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Retrofitting of existing conventional concrete coloumn with Carbon Fiber-Reinforced polymer (CFRP)

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Abstract:- Carbon Fibre Reinforced Polymer (CFRP) wrapping in the existing structure column is one of the best method of retrofitting. The sharpness in the square column edges reduce the uniform distribution of confinement pressure and reduce the confined column performance. The square columns are modified to circular to avoid sharp edges in the columns. In this project the CFRP is used with PVC (Poly Vinyl Chloride) to check the axial and load-deformation behaviour of the columns. Ten columns with five different types are used in this project to fully utilize the efficiency of CFRP confinement. The different types of columns are Square RC (SRC) , Circularized RC (CRC) , Circularized PVC RC (CRC PVC) , Circularized CFRP RC (CRC FRP) , Circularized CFRP+PVC RC(CRC CFRP+PVC).The CFRP is wrap with 2 layers is applied to all the cross-sectional modified columns. The axial and load-deformation behaviour of the different types of column is measured and compared with each other. The results indicate that with using CFRP the strength of the column can be suitably enhanced and they can replace the conventional concrete in retrofitting of the existing structure columns.

Keywords:Retrofitting,coulumn, jackting ,strength, repair

Introduction

In October 8 2005 moderate earthquake suffer northern parts of Pakistan with a magnitude of Mw = 7.6. The earthquake considered as one of the extreme natural disaster in South Asian regions including Himalayan and northern parts of Pakistan. Approximately 73000 peoples were died and 70000 peoples were injured and disabled. Thousands of people were homeless and were remain inaccessible of adequate foods. Communication facilities were also disturbed due to earthquake. The total economic loss includes reconstruction, rehabilitation and reliefs were approximately $5 billion. All types of infrastructures include buildings, roads, bridges, hospitals and institutional buildings were severely affected and are partially or fully damaged by earthquake in the cities located near to the epicenter i.e. northern parts of Khyber Pakhtunkhwa (North West Frontier Province NWFP) and Azad Jammu Kashmir (AJK) regions [1].

The post observations of damaged structures indicated that due to poor nature of construction of conventional buildings with no use of reinforced concrete (RC) building codes, standards and norms in RC structures lead to stage of failure which when subjected to seismic forces and hence were fully or partially damaged. According to [2] about 261990 domestic buildings were completed destroyed and 177890 were damaged to a little extent. The reason of large number of residential buildings were heavy weight floors which are concerned to large amount of inertial forces. Most of the buildings were made of rubble stone masonry with a timber supported roof subjected to heavily mud superimposed loads and snow loads also called as (Katcha) construction. The (Pucca) construction includes the rubble masonry with floors consists of reinforced concrete RC flat slabs. No connection was found between the unreinforced walls with the heavy loaded floors and hence out-of-plane failure could takes place. It was concluded that due to poor practice of construction with no proper structural detailing and seismic consideration were the main causes of failures [2]. Some pictures of Katcha and Pucca damaged buildings in AJK and Balakot are given in Figure 1.1.

a) Reinforced concrete consruction(pucca) b) stone masonry construction(katcha)

Figure 1.1: collapsed building in kashmir earthquake [2]

Madina Market is a well known market located in Muzaffarabad the capital of AJK were destroyed and after site observations it was concluded that the main reason of failure was due to no proper bond between concrete and reinforcement, the use of poor quality stone masonry, use of plane bars and lack of continuity between structural elements to distribute loads safely [2]. Figure 1.2 shows damaged RC buildings in Madina Market Muzaffarabad AJK.


a)soft story failure b)beam column joint failure


C)Inner street d)shops demmaged

Figure 1.2 common Filure due to lack of engineering practicise [2]

Due to importance of hospitals and institutional buildings on basis of providing health and educational facilities it must there be operational in design level earthquake. According to [1]

a total of 7669 schools were suffered ranging from primary level to higher educations including a public and private sectors institutions. Similary about 574 health structures were partially or completely damaged. The pictures shown in Figure 1.3 illustrates partially and fully damaged hospitals and institutional buildings [2]

Fig. 1.3. (a) Cracks appeared in Combined Military Hospital (CMH) in Muzzafarabad

Fig. 1.3. (b) Collapse of an Institutional Buildings

Figure 1.3: Damaged institutional and health buildings [2]

Nearly half institutional buildings (schools, colleges, universities etc.) were completely collapsed and need to be reconstructed, however institutions partially collapsed needs to retrofit. Typical reinforced concrete RC buildings consist of several structural elements i.e. beams, columns, beam-column joints, slabs and foundations. It is important to restrengthen partially collapsed RC structures using different retrofitting techniques. In reinforced concrete RC structure column acts as one of the key element to transfer storeys loads safely to the foundation. We provide columns to support superstructure. But when the column unable to transfer the loads from superstructure safely thus will not fulfill their function due of which the structure is unserviceable and will not be used by the occupants.

1.2 Problem Statement

The studies available so far is concerned with the behaviour of RC columns confined externally with FRP. Mainly square columns confined with FRP shows less efficiency due to non-uniform stresses at its corners. It is therefore necessary to modify the shape of square columns into circular columns with the help of ordinary concrete. Use of ordinary concrete (CRC) for shape modification are advantageous due to its good impact energy dissipation characteristics, locally available, easy to used and also environment friendly.

Therefore, studies are needed to address the behaviour of carbon fiber reinforced polymer CFRP, and polyvinyl chloride PVC in strengthening the ordinary moment resisting frame OMRF reinforced concrete columns (square shape).

1.3 Objectives

- To determine the load-deformation behavior of externally confined concrete columns by **PVC and FRP by axial compressive loadings.**

- To study failure/damaged pattern of column specimens.
- Compare the result of externally confinement specimens with reference column specimen.

LITERATURE REVIEW

2.1 Introduction

The needs of fiber reinforced polymers FRP retrofitting gains popularity to strengthen RC columns in earthquakes affected regions which are partially damaged due to deficient construction with poor workmanship skills and not intended the use of construction norms and standards i.e. High water-cement ratio, undeformed bars, plain concrete with low concrete compressive strength and deficient transverse reinforcement. Variety of research work have been done by many researchers. Different researchers perform different types of experiments to explain the behavior of FRP used in the retrofitting of RC columns.

2.2 Seismic Retrofitting of RC Columns

”Retrofitting is a strengthening technique for partially collapsed/damaged existing structures which make the damaged structure capable to perform well under different kinds of loads and enhances mechanical properties to a great extent of existing damaged structures”.

There are many methods of retrofitting applied to RC structures. In this research work the main focus is on strengthening of RC columns. Fig. 1.4 shows methods for retrofitting depends on availability of existing technologieS.

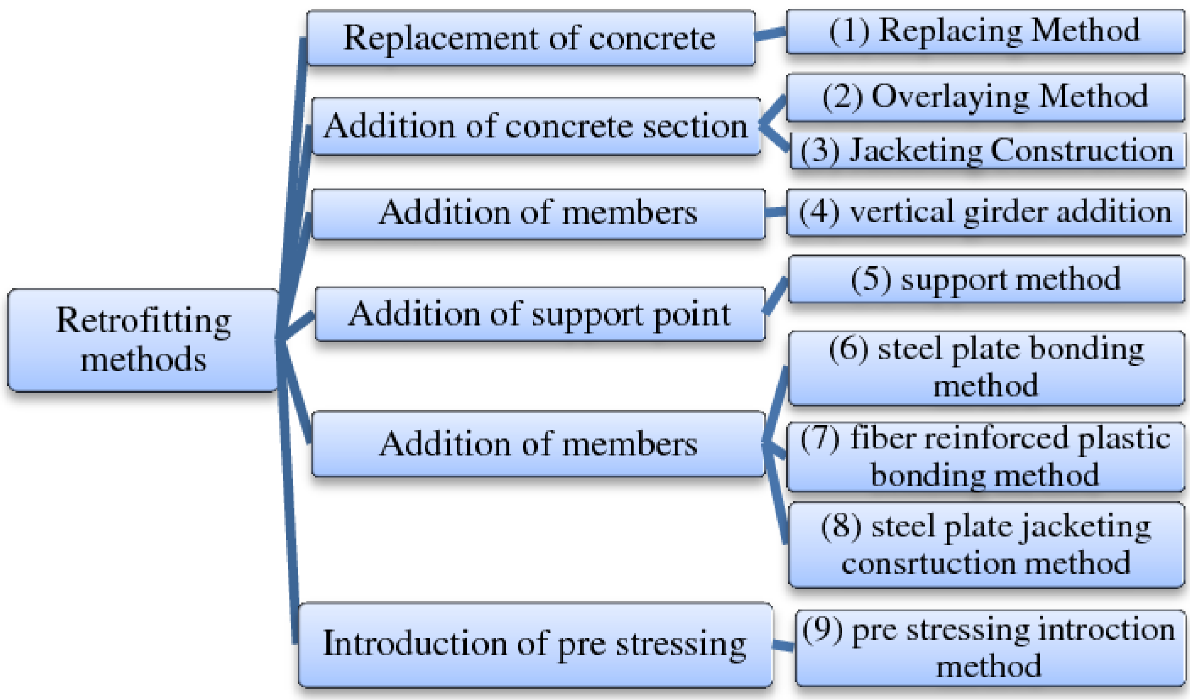


Figure 1.4: Different retrofitting techniques [3]

2.3 Process of Retrofitting

Once the performance of the structures are evaluated quantitatively and found that it needs to retrofit it is necessary to inspect the damaged structure and collect data for retrofitting required with the help of reconnaissance survey. After complete analysis has been done then it will have decided that whether the structure behave well under different circumstances and fulfill the performance requirements or it does not behave well and does not fulfill its requirements. The next step is to analyze and design the structure for retrofitting based on their performances. Once analysis and design are complete, the design experts mention the use of particular techniques, its materials and specifications, dimensions and method of constructions. When retrofitting has been done it is necessary to again evaluate the performance of the structure such that this time it perform well from the structure when this structure behave before retrofitting [3].

2.4 Retrofitting of Reinforced Concrete (RC) Columns

In this research work the main concern is on the retrofitting and restrengthen of reinforced concrete columns. RC columns play an important role in RC special moment resisting frames (SMRF). The common types of failure in short columns causes due to shear stress with diagonal fracture of brittle failure [4]. There are many reasons of strengthening the existing damaged RC columns which may cause due to error cause in initial analysis and design or due to deterioration of materials degradation. Seismic forces also influence the function of columns due to lateral loads. There are many techniques available for strengthening of RC columns. The most common method of retrofitting used for RC columns are fiber reinforced polymer (FRP) bonding and wrapping. The confinement of RC columns using carbon fibre reinforced polymers (CFRP) are well known and are used globally due to light in weight and ease to apply with excellent mechanical properties, provide good durability and high tensile strength. CFRP confinement enhancing the load taking ability of RC columns subjected to axial compressive loadings. When load is applied in compression RC columns expand laterally (Poisson effect). The CFRP confinement restrains the movement of reinforced concrete in lateral direction due to lateral pressure provided by CFRP loaded in tension in hoops directions and hence will increase the capacity of RC columns. Figure 1.5 shows the application of CFRP wrapped from RC columns and bridge piers.

(a) Application of CFRP in Hotels Apartments

(b) Application of CFRP in Residential

Figure 1.5: Applications of CFRP in Civil Engineering Practices [5]

CFRP are wrapped with epoxy by wet-layup process. Epoxy is a bonding material between CFRP and concrete and are widely used in application of strengthening of concrete, steel, ceramics and wood.

According to manufacturer manuscript epoxy are operable at a temperature of 0-40ºC and are not working beyond a temperature of 65ºC. In this experimental **work Carbon fiber impregnated adhesive HM-180C3P** are used. Efficiency of CFRP in square columns reduces due to non-uniform stressed induced at sharp corners of RC columns.

From literature point of view Polyvinyl chloride (PVC) are good to use for external confinement of RC columns especially in aggressive and saline environments. The use of PVC restricts the chloride ingress into reinforced concrete columns and hence protect the columns from deterioration. The use of PVC also act as stay-in-place form work which reduces the cost of shuttering. PVC also used for thermal and electrical insulation with good durability and ductility.

In this research study initially ordinary RC columns are restrengthen by modification from square columns to circular columns incorporating crumb rubber and confined it by using polyvinyl chloride PVC and CFRP individually and compare their result with column specimen confined with CFRP and PVC both.

2.5 FRP Composites in Civil Infrastructures [10]

Few researchers have been studied advance polymer composite (APC), the properties of these composite is that it shows high ductility and tensile strength.

In this research paper two studies were carried out to find the existing physical properties of these composites and how these composites behaves when we integrate it with other composites and improve their properties in regards of civil engineering infrastructure.

FRP not only provide strength, stiffness and ductility to demand over it but also behave well when exposed to aggressive environment.

After long term temperature change, a chemical reaction takes place results in aging which affects the properties of FRP.

The mechanical properties of thermosetting polymer includes; Ultimate tensile and compressive strength, compressive strength in creep, and stiffness.

The conclusion and observation predicts that APC will be used integrally with conventional materials. The rewards of FRP composites from in-service and physical characteristics shows that it provides economical alternatives if used with APC Due to low weight it did not increase the dead load of buildings and reduce time in installation with a reasonable cost.

Due to good mechanical properties of FRP less materials was used instead of conventional materials and provide sufficient enhancement.

In general sense the FRP extends the service life of a structure and prevent to demolish any deficient structure, it also protects the core conventional materials from aging and weathering effects.

Due to enhancement in mechanical properties FRP was also used in new RC construction as well e.g. bridges, RC buildings etc. FRP can also be used in combination with PVC, steel jacketing, steel tubing etc. to make a hybrid composite structure.

2.6 High Strength Concrete Columns Jacketed with FRP Laminates [8]

The main aim of this research work is to know the behavior of full scale HSC short columns which were partially and fully wrapped with different layer of glass fiber reinforced polymers GFRP laminates tested under axial compressive loadings with small and large uniaxial eccentrics.

Seven (7) full scale HSC short columns were constructed having dimension of (200mm x 200mm x 1050mm) with top and bottom corbel (400mm x 400mm x 200mm) to avoid premature failure of column top and bottom due to concentric loadings.

The laminates were arranged in two different techniques; for small eccentricity FRP laminates were used in transverse direction act as an external confinement and different layers of GFRP wrapped either partially or fully wrapped and for large eccentricity the FRP laminates were used longitudinally to tension side of large eccentricity.

For determining the concrete longitudinal compressive and tensile strain at a position of theoretically predicted neutral axis of the specimen two linear voltage displacement transducers LVDT's were installed. Seven (7) strain gauges were installed on each column specimen with additional one (1) strain gauge on specimens of large eccentricities.

Conclusions were drawn after experiments conducted. The transverse FRP laminate fully or partially wrapped did not improve significant stiffness of specimen. The load-deformation of transverse FRP laminates show a non-linear behavior which predicts the nonlinearity behavior of FRP wrapping.

It was also concluded that if we increase the transverse FRP laminates the volumetric ratio of steel tie will be reduced and hence it enhances the lateral confinement.

In small eccentricities as if compared with large eccentricities the transverse FRP laminates avoid the explosive behavior of column failure and hence it brought ductility on short column failure.

2.7 Retrofitting of RC Column-Steel Jacketing and Wrapping of CFRP [12]

Mostly structures if compared with current standards and design codes, were deficient in a sense of stiffness, strength and ductility. When such type of deficient structures suscepted to natural disasters such as earthquake strong ground motion then catastrophic failure caused in a deficient structure.

To counteract such type of problems, researchers carried out experiments based upon different repairing and strengthen techniques. In this research study researchers compare certain retrofitting techniques and determine which method was the most effective.

The primary methods used were steel jacketing and steel confinement techniques applied to reinforced concrete (RC) columns.

After the experiments perform, following conclusion were drawn, steel jacketing and steel cage. The circular columns provide better results as compared with square columns. The transverse reinforcement of column jackets provides good ductility to the structure. In steel tubing no adhesive materials were required. For rectangular columns octagonal and elliptical cross-section provides good results.

2.8 Concrete Filled with PVC Tube [9]

Early techniques used for strengthening of RC square columns are steel jacketing and steel tubing. The problem arose with steel jacketing that the dead load of the structure was increased which was problematic in seismic forces due to inertia.

The steel tube was also corroded in aggressive environments and skilled labour were required for steel tubing, steel tubing also increase dead load of a column. This gap can be filled with the replacement of steel tubing with PVC tubing.

This composite system of PVC tubing ensures ductility, durability, environmental and economic advantages. PVC tubing also work in aggressive environments, marine structures and tubing provide protection from chlorine ingress and carbon dioxide into concrete to prevent carbonations. In this review study different types of confinement and tubing provided by PVC were discussed in following phrases.

The overall results are: concrete filled with PVC tube is composite materials in which PVC act stay-in-place form work and to protect the column from weathering action as well as give confinement pressure against lateral expansion to column.

PVC confined concrete columns provides high bearing capacity, excellent ductility, good applicability in both normal and aggressive environments, time saving convenient construction, light weight and good durability.

Thickness of tube and compressive strength of concrete core have large influence on the post peak behaviors of stress-strain relationship.

2.9 Carbon Fiber Reinforced Polymer and Shape Modification [4]

This paper presents the confinement of fully wrapped carbon fiber reinforced polymer (CFRP) from square columns and partially or fully wrapped circularized square columns (CSCs).

The strength of fully wrapped FRP confined square columns desperately less than circularized square column confined with partially or fully wrapped FRP. The ultimate axial stress varying contrariwise to net spacing of adjacent FRP. FRP hoop rupture strain and ultimate axial strain of concrete does not depends upon the spacing of adjacent FRP.

The study of stress-strain curve revealed that the first part of stress-strain curve shows the relation between volumetric ratio and ultimate axial stress and strain and have a direct relation with each other. The second part of stress-strain curve increase with FRP confinement stiffness.

It is revealed that the use of partially confinement of FRP from square columns reduced the FRP volumetric ration by 50% with good axial strength and deformation as compared with fully strengthen FRP confinement from square columns and hence are economical alternative.

METHODOLOGY

2 Introduction

Every research work follows a systematic and academic approach for performing experiments. Actually methodology is the implementations of qualitative or quantitative analysis using standard procedures based on the literature studies and some standard principals and regulations. However, methodology does not aim to provide us a solution. In fact, methodology recommends us methods, steps, procedures to be followed for a specific situation. In short methodology is the study of illustration.

In this experimental research work the main focus is on the restrengthening of reduced scale (RC) columns using composites materials by providing external confinement and explain the procedures of tests perform to evaluate the failure pattern and load-deformation curve of selected test specimens. Preliminary tests and main experiments are perform on standard cylinders in "Materials Testing Laboratory-iqra national universty Peshawar " (INU Peshawar) to obtain the compressive strength and tensile strength of conventional concrete. TEN (10) specimens are constructed and test under half cycle axial compressive loads to understand the behavior of external confinement provided by carbon fiber reinforced polymers CFRP, poly-vinyl chloride PVC and CFRP & PVC used simultaneously.

3.1 Materials used

3.1.1 Fine aggregate

Sand used in this testing procedure are locally available everywhere. Following are the tests performed to evaluate the properties of the sand used in present research work.

ASTM C128 is used to examine the specific gravity and water absorption value given in Table3.1.

Table 3.1: Specific gravity and water absorption of fine aggregates.

S :NO.	TEST DISCRIPTION	TEST RESULT
1	SPECIFIC GRAVITY	2.655
2	ABSORPTION	23.07

3.1.2 Coarse aggregate

Well graded 3/8" down coarse aggregate easily available in the market are used with the following properties as shown below.

The specific gravity and water absorption of coarse aggregate are shown in Table3. 2.

Table 3.2: Specific gravity and water absorption of coarse aggregate.

S :NO.	TEST DISCRIPTION	TEST RESULT
1	BULK SPECIFIC GRAVITY(OVER DRIED	2.614
2	BULK SPECIFIC GRAVITY(SSD)	2.648
3	APPARENT SPECIFIC GRAVITY	2.707
4	WATER ABSORPTIOIN	1.32

3.1.3 Ordinary Portland cement

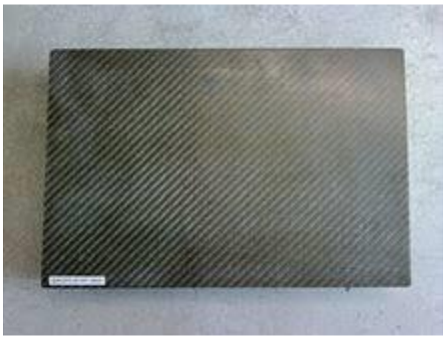
High performance water reducing admixtures (Chemrite SP 303) was used to achieve the target concrete compressive strength. According to manufacturer the amount of plasticizers used are 0.5-2% by weight of cement to achieve good workability and consistency of concrete .

3.1.4 Water reducing plasticizers

High performance water reducing admixtures (Chemrite SP 303) was used to achieve the target concrete compressive strength. According to manufacturer the amount of plasticizers used are 0.5-2% by weight of cement to achieve good workability and consistency of concrete

Carbon fiber reinforced polymer (CFRP) (ASTM C1836-16):

Carbon fiber reinforced polymer (CFRP) or simply called carbon fiber are fiber-reinforced plastic with carbon fibers as shown in Fig. 3.4.



(a)

(b)

Figure 3.34: (a) CFRP strip, (b) Application of CFRP [2].

CFRP are used where ever high strength-to-weight ratio are required such as aerospace, automotive industry, civil engineering and other applications.

In this research study CFRP are used and was imported from Horse Construction, Shanghai China.

Typical FRP properties are shown in Table 3.3 and Table 3.4.

Table 3.3: Dry fiber typical properties [3].

STANDARD VALUE OF TENSILE STRENTH	7.1*10^5PSI(4900MPA)
TENSILE ELASTIC MODOLUS	3.4*10^7PSI(234500MPA)
ELONGATION	1.70%

Table 3.4: Laminated fiber typical properties [3]

Standard value of tensile strenth	5.51*10^5psi(3800mpa)
Tensile elstic modulus	3.4*10^7psi(234500mpa)
elongation	1.70%
Bending strenth	1.01*10^5psi(700mpa)
Interlaminar shear strenth	6525psi(45mpa)
Frp with concrete bonding strenth	>or equal2.5mpa
Density	0.065lbs/in3(1.8g/cc)
Fiber thickness	0.0066in

3.1.6 Poly-vinyl chloride (PVC) (ASTM D1785-15)

Polyvinyl Chloride (PVC) is a thermoplastic polymer also known as polyvinyl or vinyl as shown in Fig. 3.5.

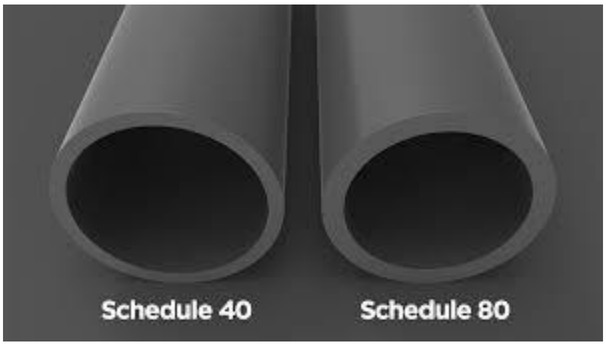


Figure 3.5:schedual 40 and shedual 80 pipes.

Four different classes of PVC are locally available: Class A, B, C and D. Class B pipe are selected in this research work.

Grey color PVC (D = 8 inch, Class C) used in this research work are obtained from Shanghai PVC Pipes, Industrial Estate Hayatabad, Peshawar.

Properties of PVC are usually classify based on rigid and flexible PVC are shown in Table 3.5.

Table 3.5: Properties of rigid and flexible PVC [4]

Property	Rijid pvc	Flexible pvc
Density(g/cc)	1.3-1.45	1.1-1.35
Thermal conductivity(w/m.k)	0.14-0.28	0.14-0.17
Yield strength(psi)	4500-8700	1450-3600
Elastic modulus(psi)	490000	
Flexural strength(psi)	10500	
Compression strength(psi)	9500	
Thermal expension coifficiant	5*10^5-5	
Vicat B[c]	65-100	Not recommended
Resistivity(ohm)	10^15	10^12-10^15
Surface resistivity	10^13-10^14	10^11-10^12

3.2 Experimentations

3.2.1 Mix Design

Cement	Fine aggregate	Coarse aggregate	Water reducing admixture	Target compressive strength
1	1.3	2	1.5%	3000psi

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3.2.2 Preparation of Cylinder Specimens

Standard cylinder (D = 6 in and H = 12 in) was constructed according to ASTM-C39.

3.2.3 Concrete Cylinder Compressive Strength Test

Four (04) cylinders were prepared and test in UTM as shown in Fig. 3.6. The compressive strength of all specimens are shown in Table 3.7.

a)

B)

Figure 3.6.a,b,concrete compressive test in UTM

Table 3. 7: Concrete cylinder compressive strength

Dimention D(in)*H(in)	No of specimen	Average strength(psi) 7 days
6in*12in	2	2290psi
6in*12in	2	2psi

3.2.4 Concrete Compressive Tensile Strength Test

Four (04) cylinders were prepared and tested in UTM as shown in Fig. 3.7. The tensile strength of all specimens are shown in Table 3.8

a)

B)

Figure 3.7: (a), (b) Split tensile strength test in UTM.

Table 3. 8: Concrete cylinder tensile strength

Dimensions D(in) x H(in)	No of Specimens	Strength (psi) (7-Day)
6 in x 12 in	2	1042psi
6 in x 12 in	2	2psi

3.3 Preparation of Reduced Scale Column Specimens

Depends on the resources available, laboratory limitations, time and funds availability, Full scale RC columns are reduced to 1/3rd. Simple type of scaling is used in this research evaluation as shown in Table 3.9. The length of specimen is selected as 30 inch based on available length of UTM.

Table 3. 9: Reduced scaling of RC column

Prototype	**1/3rd Reduced Scaled Model**
Column:	**Column:**
15 in x 15 in	15 in x 15 in
Concrete Strength:	**Concrete Strength:**
3000psi	3000psi
Aggregate size 1”	Aggregate size 3/8”
Steel Strength:	**Steel Strength:**
60000 psi	60000 psi
#6 Rebar	#2 Rebar
#3 Rebar	#1 Rebar

Table 3.10: Specimen arrangement and test parameters detail

Column Name	Ht. (in)	Dimension (in x in)	Circularize coloumn Dia. (in)	FRP type	FRP Layer	PVC Tube	Number of Specimen
SQ-RC	30	5x5	----	---	----	----	2
CCR	30	5x5	8	CARBON	2	-----	2
CRPT	30	5x5	8	CARBON	2	---	2
CRWF	30	5x5	8	----	2	Class c	2
CRFP	30	5x5	8	----	2	Class c	2

Where

SQ-RC control square specimen (SQRC)

Control CRC-RC column specimen (CCR).

CRC-RC columns filled with PVC tube (CRPT).

CRC-RC columns wrap with CFRP (CRWF).

CRC-RC columns filled with PVC tube and wrap with CFRP (CRFP).

3.3.2 Casting of Reduced Scale Square RC Column Specimens

The square columns are cast with the help of steel formwork as shown in Fig. 3.9. Tamping are done with the help of tamping rod to reduce the air gaps between concrete placing to assure good compactness of concrete.

a) B)

Figure 3.9: (a) Transverse and longitudinal steel, (b) Casting of RC column

3.4 Modification of Reduced Scale RC Square Columns to Circularized Column Specimens

After construction of square columns, the square columns then modify into circular columns using crumb rubber concrete (CRC) in which PVC act as stay-in-place form work as shown in Fig. 3.10.

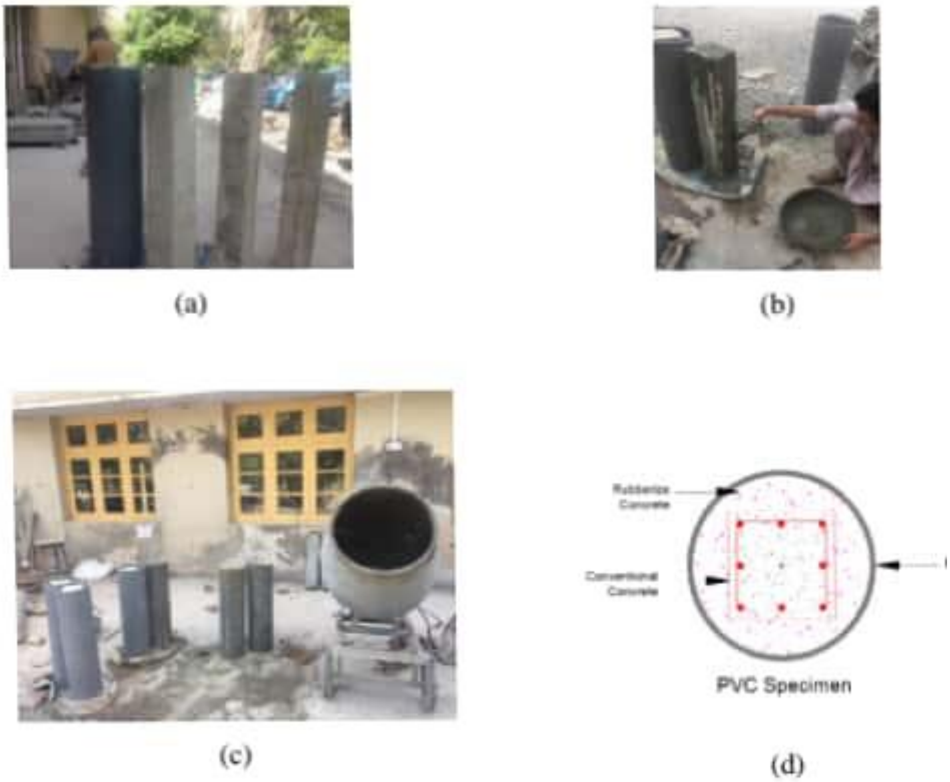


Figure 3.10: (a) square RC Column, (b) Cement Pasting after chapping (c) Modification from square to circular columns, (d) Arrangement of PVC specimen

After 28 days curing as recommended by ASTM, PVC tubes are removed from total four (04) specimens including 2 control specimen and 2 CFRP wrap specimen.

3.4.1 Installation of CFRP on Reduced Scale Modified Circularized Column Specimens

CFRP are wrapped from circularized RC columns in 2 layers with 20 mm apart from adjacent FRP layer with the help of Adhesive (HM-180C3P). HM-180C3P composed of two parts: Component A and B: Component A is transparent viscous liquid and Component B is brownviscous liquid. For application purpose both components are mixed with each other (A: B = 2:1).

Application of CFRP are shown in Fig. 3.11

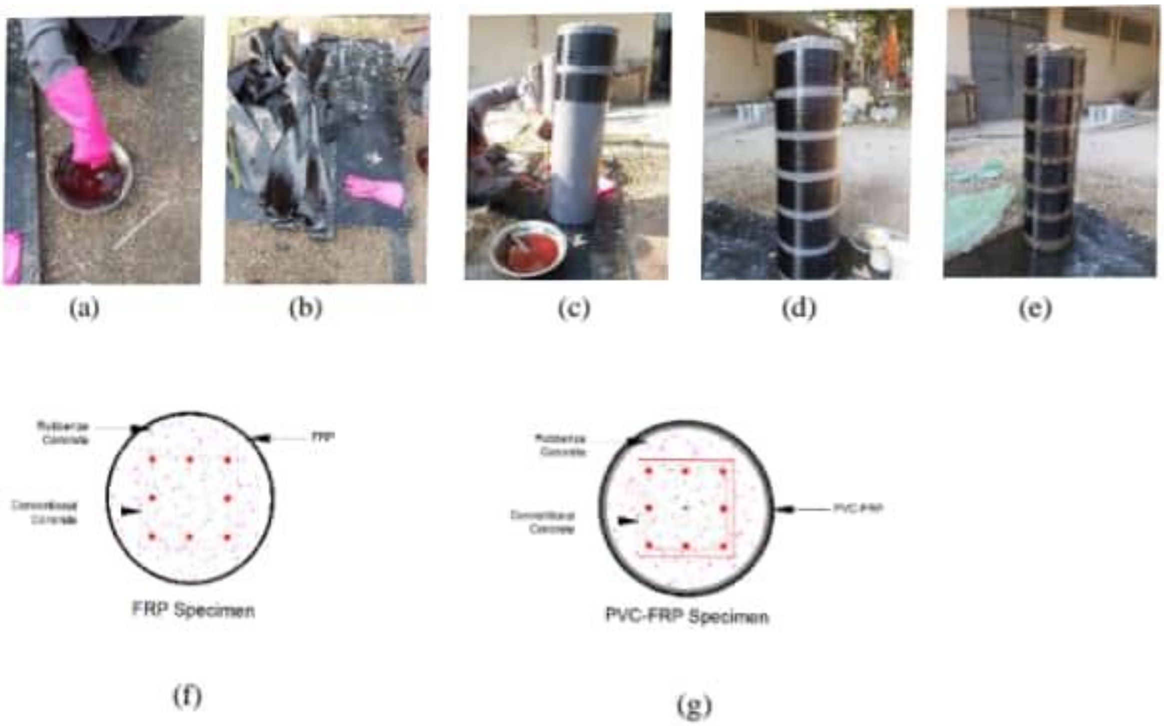


Figure 3.11: (a) Epoxy, (b) CFRP strips, (c) Application of CFRP, (d) CFRP wrap on PVC, (e) CFRP wrap on modified concrete, (f) FRP specimen arrangement, (g) PVC-CFRP specimen arrangement.

3.5 Half Cycle Axial Compressive Strength Test and Collection of Test Data

All specimens are tested under half cycle axial compression in (UTM) in Materials Testing Laboratory, IQRA NATIONAL UNIVERSTY, Peshawar. Two (LVDTs) (20 mm) are used. The LVDTs are connected with UCAM-70 A data logger. UTM is connected to UCAM70 A with channel 0. Three channels (0-1-2) of data logger are active and collect load and displacements from sensors. The Schematic view of test setup are shown in Fig. 3.12.

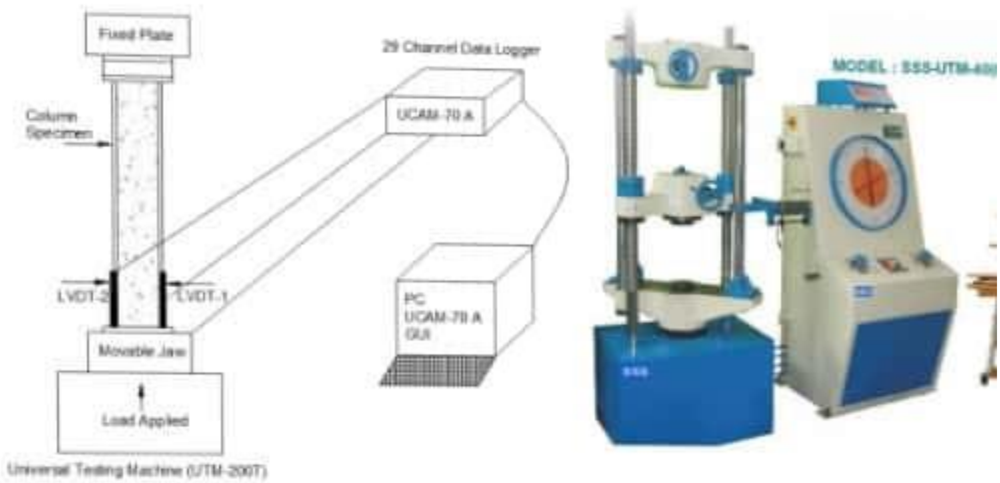


Figure 3.12: Schematic view of experimental setup.

4.Result/discussion

4.1 Square RC Column

The load is applied on the square RC column, deformation occurred when the load is increased. The deformation in the column increases with increase in the load. At 85% of the ultimate load a small hair like cracks were observed, the cracks expand as the load increases. In addition, in the first column there were no cracks at small loads but in the second column the cracks occurred at low load but after that the column stabilize and the ultimate load of second column is greater than first one. At the Ultimate Load the columns fail and the deformation was maximum at the ultimate load.

Square RC 1

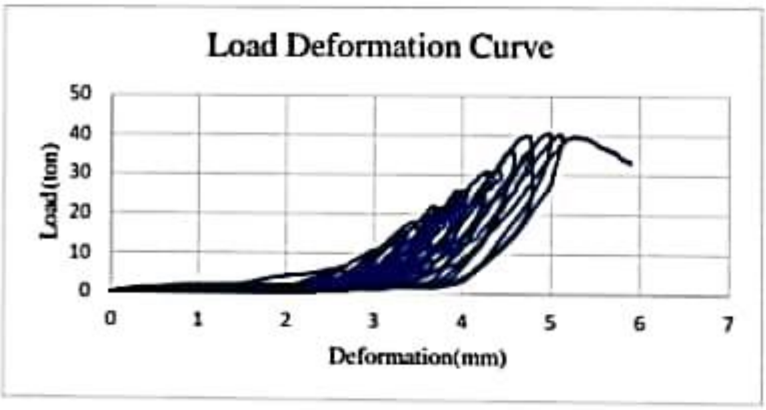


Fig 4.4 (a) : Load-Deformation Curve

Fig4.4(b) Square RC Column

Square RC 2

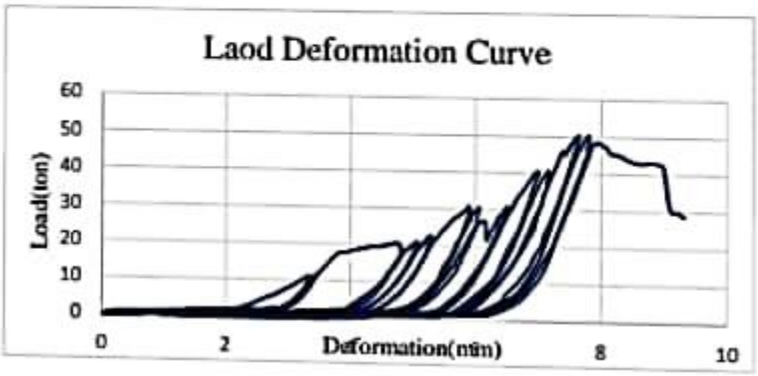


Fig 4.4(c) : Load-Deformation Curve

Fig4.4(d) Square RC Column

Table 4.1 Saqure Rc Column

Type of Specimen	No of Specimen	Ultimate Load (ton)	Max Deformation(mm)	Failure Cycle
SQAURE RC	1	40.196	6	40(ton) 2nd
SQAURE RC	2	50.324	8	50(ton) 3rd

4.2.2 Circularized RC Column

The square RC column are modified to circular to avoid sharp edges, and tested under cyclic loading in UTM machine. The load is applied on the circular column, the core concrete and the outer concrete used in shape modification act as a single structure upto 70% of the ultimate load, after that cracks were observed in the column outer surface. This happens due to improper bonding at the interface of core and the outer concrete of the column, also the outer concrete is not confined. Although the outer concrete doesn't separate from the inner core but, wide cracks appear in the outer concrete till the ultimate load. Due to modification of square shape the ultimate load of the column is sufficiently increased. The strength of the column increased by 12% as compared to square column.

Circularized RC 1

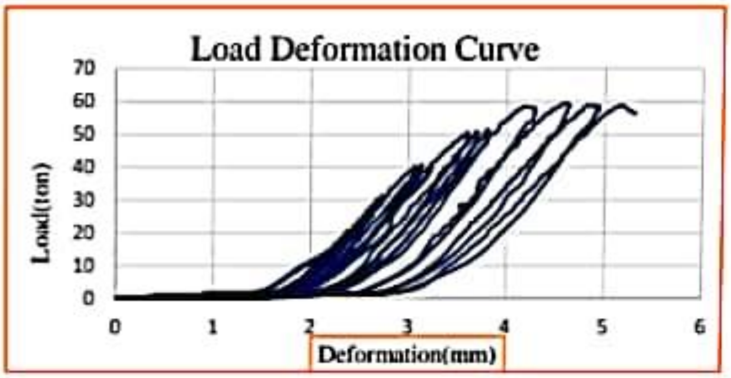


Fig 4.5(a) Load and Deformation of Circular RC Column Fig4.5(b) Circular RC column

Circularized RC 2

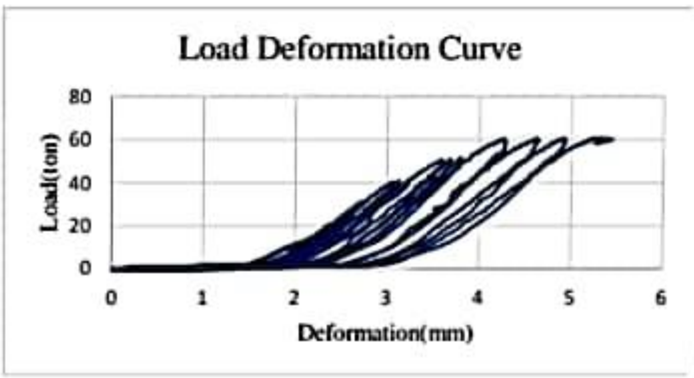


Fig 4.5(c) Load and Deformation of Circular RC Column Fig4.5(d) Circular RC column

Table 4.2 CRC RC Column

Type of Specimen	No of Specimen	Ultimate load (ton)	Max Deformation(mm)	Failure Cycle
Circularized RC	1	60.088	5.5	60 3^{rd}
Circularized RC	2	56.34	5.3	60 1^{st}

4.2.3 Circularized PVC RC column

The modified RC columns are confined with PVC; the modified RC column acts as a single structure upto certain limit after that due to the un-confinement of the outer concrete the column did not act as a single structure. The PVC provide confinement to the outer concrete and hence the ultimate load of the column increases. When the load is applied to the Circulized RC (PVC) column initially no cracks were observed in the PVC core and at 95% of the ultimate load small cracks appear at the top end of PVC after that the PVC suddenly burst at the ultimate load. The strength of the column increased by 47% as compared to the square RC.

CRC PVC 1

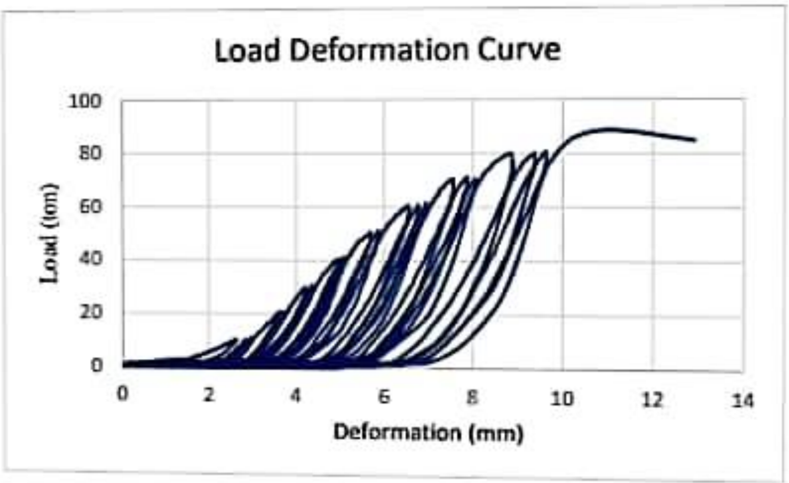
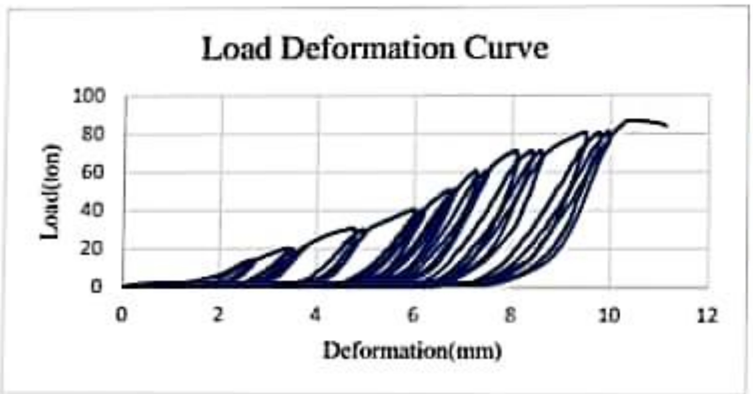


Fig 4.6(a) Load and Deformation of CRC(PVC) Column Fig4.6(b) CRC(PVC) Column

Table 4.3 Load and Deformation of CRC (PVC)

Type of specimen	NO OF SPECIMAN	Ultimat load(ton)	Max Deformation(mm)	Failure Cycle
CRC PVC	1	88.62	10	90 1^{st}
CRC PVC	2	86.68	10.2	90 1^{st}

CRC PVC 2



4.6(c) Load and Deformation of CRC(PVC) Column

Fig4.6(d) CRC(PVC) Column

4.2.4 Circularized FRP RC column

In this type of RC columns FRP is provided in the modified RC column for confinement. The FRP is wrapped in two layers to the columns. The FRP layers are two inches apart from each other. The failure initiated with the cracks occurred between the layers of the FRP, under high loads the cracks of the concrete extended and eventually crushed which results into the rupture of FRP strips. The rupture of the FRP strips only occur at the top due to the unevenness at the surface of the column. The results indicate an increase in strength by 114% as compared to the square RC column.

CRC FRP 1

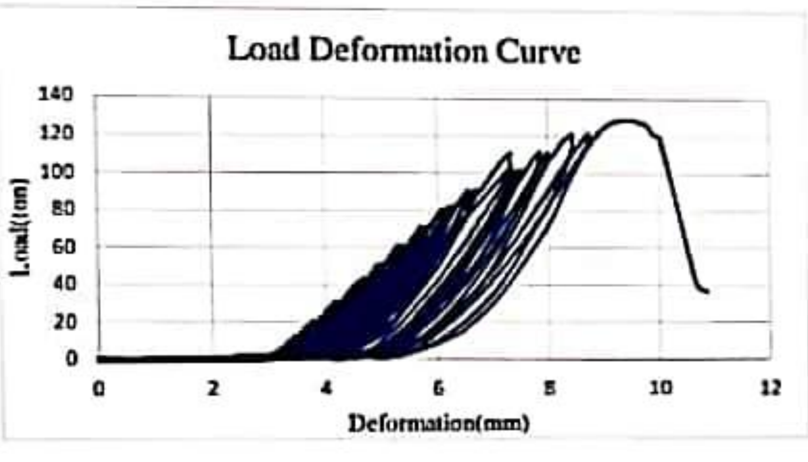


Fig 4.7(a) Load and Deformation of CRC(FRP) Column Column

Fig4.7(b) CRC(FRP)

CRC FRP 2

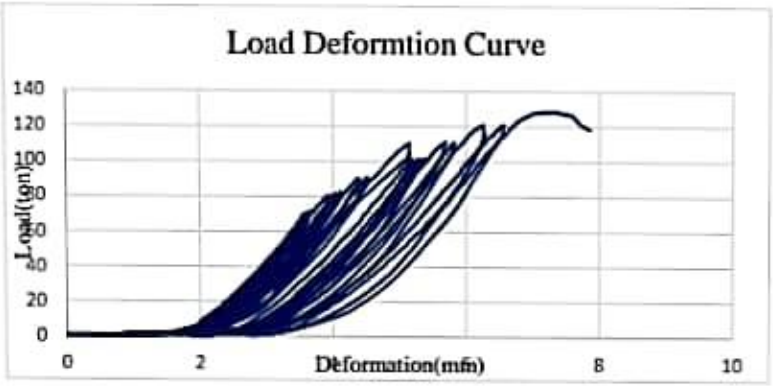


Fig 4.7(c) Load and Deformation of CRC(FRP) Column Column

Fig4.7(d) CRC(FRP)

Table 4.4 Load and Deformation of CRC (FRP)

Type of Specimen	No of speciman	Ultimate load(ton)	Max deformation(mm)	Failure cycle
CRC FRP	1	128.604	9	130 1st
CRC FRP	2	128.566	7.5	130 1st

4.2.5 Circularized FRP+PVC RC column

In this of circularized RC column the confinement is provided by using FRP and PVC simultaneously. The load is applied to the column and a significant increase in the strength of the column is observed. No crack is observed in the column due to the confinement of PVC and FRP, the outer concrete and inner core act as a single structure. The column fails internally because the strength of the outside provided confinement is greater than the concrete strength. The strength increases by 123% as compared to the square RC

CRC (FRP+PVC) 1

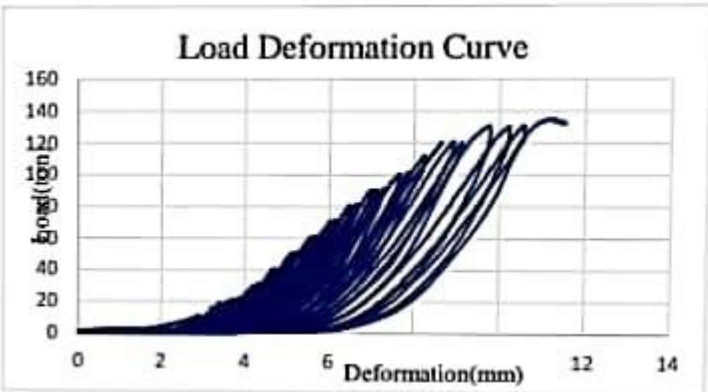


Fig 4.7(a) Load and Deformation of CRC(FRP+PVC) Column Fig4.7(b) CRC(FRP+PVC) Column

CRC (FRP+PVC) 2

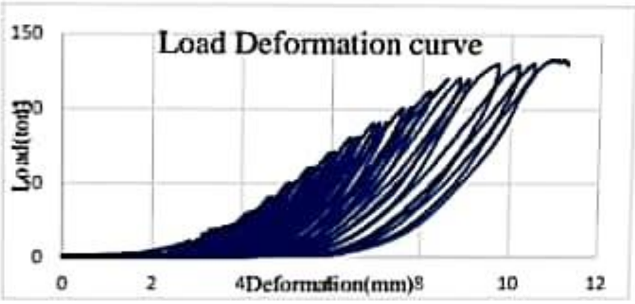


Fig 4.7(c) Load and Deformation of CRC(FRP+PVC) Column Fig4.7(d) CRC(FRP+PVC) Column

Table 4.5 Load and Deformation of CrC (FRP+PVC)

Type of Specimen	No of Specimen	Ultimat load (ton)	Max Deformation(mm)	Failure Cycle
CRC FRP+PVC	1	134.456	10.2	140 1st
CRC FRP+PVC	2	132.833	10.5	140 1st

4.3 Backbone Curve

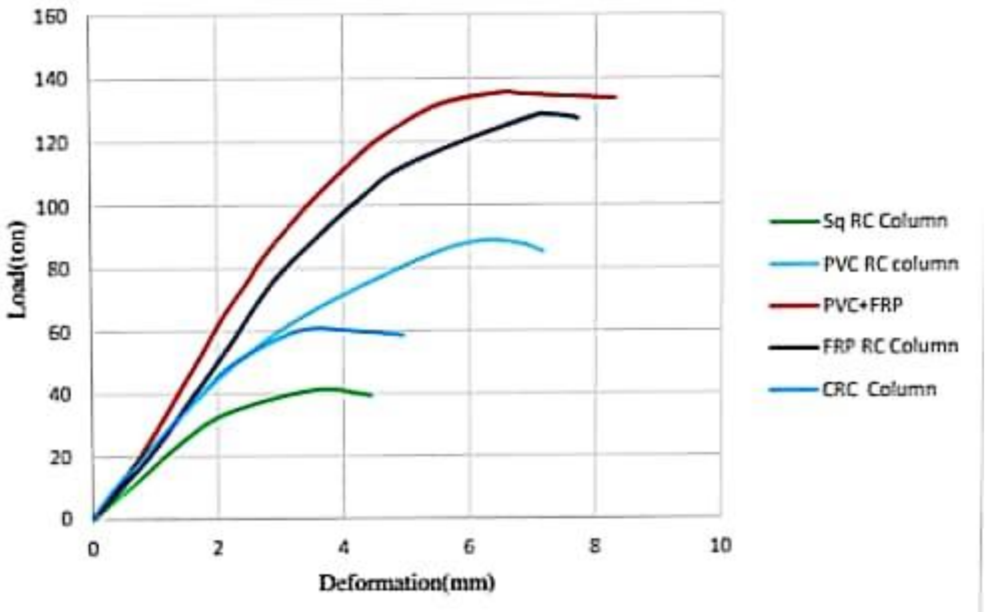


Figure 4.8 back bone curve

in Fig 4.8 Back Bone Curve e indicates that the initial stiffness of the all the specimens are same after certain load stiffness of the specimens increases and show less deformation at higher loads. The stiffness of specimens increases by Circular RC column>square RC column, Circular RC column(PVC)>Circular RC column, FRP wrapped RC column>PVC Confined RC Column, FRP+PVC RC column>FRP wrapped RC Column

5.Aknowledgment

The authers would aknowledge to iqra national university civil department lab for providing sufficient environment and guidance.

6. Conclusion

In this study an experimental program was carried out to examine the structural performance and failure pattern of RC columns, total of 10 columns were tested under axial compression cyclic load, 2 of them were test as RC square column while rest of them were modified to Circular RC Column which include 2 controlled specimens, 2 confined with PVC, 2 Wrapped with CFRP and 2 is confined with PVC and wrapped with CFRP. The modified RC columns are compared with square columns based on experimental results and analytical investigations following conclusion are identified.

1) In case of controlled specimens, the concrete core and concrete attached for shape modification does not worked as single structure up to ultimate load carried out by the specimens.
2) In case of PVC confined and Wrapped CFRP modified circular RC columns, the concrete core and concrete attached for shape modification worked as single structure and no failure was observed at core/modified concrete joint.
3) In case of PVC confined, no warning cracked was observed, failure was abrupt and PVC burst longitudinally.
4) In case of partially CFRP wrapped, warning cracked was observed in concrete, failure was abrupt and CFRP burst layer by layer.
5) In case of PVC and CFRP confined, Columns failed internally, no failure of PVC and CFRP was observed remains alive.
6) From all the tested columns, significant increase in axial and stress strain behaviour was observed in CFRP columns, more over the PVC and CFRP confined column showed the highest modulus of toughness.
7) Initially no significant increase in axial and stress strain behaviour was observed for all columns, after a certain load increase was observed.
8) From all the tested specimens, load/strength enhancement ratio between square RC column and Circular RC column was 12%, PVC confined RC column was 47.8%, CFRP wrapped RC column was 114% and PVC and CFRP confined RC column was 123%.
9) Confinement with PVC and CFRP of CRC column delayed the local buckling and significantly increase the stress strain capacity of column.
10)) By using CFRP, dead load and size of RC column can be reduced while achieving the target strength.

11) PVC can be used as a formwork while increase in strength can also be achieved.

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