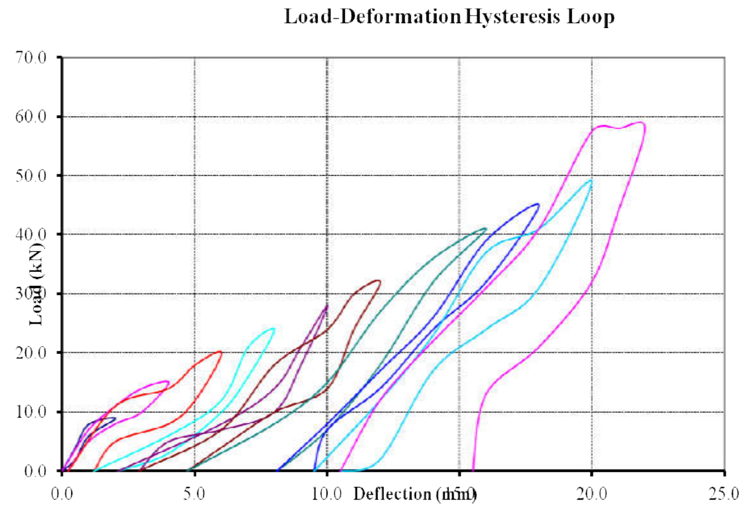


Figure 27: SSCJ 02 (2-4-14) Curves

4.5.5 Testing of SSCJ 1.3 (1-4-18)

In 10th cycle of loading 20% degradation was achieved. The deformation in the joint started at 9 KN load during the 1st cycle and achieved a displacement of 2 mm, with the appearance of a hair line crack at a distance of 12 mm from joint. In the 10th cycle peak load of 58 KN was recorded. The response of the sample in the form of hysteresis curve is plotted in Figure 28. The residual displacements became significant after 5th cycle. The residual displacement was 15.5 mm at the completion of test. The hysteresis response and backbone curve are shown below.



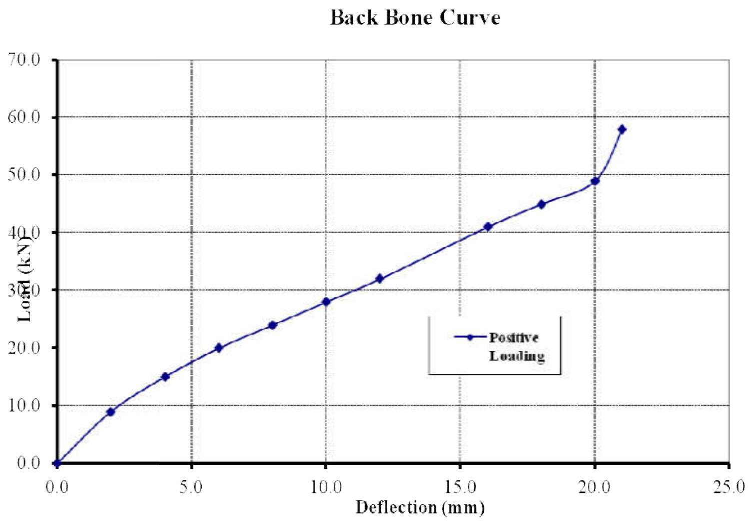
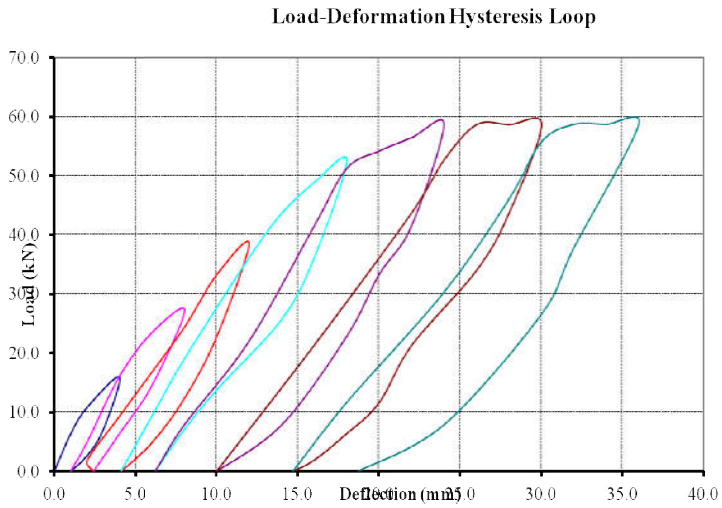


Figure 28: SSCJ 1.3 (1-4-18) Curves

4.5.6 Testing of SSCJ 1.3 (2-4-18)

In 7th cycle of loading 20% degradation was achieved. The deformation in the joint started at 16 KN load during the 1st cycle and achieved a displacement of 4 mm, with the appearance of a hair line crack at a distance of 10 mm from joint. In the 9th cycle peak load of 59 KN was recorded. The response of the sample in the form of hysteresis curve is plotted in Figure 29. The residual displacements became significant after 5th cycle. The residual displacement was 18.7 mm at the completion of test. The hysteresis response and backbone curve are shown below.



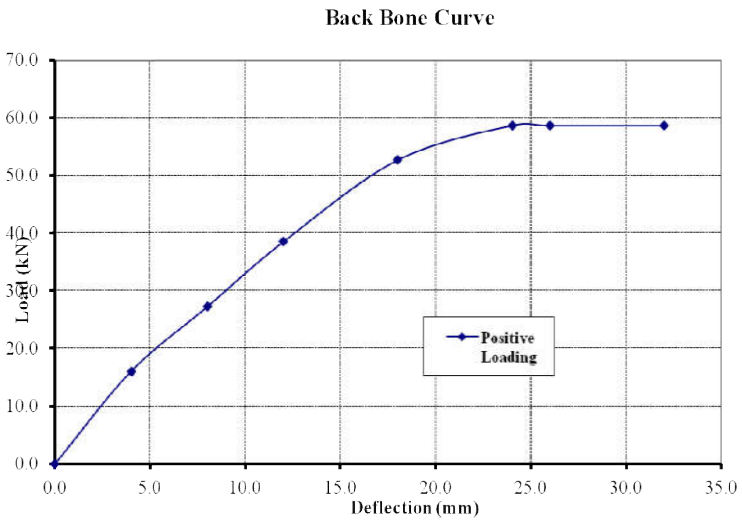
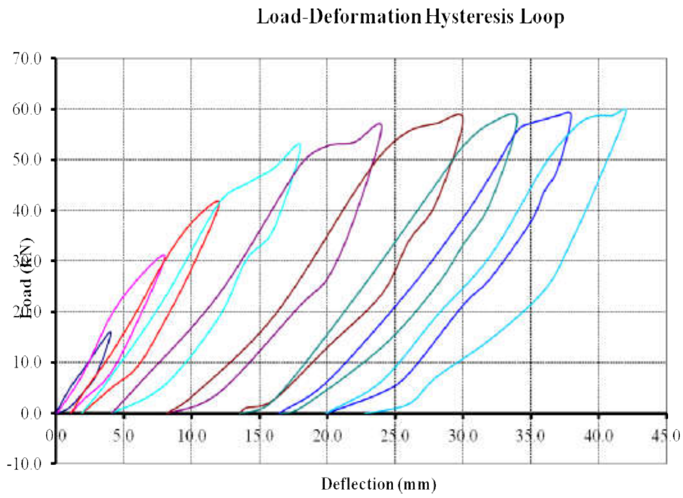


Figure 29: SSCJ 1.3 (2-4-18) Curves

4.5.7 Testing of CRCJ (1-3#3)

In 9th cycle of loading 20% degradation was achieved. The deformation in the joint started at 16 KN load during the 1st cycle and achieved a displacement of 4 mm, with the appearance of a hair line crack at a distance of 32 mm from joint. In the 9th cycle peak load of 59 KN was recorded. The response of the sample in the form of hysteresis curve is plotted in Figure 30. The residual displacements became significant after 4th cycle. The residual displacement was 22 mm at the completion of test. The hysteresis response and backbone curve are shown below.



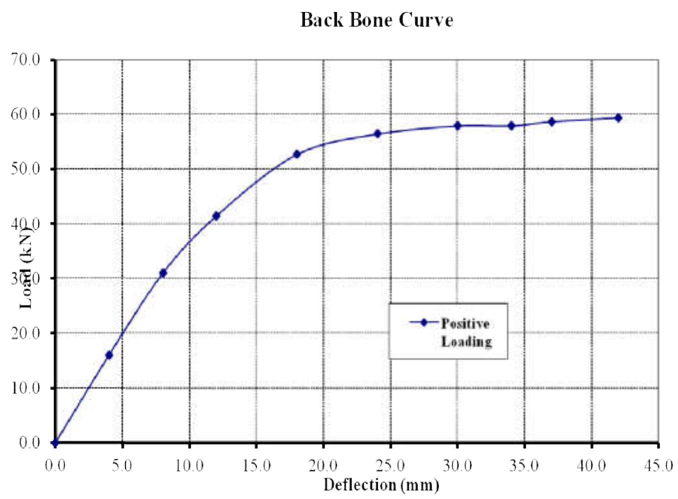
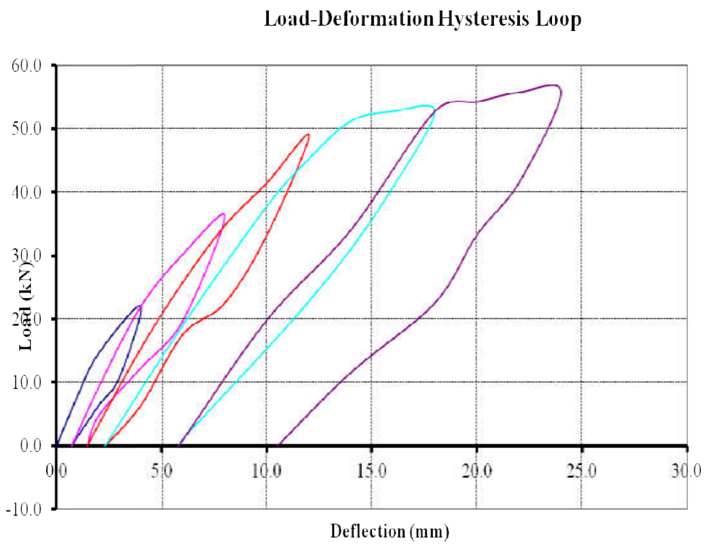


Figure 30: CRCJ (1-3#3) Curves

4.5.8 Testing of CRCJ (2-3#3)

In 5th cycle of loading 20% degradation was achieved. The deformation in the joint started at 22 KN load during the 1st cycle and achieved a displacement of 5 mm, with the appearance of a hair line crack at a distance of 9 mm from joint. In the 5th cycle peak load of 55 KN was recorded. The response of the sample in the form of hysteresis curve is plotted in Figure 31. The residual displacements became significant after 3rd cycle. The residual displacement was 10.5 mm at the completion of test. The hysteresis response and backbone curve are shown below.



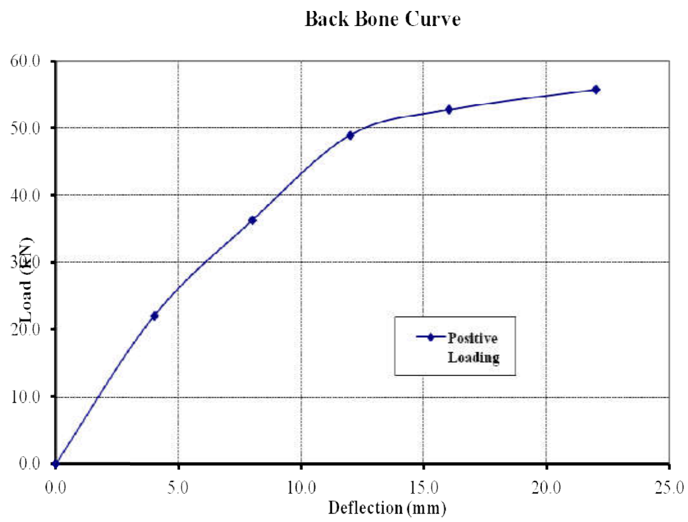
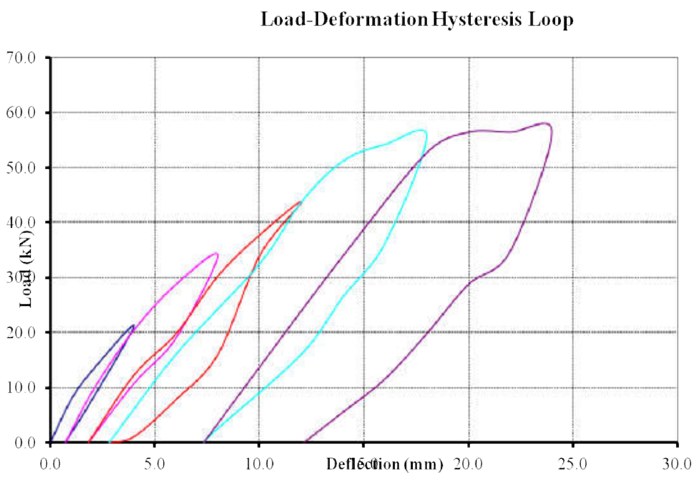


Figure 31: CRCJ (2-3#3) Curves

4.5.9 Testing of SSCJ 2 (1-3-14)

In 8th cycle of loading 20% degradation was achieved. The deformation in the joint started at 21 KN load during the 1st cycle and achieved a displacement of 3 mm, with the appearance of a hair line crack at a distance of 12 mm from joint. In the 9th cycle peak load of 57 KN was recorded. The response of the sample in the form of hysteresis curve is plotted in Figure 32. The residual displacements became significant after 4th cycle. The residual displacement was 12 mm at the completion of test. The hysteresis response and backbone curve are shown below.



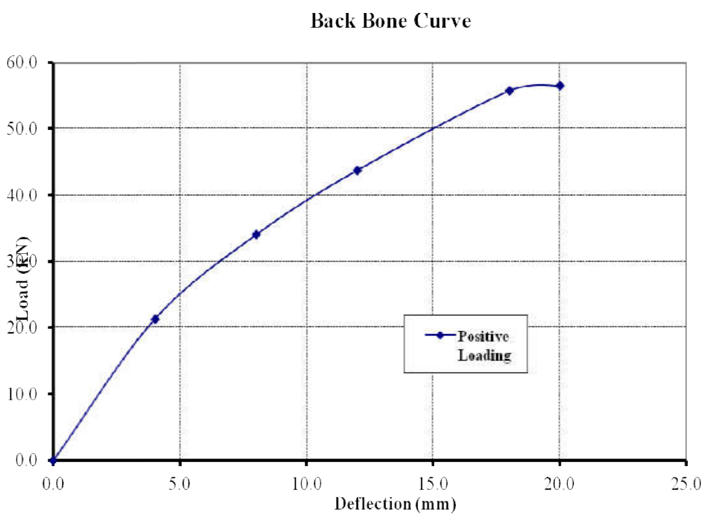
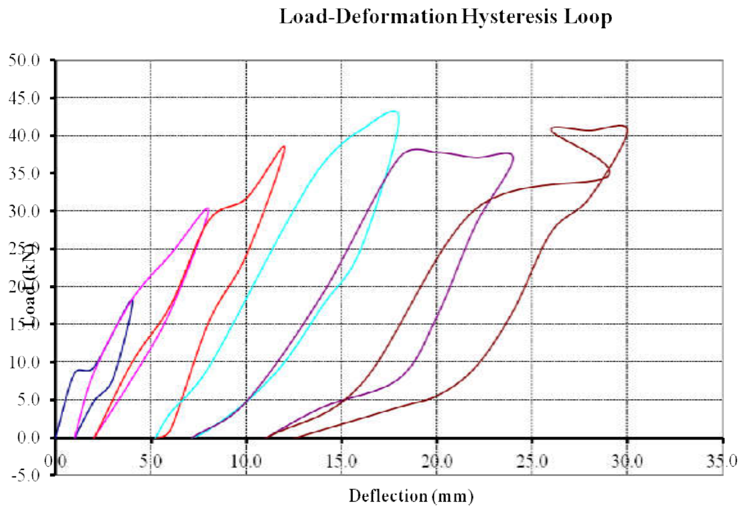


Figure 32: SSCJ 2 (1-3-14) Curves

4.5.10 Testing of SSCJ 2 (2-3-14)

In 8th cycle of loading 20% degradation was achieved. The deformation in the joint started at 18 KN load during the 1st cycle and achieved a displacement of 2 mm, with the appearance of a hair line crack at a distance of 9 mm from joint. In the 8th cycle peak load of 50 KN was recorded. The response of the sample in the form of hysteresis curve is plotted in Figure 33. The residual displacements became significant after 4th cycle. The residual displacement was 12 mm at the completion of test. The hysteresis response and backbone curve are shown below.



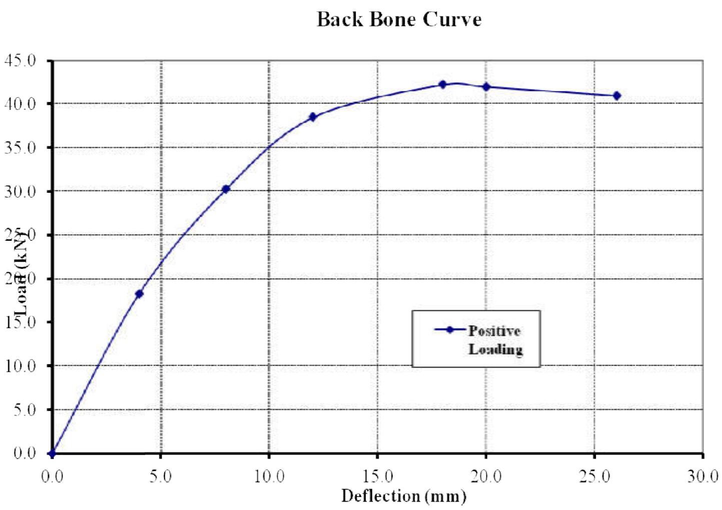


Figure 33: SSCJ 2 (2-3-14) Curves

4.5.11 Testing of SSCJ 1.3 (1-3-18)

In 7th cycle of loading 20% degradation was achieved. The deformation in the joint started at 18 KN load during the 1st cycle and achieved a displacement of 3 mm, with the appearance of a hair line crack at a distance of 9 mm from joint. In the 7th cycle peak load of 60 KN was recorded. The response of the sample in the form of hysteresis curve is plotted in Figure 34. The residual displacements became significant after 4th cycle. The residual displacement was 20 mm at the completion of test. The hysteresis response and backbone curve are shown below.

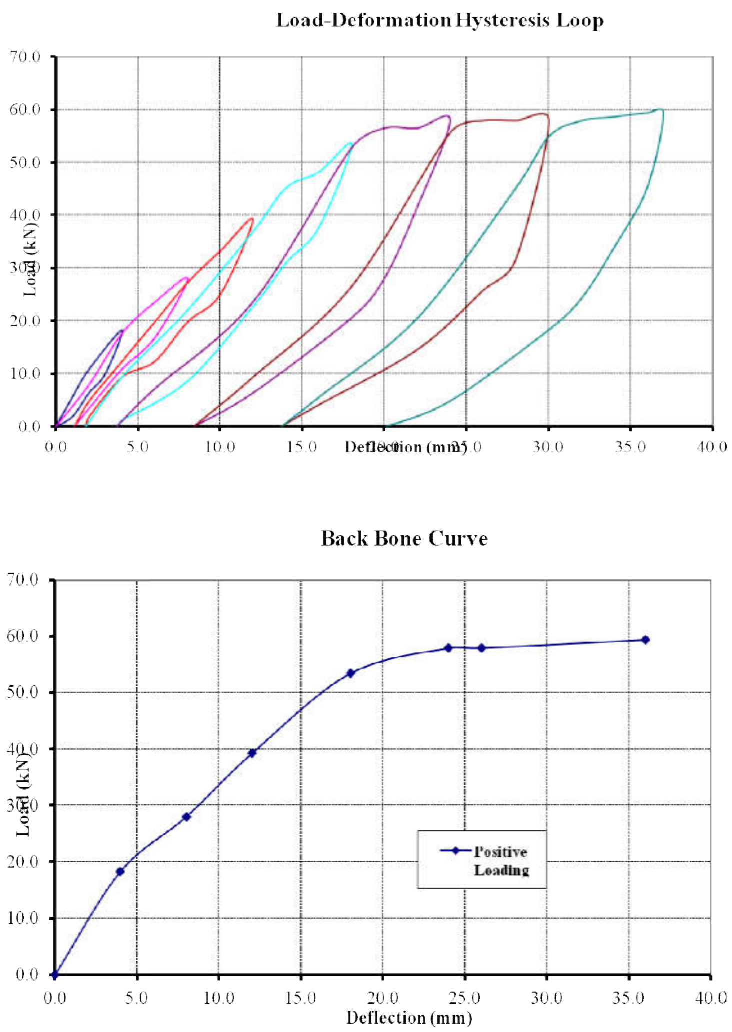
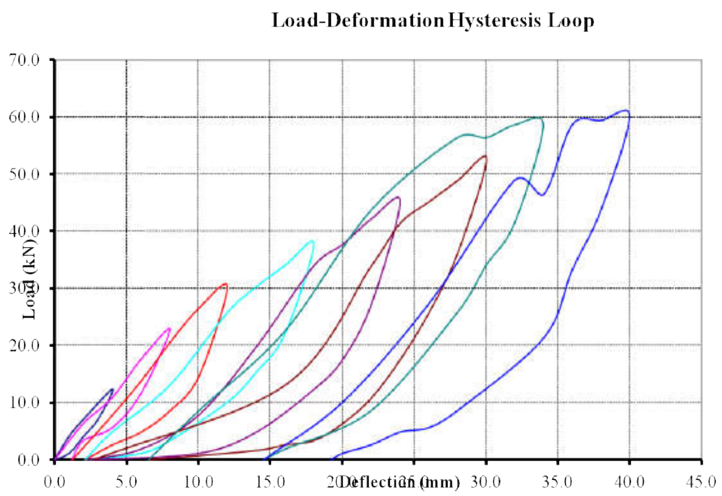


Figure 34: of SSCJ 1.3 (1-3-18) Curves

4.5.12 Testing of SSCJ 1.3 (2-3-18)

In 8th cycle of loading 20% degradation was achieved. The deformation in the joint started at 12 KN load during the 1st cycle and achieved a displacement of 3 mm, with the appearance of a hair line crack at a distance of 9 mm from joint. In the 8th cycle peak load of 61 KN was recorded. The response of the sample in the form of hysteresis curve is plotted in Figure 35. The residual displacements became significant after 4th cycle. The residual displacement was 19 mm at the completion of test. The hysteresis response and backbone curve are shown below.



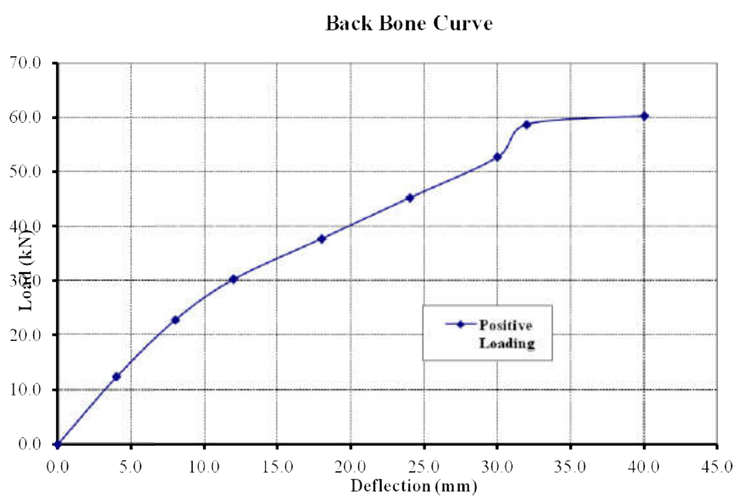


Figure 35: of SSCJ 1.3 (2-3-18) Curves

CHAPTER 5

COMPARISONS AND ANALYSIS

5.1 Comparison of Test Results

In this chapter the test/ experimental results will be compared and analyzed. In the tables of comparison, gain and loss of a specific parameter for the joint being compared is indicated with a positive or negative sign respectively. Joint from 28 Mpa and 21 Mpa samples will be compared and average values of same type of samples in each group will be used.

5.2 Hysteresis Response

The backbone curves obtained from the hysteresis loops of the beam column joint samples of 28 Mpa strength are superimposed in Figure. It is observed that the response is approximately identical up to 30 KN. SSCJ-02 (2-4-14) gave a higher peak load and exhibits better ductile response. The better performance of joint is due to the fact that it has withstood additional number of cycles before reaching 20% degradation level of its peak strength. The comparison of hysteresis response is done as area under the backbone curve. It can be seen that SSJC-02 has depicted larger energy dissipation, which is actually the work done or area under the curve. This was possible because of relatively better post peak response. The concrete being of lesser strength than steel in fact fails well below the yield stress of steel transverse reinforcement. However, SSJC-02 samples have displayed comparatively better response, this was due to the reason that steel strip confinement was relatively more ductile in nature. Table 11 and 12 shows the % gain/ loss of area under the backbone curves and the peak load.

BEAM COLUMN JOINT	CRCJ	SSCJ-02	SSCJ-1.3	GAIN / LOSS OF SSCJ-02 VERSUS CRCJ (%)	GAIN / LOSS OF SSCJ-1.3 VERSUS CRCJ (%)
Peak load (KN)	52	62	59	19.2	13.4
Area under backbone curves (kN-mm)	590	750	660	27.1	11.8

Table 11: Comparison of peak load and area under the backbone curve for 28 Mpa samples

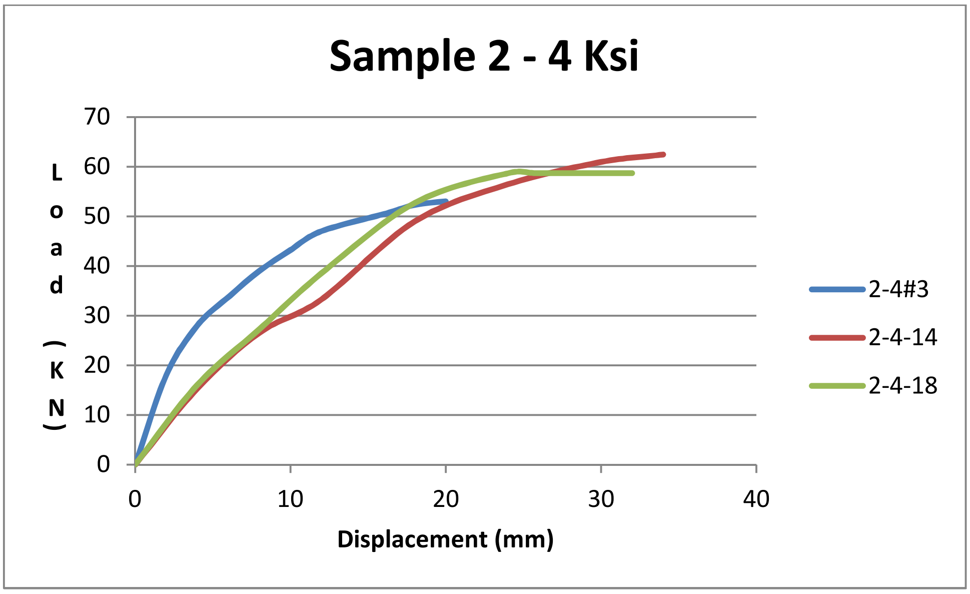


Figure 36: Backbone Curves for 28 Mpa samples

BEAM COLUMN JOINT	CRCJ	SSCJ-02	SSCJ-1.3	GAIN / LOSS OF SSCJ-02 VERSUS CRCJ (%)	GAIN / LOSS OF SSCJ-1.3 VERSUS CRCJ (%)
Peak load (KN)	55	60	58	9	5.4
Area under backbone curves (kN-mm)	910	1120	940	23.1	3.3

Table 12: Comparison of peak load and area under the Backbone curve for 21 Mpa samples

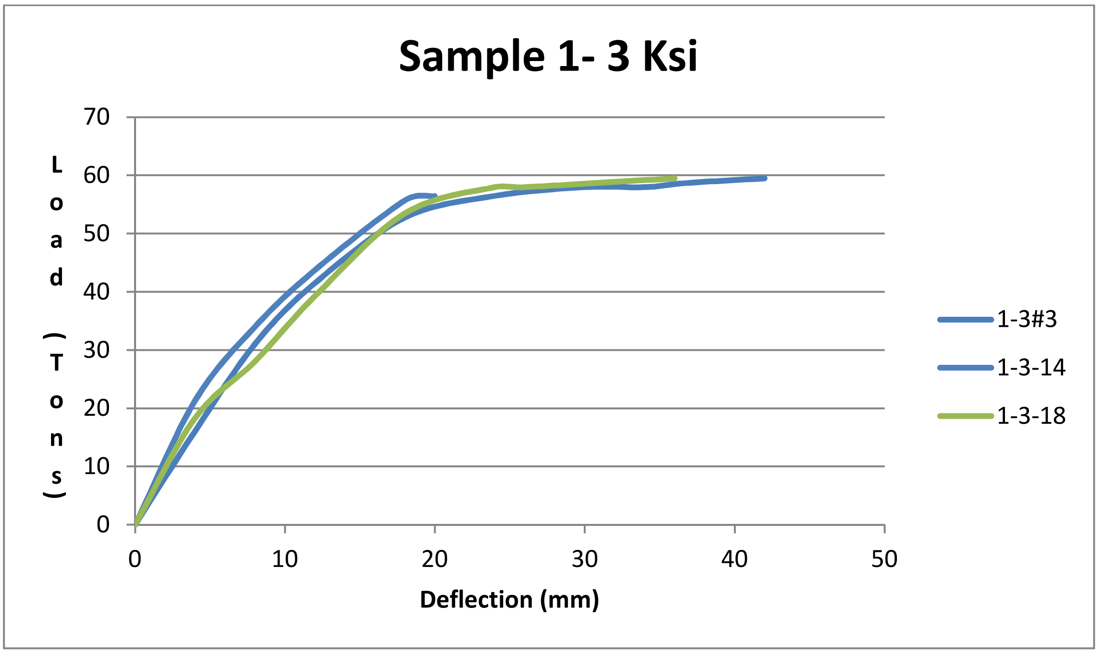


Figure 37: Backbone Curves for 21 Mpa samples

5.3 Yield, Peak and Ultimate Load Displacement Points

Table 13 and 14 shows a comparison of the yield load, peak load and ultimate displacement points. It is clear that SSCJ-02 resisted average 12.5% and 7% greater load at peak load points as compared to CRCJ and SSCJ-1.3 respectively.

PARAMETER	DISPLACEMENT	LOAD
CRCJ		
Yield point	4	28
Peak load	18	48
Ultimate displacement	38	52.7
SSCJ-02		
Yield point	6	18
Peak load	16	54
Ultimate displacement	31	62
SSCJ-1.3		
Yield point	6	17
Peak load	18	50
Ultimate displacement	32	56

Table 13: Yield, peak and ultimate load-displacement points of 28 Mpa Samples

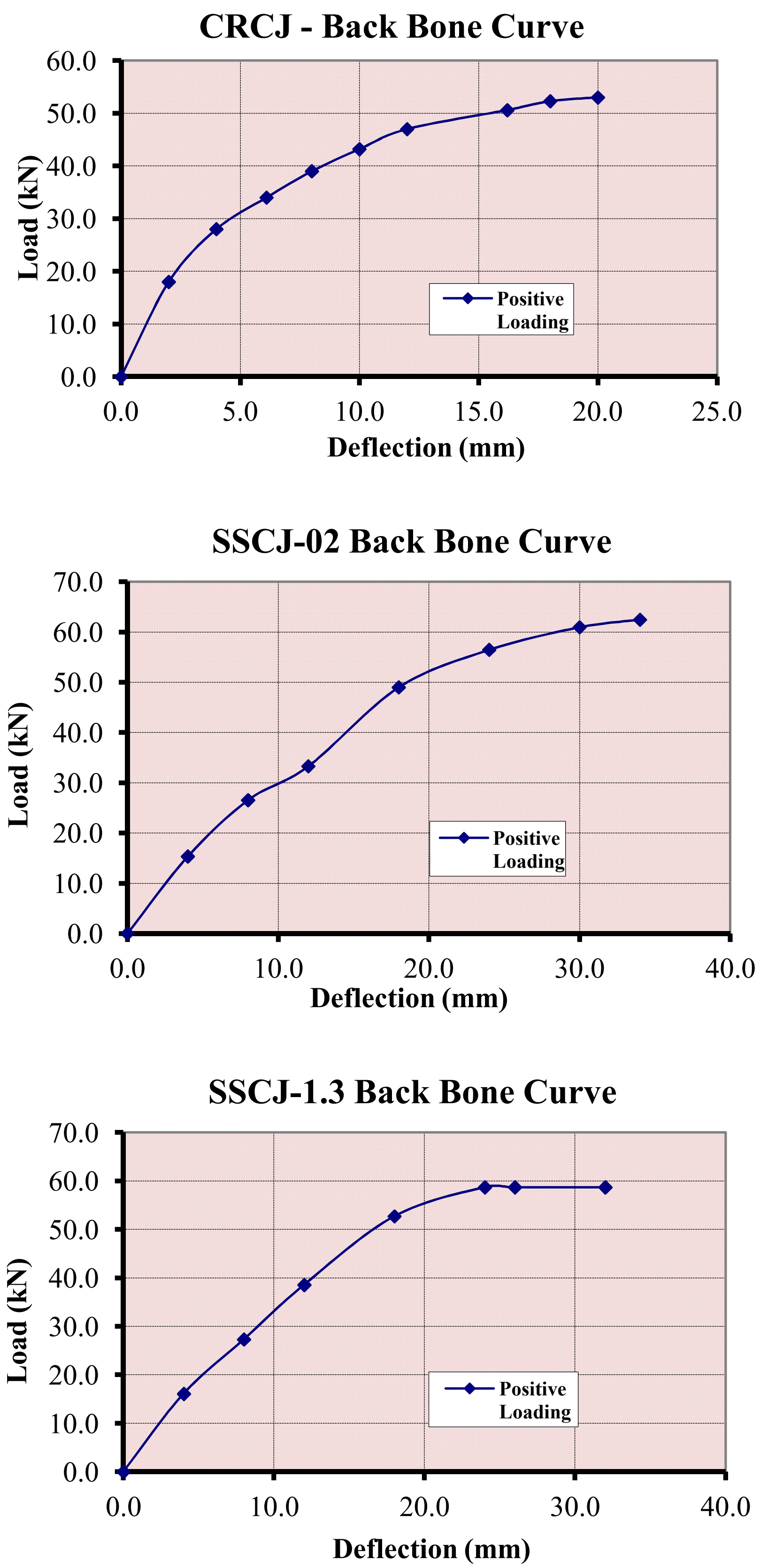


Figure 38: Yield, peak and ultimate load-displacement points of 28 Mpa Samples

PARAMETER	DISPLACEMENT	LOAD
CRCJ		
Yield point	11	28
Peak load	18	52
Ultimate displacement	42	55
SSCJ-02		
Yield point	4	21
Peak load	18	55
Ultimate displacement	20	59
SSCJ-1.3		
Yield point	5	20
Peak load	18	52
Ultimate displacement	35	58

Table 14: Yield, peak and ultimate load-displacement points of 21 Mpa Samples

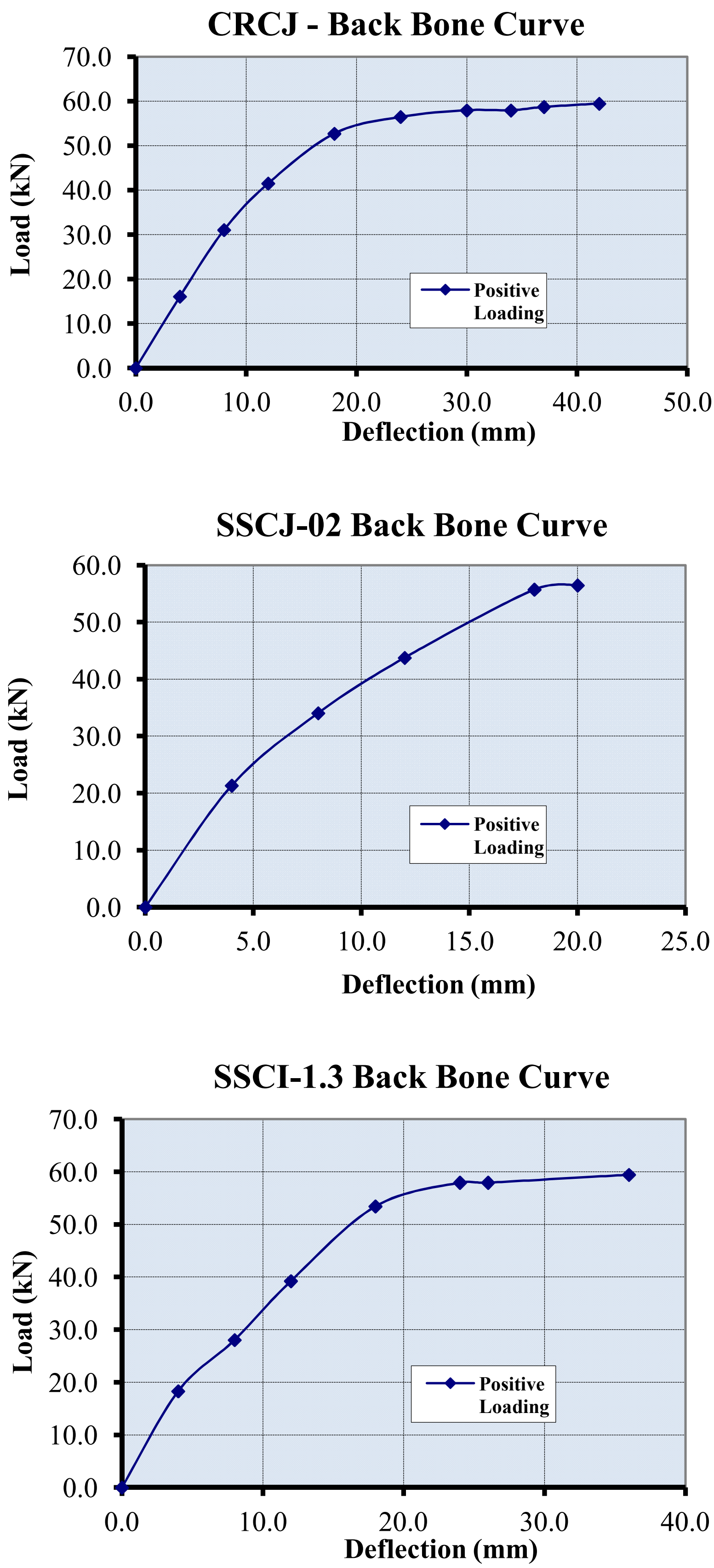


Figure 39: Yield, peak and ultimate load-displacement points of 21 Mpa Samples

5.4 Residual Displacement

The residual displacement were recorded and shown in table below. CRCJ and SSCJ samples depicted the same trend. Comparatively lesser residual displacement of SSCJ-02 samples indicates a higher confining pressure as compared to CRCJ and SSCJ-1.3 samples.

JOINT	YIELD POINT (mm)	PEAK LOAD (mm)	ULTIMATE DISPLACEMENT (mm)
CRCJ	8	18	38
SSCJ-02	6	16	31
SSCJ-1.3	6	18	32

Table 15: Residual displacements of 28 Mpa Samples

JOINT	YIELD POINT (mm)	PEAK LOAD (mm)	ULTIMATE DISPLACEMENT (mm)
CRCJ	11	18	42
SSCJ-02	4	18	20
SSCJ-1.3	5	18	35

Table 16: Residual displacements of 21 Mpa Samples

5.5 Energy Dissipation

Hysteresis response of structural members under cyclic loading can be used for calculation of their energy. The area in a hysteresis cycle/ loop is the total energy dissipated in a cycle. The addition of damping and damage energy gives us the total energy. Figure 40 shows the total, damage, damp and strain energy on the hysteresis loop. These energies are calculated from the backbone curves of the samples. The amounts of energies dissipated by different samples are compared in Table 17 and 18. It is pertinent to mention that due to improved post peak behavior SSCJ-02, it has dissipated 23.1 to 27.1% higher energy as compared to CRCJ.

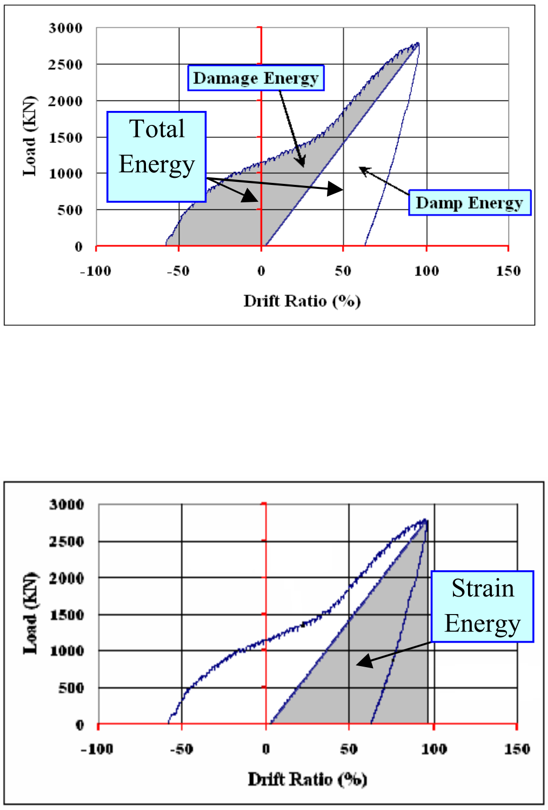


Figure 40: Damage, Damp and Strain Energy

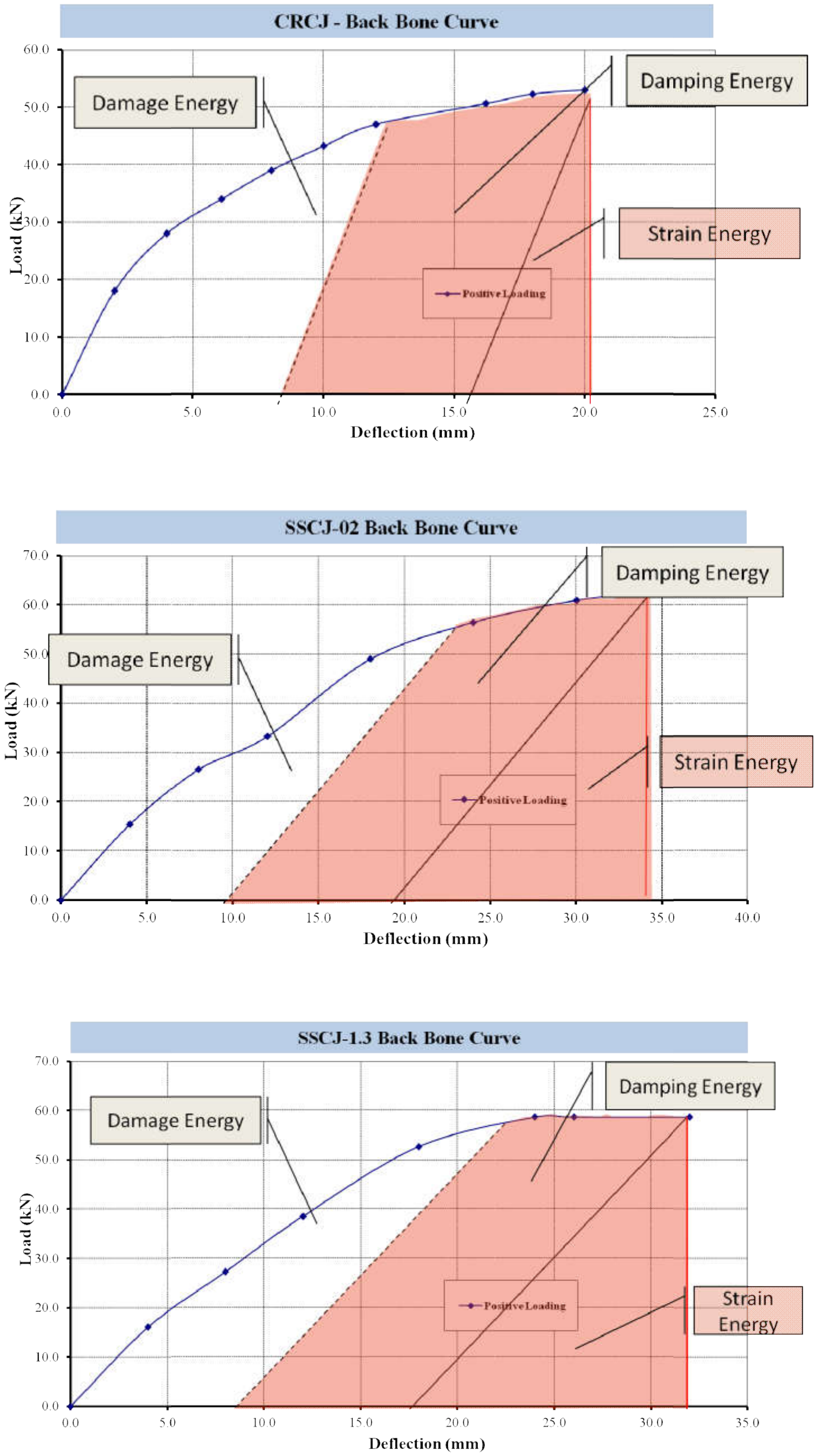


Figure 41: Energy Dissipation 28 Mpa Samples

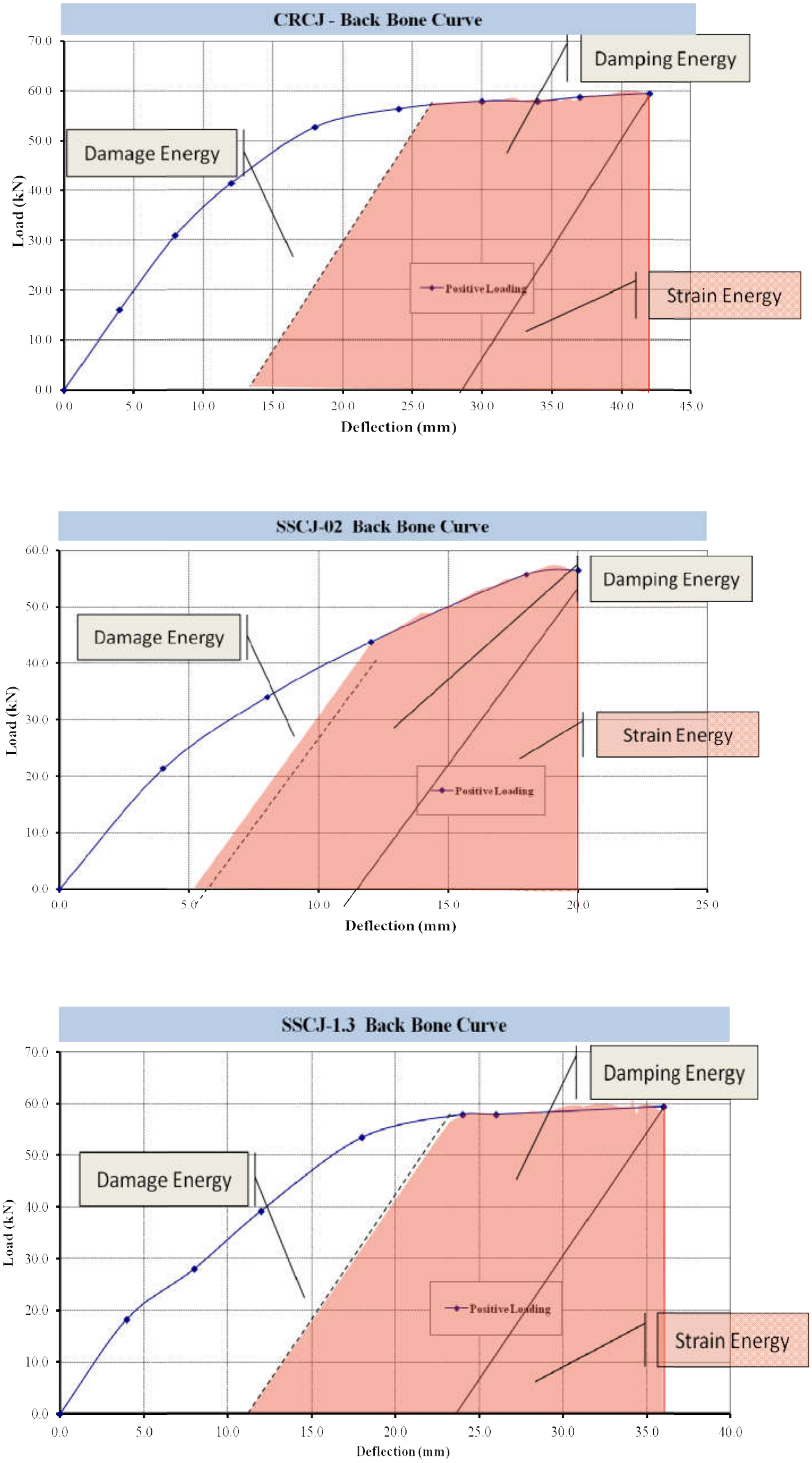


Figure 42: Energy Dissipation 21 Mpa Samples

ENERGY DISSIPATED	CRCJ (KN/mm)	SSCJ-02 (KN/mm)	SSCJ-1.3 (KN/mm)	GAIN/LOSS SSCJ-02	GAIN/LOSS SSCJ-1.3
Total energy	590	750	680	27.1%	15.2%
Damping energy	280	340	310	21.4%	10.7%
Damage energy	310	410	370	32.2%	19.3%
Strain energy	450	560	510	24.4%	13.3%

Table 17: Energy Dissipated by Joints of 28 Mpa

ENERGY DISSIPATED	CRCS-40 (KN/mm)	SSCJ-02 (KN/mm)	SSCJ-1.3 (KN/mm)	GAIN/LOSS SSCJ-02	GAIN/LOSS SSCJ-1.3
Total energy	910	1120	990	23.1%	8.7%
Damping energy	480	600	530	25%	10.4%
Damage energy	430	520	470	20.9%	9.3%
Strain energy	490	610	580	24.5%	18.3%

Table 18: Energy Dissipated by Joints of 21 Mpa

5.6 Ultimate Strength

Strength is important factor for stability and serviceability of a structure. Strength is the total amount of load the structure can bear before failing/ collapse. I calculated the strength by applying cyclic loading. The procedure of loading is apply a certain load and then remove it The procedure is continued until the ultimate load is reached, where the load started decreasing or remains constant with the increase in displacement.

The ultimate strength of steel stirrups and steel strips are compared, strength of 14 gauge (2mm) strips are found to be 10 - 12% higher than that of stirrups likewise strength of 18 gauge (1.3mm) strips are 7 - 10% higher that of stirrups.

We also tested three concrete cylinders to check the compressive strength of concrete and 28 days compressive strength of concrete is found to be 28 Mpa and 21 Mpa respectively for both the specimen groups. Non-destructive test of beam column joints was also conducted by Schmidt-hammer test and the average compressive strength at joints and top of specimen was found to be more than the desired range.

5.7 Ductility

Performance of a structure beyond its peak load point is measured by its ductility. Ductility is the property of a structure due to which it can withstand large deformations without collapse. The ductile behavior of RC structures is greatly influenced by the use of steel reinforcement and confinement. Ductility of members is termed as the ability to deform after the yield point, it is also the ability to dissipate energy. In general, ductility is a structural property which is governed by fracture and depends on structure size. Figure below shows a typical comparison of ductility curves of confined and un-confined concrete. It is evident that with increase in confinement the ductility of the concrete member/ structure increases. Mathematically it is the ratio of prescribed displacement beyond yield to the displacement at yield. Hence, in general terms the ductility of a structure can be defined by the ductility factor:

$$\mu = \frac{\Delta_u}{\Delta_y}$$

Δu = the ultimate deflection of member

Δy = the deflection at the yield point

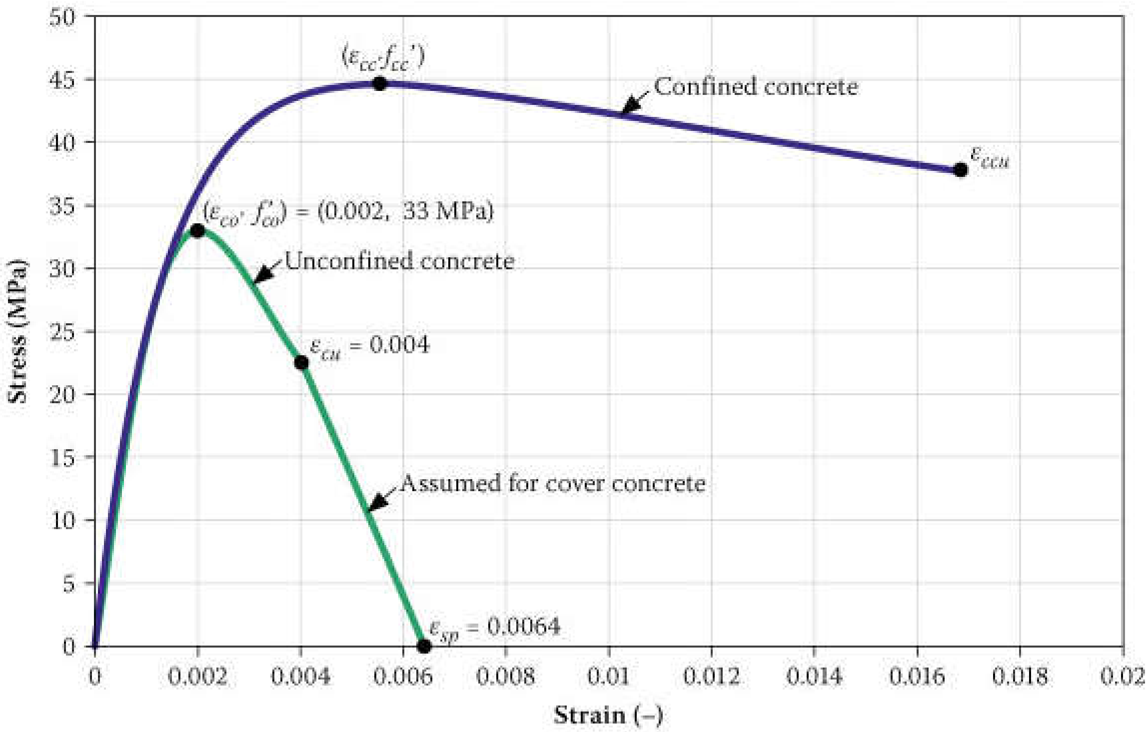


Figure 43: Ductility of Concrete

Ductility of different samples (28 Mpa and 21 Mpa samples consisting of CRCJ, SSCJ-02 and SSCJ-1.3) is calculated and compared in Table 19.

JOINT TYPE	DUCTILITY	GAIN/LOSS % SSCJ-02	GAIN/LOSS % SSCJ-1.3
CRCJ	4.75	7.3	12.2
SSCJ-02	5.10		
SSCJ-1.3	5.33		

Table 19: Ductility of 28 Mpa Samples

JOINT TYPE	DUCTILITY	GAIN/LOSS % SSCJ-02	GAIN/LOSS % SSCJ-1.3
CRCJ	3.81	23.3	27.3
SSCJ-02	4.7		
SSCJ-1.3	4.85		

Table 20: Ductility of 21 Mpa Samples

From comparisons it is evident that the ductility of strip confined beam column joints was found to be 7-27 % more than of samples confined with stirrups. In fact our basic aim is to increase the ductility by increasing confining area/ pressure, as we are doing static cyclic analysis and during an event of seismic activity ductility of structural components like beam column joint plays a vital role in dissipation of energy. 7.3 – 23.3 % increase in ductility is observed in 14 gauge (2 mm) samples, while 12.2 – 27.3 % increase in ductility is observed in 18 gauge (1.3 mm) samples.

The crack propagation in samples during conduct of test were observed and recorded. In 28 Mpa samples first crack in CRCJ was observed at 4 mm deflection, first crack in SSCJ - 02 was observed at 5mm deflection and in SSCJ – 1.3 first crack was observed at 7mm defection. The pattern of crack propagation is shown in figures.

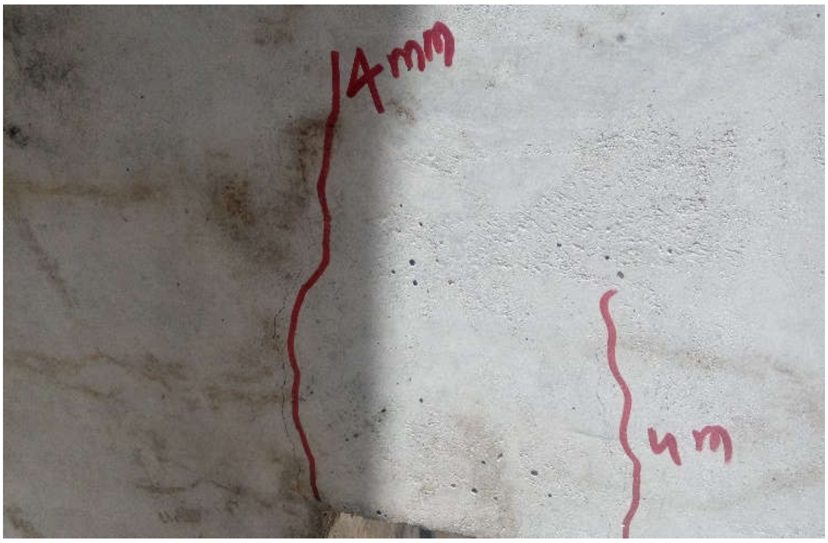


Figure 44: First Crack Propagation

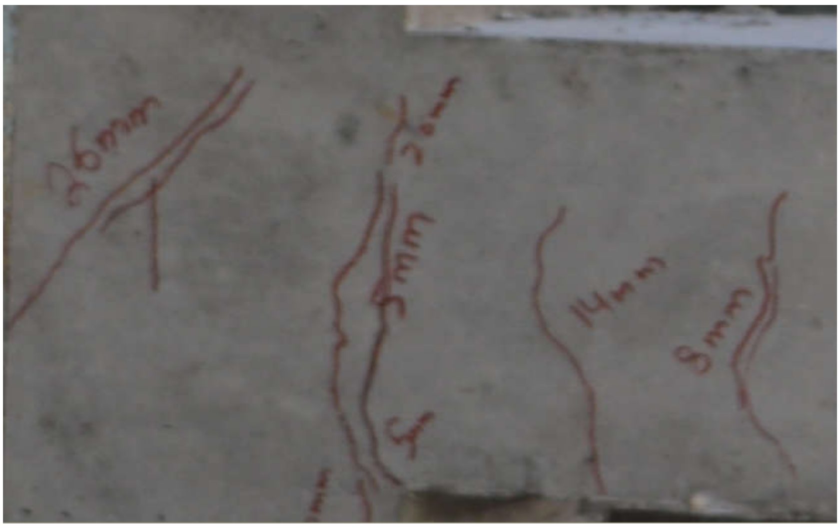


Figure 45: Appearance of cracks in joint

Figure 46: On Completion of Test

CONCLUSIONS

The research conducted was based on enhancing the contact area and confining pressure of transverse reinforcement in RC beam column joints, which reflected positive results. The experiment on Reinforced Concrete beam column joints confined with steel stirrups and steel strips under cyclic loading indicated better performance results for steel strip confined samples. The comparison of peak load, ultimate strength, energy dissipation and ductility of SSCJ with CRCJ indicates that SSCJ-02 samples displayed better performance in the post peak region.

Thus it is concluded that using steel strips of 14 gauge as transverse reinforcement yields better results for normal strength concrete. This study serves as a baseline to conduct future experimentation of steel strip confined joints at an enhanced scale. The conduct of test under cyclic loading gives us an insight of the damage progression and the occurrence of failure. The comparison of data of backbone curves and hysteresis response discussed in the study serves as a guideline for future research.

RECOMMENDATIONS

Following Recommendations are suggested for future research projects.

1. As area of transverse steel reinforcement has been kept same for all the samples, further study can be conducted with reduced steel area, keeping parameters of strength and ductility same. Thus optimization in use of steel area can be achieved which can reduce the cost of construction.
2. Steel strips of different gauges can be used to find the most optimum width to thickness ratio for strips.
3. The number of specimens can be increased to further study the behaviour of RC joints.
4. This experimental study was focused on exterior RC beam column joints, further research on interior joints with high strength concrete can be carried out.
5. The damaged samples can be retrofitted with various techniques and further evaluated.

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