A COMPREHENSIVE STUDY ON SHEAR STRAIN, CRACK PATTERNS AND CRACK WIDTH PROFILE FOR MODERATE DEEP BEAM WITH FIBRES

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By

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CERTIFICATE

This is to certify that the thesis entitled **A COMPREHENSIVE STUDY ON SHEAR STRAIN, CRACK PATTERNS AND CRACK WIDTH PROFILE FOR MODERATE DEEP BEAM WITH FIBRES** *submitted by* **Shri Vinubhai Ratilal Patel** *represents his original work which was carried out by him at Applied Mechanics Department, Faculty of Technology and Engineering, The M. S. University of Baroda, Vadodara under my guidance and supervision for the award of the Degree of Doctor of Philosophy in Civil Engineering.*

The matter presented in this thesis has not been submitted anywhere else for the award of any other degree.

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August 2012 **Vinubhai R. Patel**

ABSTRACT

The concept of using fibers in a brittle matrix was first observed with the ancient Egyptian work. Animal hairs and straw were used as reinforcement for mud bricks and walls in housing. In the past two decades serious consideration has been given to use of fibers in the conventional moldable construction materials like asbestos gypsum plasters, cement plasters and concretes to improve performance. The use of fibers imparts ductility to the concrete and delays its catastrophic nature of failure. The process of fiber pull out absorbs lot of energy and imparts higher toughness and impact resistance of concrete. Remarkable improvements in tensile strength, cracking characteristics, fatigue resistance and abrasion resistance are observed in RCC beams due to addition of fibers. In last decade, FRC has proved its worth as a cost effective and innovative construction material for large durability. Various types of synthetic fibers, acrylic, carbon, nylon, polyester, polyethylene, and polypropylene fibers apart from steel have found their way in forming vibrant FRC. Polypropylene, Steel and Hybrid (Steel & Polypropylene mix) Fibers are used in the present research work.

Generally, the shear failure of a Reinforced concrete beam is directly related to the diagonal tensile cracking that develops in the direction, perpendicular to the principal tensile stress axis. Once tensile cracking occurs, the tensile stress at the crack surface rapidly softens the concrete. This significantly reduces the shear strength of the beam. According to existing experimental results, the addition of fibers effectively improves the shear strength of concrete. This is because the fibers can transfer tensile stress effectively across crack surfaces by generating crack tip forces, which is called the crack-bridging stress.

IS 456: 2000, along with other various codes of different countries, classifies the beam into three categories; namely Shallow Beam, Moderate Deep Beam, and Deep Beam, according to their effective span (L) or shear span (a) to overall depth (D) ratio. In general, it can be classified as **1)**Shallow Beams ($L/D \geq 6.0$) or ($a/D \geq 2.5$), **2)**Moderate Deep Beams ($2.0 < L/D < 6.0$) or ($1 \leq a/D < 2.5$), **3)**Deep Beams ($0.5 < L/D \leq 2.0$) or ($a/D < 1.0$).

Moderate Deep Beams are widely used in various important structures such as nuclear reactors, water tanks, halls, hotels, complex foundations, offshore structures, corbels. Therefore an attempt has been made through the experimental study to understand the complex but most significant shear response and cracking characteristics such as crack patterns & crack width profile of such beams under fibrous matrix.

Total eighty eight (88) numbers of Fiber Reinforced Cement Concrete beams were tested with simply supported conditions having an effective span of 1200 mm. The Length of the beams (1300 mm) and width of the web (150 mm)

were kept constant. The beams were divided into four series having depths of 300 mm, 400 mm, 500 mm and 600 mm respectively. Forty eight (48) numbers beams of were tested under symmetrically placed two point loading and Forty (40) numbers of beams were tested under single central point loading.

The aim of the present investigation is to provide a systematic and comprehensive study on the cracking characteristics with respect to crack width & crack patterns as well as shear strain distribution in Fiber Reinforced Cement Concrete Moderate Deep Beams. In course of investigations, three empirical equations are suggested to estimate the shear strength of Fibrous Moderate Deep Beams using different types of fibers and four empirical equations are suggested to calculate the maximum crack width for different Fibrous Moderate Deep Beams.

The graphs plotted for the variation of shear strain at top surface and at in-depth surface along the vertical axes in shear zone show D shape of strain distribution. This is in good agreement with the theoretical shear stress distribution of parabolic nature along the vertical axes of the beam.

In all the beam specimens, initiation of flexure cracks was from the bottom of the beams. In most of the cases, all the flexure cracks were almost vertical in flexure zone. The most of the shear cracks were inclined in shear zone and their direction of propagation was towards the nearest load point irrespective of its place of origin. Beams of series D30 and D40 (having L/D ratio 3 & more) failed in pure flexure failure by yielding of longitudinal tensile reinforcement. Beams of series D50 (having L/D between 2 to 3) failed in flexure-shear mode. Beams of series D60 (having L/D less than 2) failed in pure shear failure. It is observed that the inclination of predominant crack has been changed from $60^\circ$to approximately 45°due to increase in a/D ratio by 50%.

By the detailed analysis and its results, it can be concluded that fibers can be the best alternative solution to avoid congestion of reinforcement along with crack arresting mechanism especially at the beam-column junctions where more shear reinforcement is required.

In the present investigation, it is observed that Ultimate shear strength of Fibrous Moderate Deep Beams without web reinforcements (stirrups) is 70 to 75 % more than that of the RCC Moderate Deep Beams without web reinforcements.This shows that shear reinforcement in the form of stirrups can be effectively partially replaced by fibers with proper design.

The Ultimate Shear load and maximum crack width calculated by the proposed empirical formulas shows good agreement with the test results of the Fibrous Moderate Deep Beams.

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LIST OF SYMBOLS

a	SHEAR SPAN OF THE MEMBER
A	AREA OF LONGITUDINAL OR TRANSVERSE REINFORCEMENT
α	INCLINATION WITH HORIZONTAL
Ast	AREA OF TENSILE REINFORCEMENT
Φ	DIAMETER OF STEEL REINFORCEMENT BAR
B,b	WIDTH OF THE MEMBER
$d_{eff.}$	EFFECTIVE DEPTH OF THE MEMBER
D_f, d_f	DIAMETER OR DENIER OF FIBER
D,h	DEPTH OF THE MEMBER
E	YOUNG'S MODULAS OF ELASTICITY
Wcr_{max}	MAXIMUM CRACK WIDTH
fy	YIELD STRESS OF REINFORCEMENT
f'c	COMPRESSIVE STRESS OF CONCRETE
lf	LENGTH OF FIBER
L	SPAN OF BEAM
θ	ANGLE OF HORIZONTAL TO PRINCIPAL PLANE
F	FIBER FACTOR
β	BOND FACTOR OF FIBER
ρ	LONGITUDINAL REINFORCEMENT RATIO
ρf	FIBER DENSITY
N.A	NEUTRAL AXIS
τ_c	DESIGN SHEAR STRENGTH OF CONCRETE IN N/MM^2
ACI	AMERICAN CONCRETE INSTITUTE
ASCE	AMERICAN SOCIETY OF CIVIL ENGINEERS
CIRIA	CONSTRUCTION INDUSTRY RESEARCH AND INFORMATION ASSOCIATION
ISC	INDIAN STANDARD CODE
OAP	OVER ARUP AND PARTNERS
p	ULTIMATE LOAD

Z	SECTION MODULUS
M	BENDING MOMENT
f_x	BEARING STRESS IN LONGITUDINAL BARS
b	WIDTH OF BEAM
X_u	DISTANCE OF NEUTRAL AXIS TO THE COMPRESSION FACE OF THE BEAM
V_f	VOLUME OF FIBERS IN PERCENTAGE
d'	EFFECTIVE COVER OF CONCRETE
d_c	CLEAR CONCRETE COVER
F_{be}	BOND EFFICIENCY OF THE FIBERS
PPFRC	POLYPROPYLENE FIBER REINFORCED CONCRETE
SFRC	STEEL FIBER REINFORCED CONCRETE
MT	MONOFILAMENT TYPE
FCT	FLAT CORRUGATED TYPE
FT	FIBRILLATED TYPE
CCT	CIRCULAR CORRUGATED TYPE
HFRC	HYBRID (MIX) FIBER REINFORCED CONCRETE
W/O/S	WITHOUT STIRRUPS
W/S	WITH STIRRUPS

CHAPTER-1
INTRODUCTION

1.1 GENERAL INTRODUCTION

In general, Beam can be classified into three categories as per its span-to-depth ratio namely Shallow or Normal Beam, Moderate Deep Beam and Deep Beam.

As per Indian Standard Code IS 456: 2000[96] (page no. 51, clause no. 29.1), a beam shall be said to be a deep beam when the ratio of effective span (L) to overall depth (D) i.e. L/D is less than:

(i) 2.0 for a simply supported beam and

(ii) 2.5 for a continuous beam.

As per ACI-ASCE committee 426 classified a beam with a shear span (a) to depth (D) ratio i.e. a/D ratio less than 1.0 as a Deep Beam and a beam with a/D exceeding 2.5 as an ordinary Shallow Beam. Any beam in between these two limits is categorized as a Moderate Deep Beam. It was observed that different codes of practice consider the span-to-depth ratio limit to define simply supported deep beams as per practice. The CIRIA guide 2 [Over Arup and Partners (OAP) and Construction Industry Research and Information Association (CIRIA 1977)] provides supplementary rules for Deep Beams i.e. the beams having span-to-depth ratio $<$ 2 are deep beams. The American Concrete Institute (ACI) 318-95[95] code (ACI 1995) gives special provisions for Deep flexural members i.e. the Beams having clear span-to-depth ratio $<$ 5 are Deep Beams.

In general, it can be classified as,

Shallow Beams	• $L/D \geq 6.0$ OR $a/D > 2.5$
Moderate Deep Beams	• $2.0 < L/D < 6.0$ OR $1.0 < a/D < 2.5$
Deep Beams	• $0.5 < L/D \leq 2.0$ OR $a/D < 1.0$

Shallow beams are characterized by linear strain distribution and most of the applied load is transferred through a fairly uniform compression field. It can be analyzed generally by simple bending theory based on assumption that plane sections normal to the axis remain plane after bending. The stress distribution across the section is almost linear as shown in Fig.1.1. Shallow beams are assumed as one-dimensional linear elements so they resist transverse loading mainly by bending and shear or say mainly by developing flexure and shear stresses. There is a negligible effect of normal pressure on stress distribution. Generally shallow beams predominantly fail under pure flexure failure as it posses very low flexure strength as compared to it shear strength.

Moderate Deep Beams differ from shallow beams considerably. There is a significant effect of normal pressure on stress distribution. The assumption made in simple bending (i.e. plane section remains plane after bending) becomes wrong due to nonlinear strain distribution. In Moderate Deep Beam, the flexure capacity and shear capacity of the beam is nearly same hence the failure of such type of beams is due to both combined effect of flexure and shear. This type of beams is transition between Shallow and Deep beams. As the beam become deeper the stress distribution becomes non-linear as shown in Fig.1.1. The stresses at mid span deviate more and more from those predicted by the simple bending theory. Distribution of transverse compressive stress for various shear spans to depth ratios is shown in Fig.1.2. Deep beams behave entirely different from normal beams. Normal pressure has greater effect on stress distribution and hence stress distribution no longer remains linear as shown in Fig.1.1. It has very high flexure strength as compared to its shear strength and hence type of failure is shear predominant failure. Concept of stress distribution in Moderate Deep Beam as per assumption of F. K. Kong [92] is as shown in Fig.1.3.

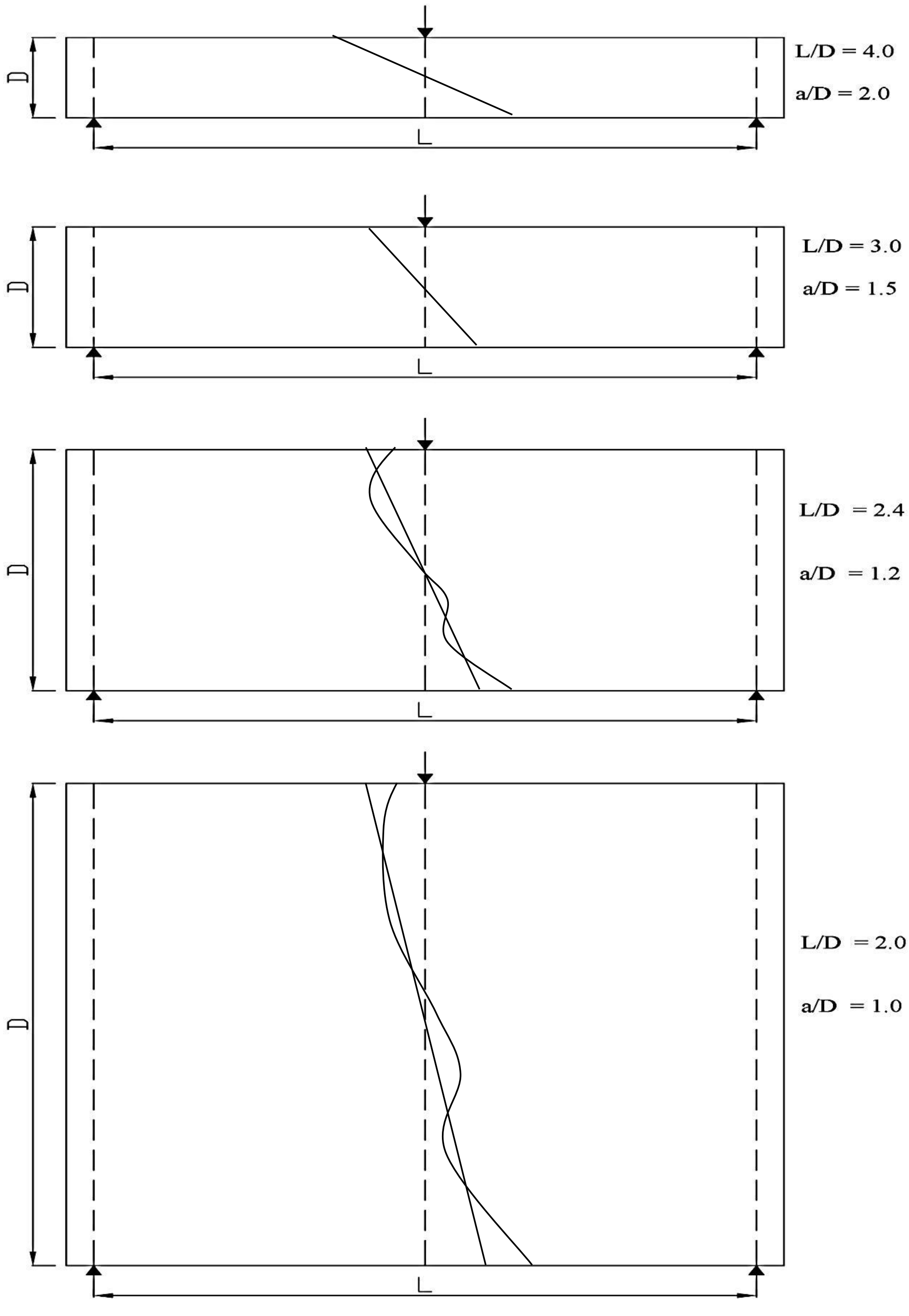


Fig.1.1 Dimensions of Beams Having Varying L/D Ratio

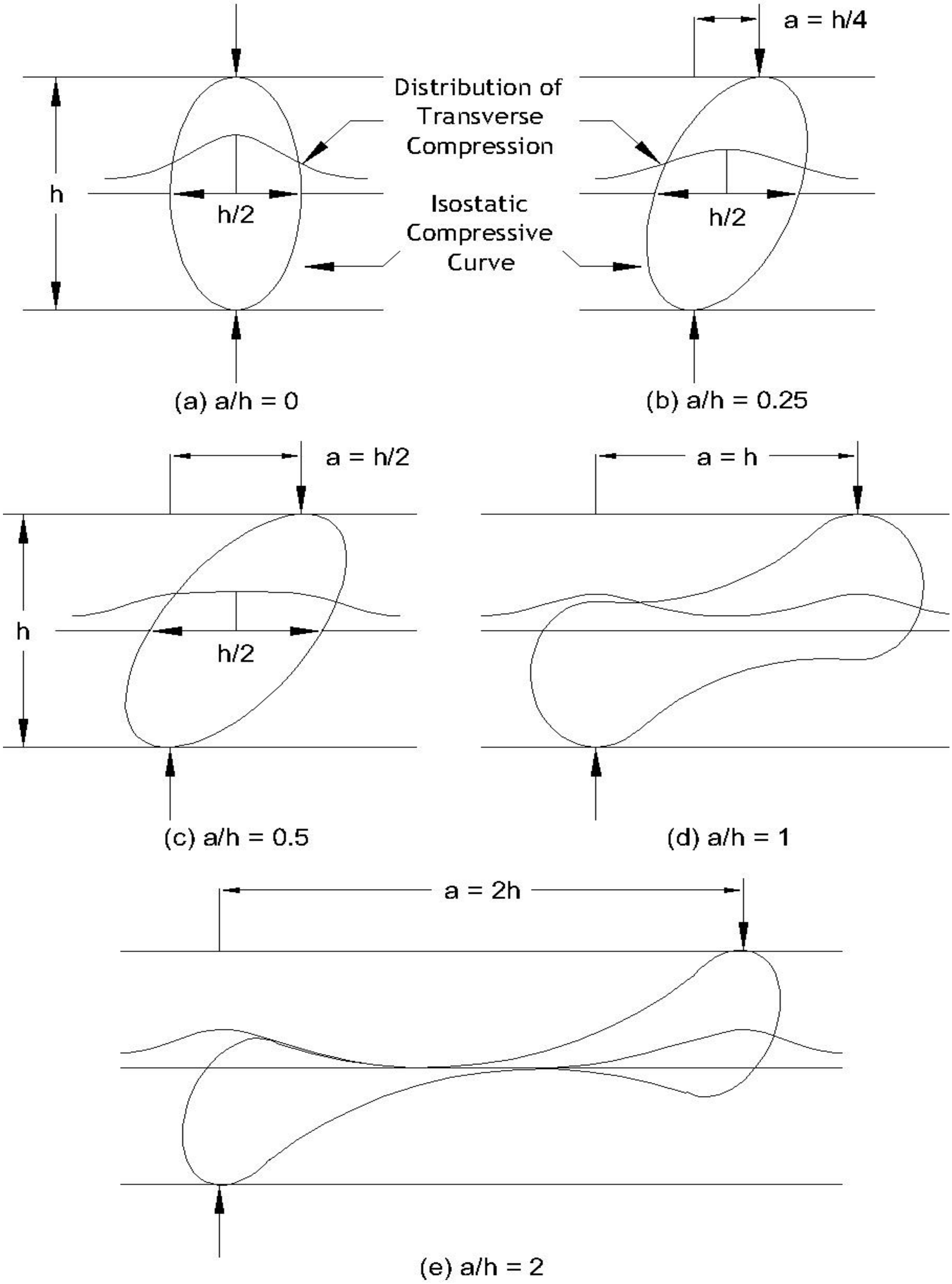


Fig. 1.2 Distribution of Transverse Compressive Stress For Various Shear Span-To-Depth Ratios

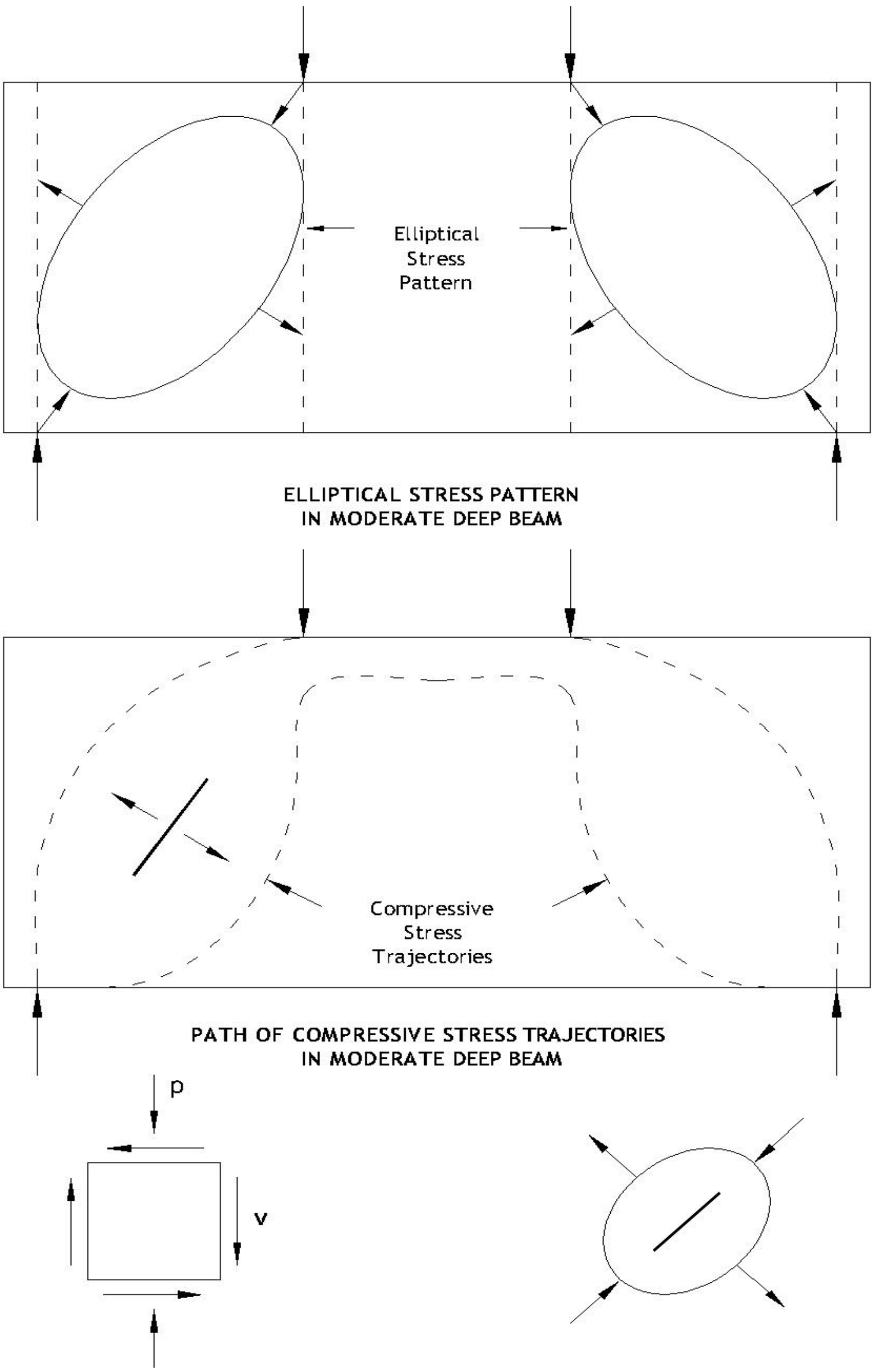


Fig. 1.3 Concept of Stress Distribution in Moderate Deep/Deep Beam

1.2 APPLICATION OF MODERATE DEEP BEAMS

- Tall buildings
- Off shore structures
- Complex foundation systems
- Water tanks
- Bunkers and silos
- Ring beam of nuclear reactors
- Shopping malls
- Hotels and theatres
- Multistory car parking buildings
- Foundation walls supported by individual columns
- Girders
- Pile caps

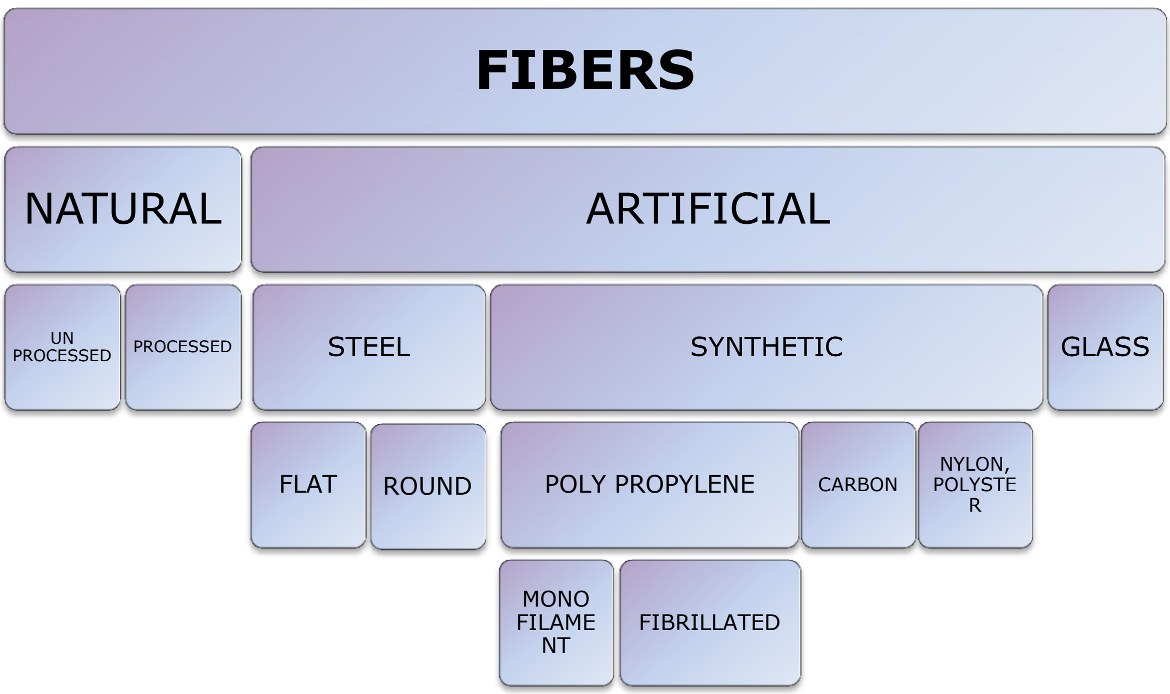
1.3 FIBROUS CONCRETE

Fibrous concrete can be defined as the cement based mixture incorporated with short discrete discontinuous fibers. The mixture can be either a cement paste or mortar or concrete.

The concept of using fibers in a brittle matrix was first observed with the ancient Egyptian work. Animal hairs and straw were used as reinforcement for mud bricks and walls in housing. Wood and bamboo are the best examples of naturally available fiber reinforced construction materials. In the past two decades serious consideration has been given to use of synthetics fibers in the conventional moldable construction materials like asbestos gypsum plasters, cement plasters and concretes to improve performance. The addition of fibers improves the many engineering properties of both fresh and hardened concrete matrix with respect to tensile stress and post cracking behavior.

Mainly three types of fibers (Glass, Steel and Polypropylene) are currently being investigated as fibers in the concrete. Due to low effectiveness, poor alkaline resistance and high cost, use of other fibers such as nylon, rayon, carbon etc. has been almost ruled out after initial investigation. The use of strong and stiff fibers in concrete improves the post cracking performance of concrete considering reserved strength. After micro cracking, fibers spanning the cracks, control rate of crack propagation as well as control the rate of widening of cracks under tensile loading. This role of fiber imparts ductility of concrete and delays its failure, which, otherwise would have occur almost catastrophic as observed in brittle material after micro cracking. After sufficient widening in of cracks at relatively higher load, the short fibers starts pulling out and load gets reduced. The process of fiber pull out absorbs lot of energy and hence the toughness of concrete and is impact resistance are considerably increased. The application of fibers to reinforced concrete structural members would be one of the major areas of use in structural engineering. Steel fibers are often used for their high tensile strength and abrasive properties. Steel fibers increase the ultimate load carrying capacity of concrete. Polypropylene fibers have some unique properties that make them very compatible for mixing with concrete matrix. They are chemically inert and very stable. They have hydrophobic surface hence do not absorb part of mixing water. They are light and can be fabricated in many forms at unit cost cheaper than steel fibers. Poly propylene is alkali resistant and is not affected by admixtures or any other concrete constituent. It is non corrosive thus eliminates unsightly rust stains common with Steel fibers.

1.3.1. Classification of Fibers



1.3.2. Properties of Fibers

TABLE 1.1 Properties of Selected Synthetic Fibers

Fiber Type	Equivalent Diameter (μm)	Relative Density	Tensile Strength (MPa)	Elastic Modulus (GPa)	Ultimate Elongation(%)	Ignition Temperature (^{0}C)	Melt, Oxidation Or Decomposition Temp^{0}C	Water Absorption Per ASTM D 570, % By Mass
Acrylic	13-104	1.16-1.18	270-1000	14-19	7.5-50.0	-	220-235	1.0-2.5
Aramid I	12	1.44	2900	60	4.4	High	480	4.3
Aramid II	10	1.44	2350	115	2.5	High	480	1.2
Carbon, PAN HM	8	1.6-1.7	2500-3000	380	0.5-0.7	High	400	NIL
Carbon, PAN HT	9	1.6-1.7	3450-4000	230	1.0-1.5	High	400	NIL
Carbon, Pitch GP	10-13	1.6-1.7	480-490	27-35	2.0-2.4	High	400	03-07
Carbon, Pitch GP^n	9-18	1.8-2.15	1500-3100	150-480	0.5-1.1	High	500	NIL
Nylon	23	1.14	970	5	20	-	200-220	2.8-5.0
Polyester	20	1.34-1.39	230-1100	17	12-150	600	260	0.4
Polyethylene	25-1000	0.92-0.96	75-590	5	3-80	-	130	NIL
Polypropylene	-	0.90-0.91	140-700	3.5-4.8	15	600	165	NIL

1.3.3. Merits of Fibers

1.3.3.1. Polypropylene Fibers

- It is useful in prevention of plastic shrinkage cracks.
- It improves toughness of concrete.
- It reduces permeability of concrete. Plastic cracks are developed during the early stages of hydration of concrete. These plastic cracks allow water to pass through concrete. The use of polypropylene fibers in the concrete reduces micro-crack formation hence it lowers permeability.
- It improves shear strength of matrix.
- It resists impact and shatter forces.
- It increases freeze/thaw durability.

1.3.3.2 Steel Fibers

- It improves fatigue and impact resistance.
- It improves wear and tear resistance.

- Thinner section is possible due to higher flexural strength of SFRC.
- It gives long service life with little or no maintenance.
- It improves performances under action of any kind of loading.

1.3.4. Major Parameters Affecting The Fiber Interaction With The Matrix

- Matrix composition
- Geometry of the fiber
- Type of fiber
- Surface characteristics of fiber
- Stiffness of fiber in comparison with matrix stiffness
- Orientation of the fibers
- Volume fraction of fibers by volume of concrete
- Rate of loading

1.4 APPLICATION OF FIBERS

- Shear predominant concrete structures
- General plaster work
- Foundation piles
- Pre-stressed piles
- Road patching material
- Heavyweight coatings for underwater pipeline

1.5 STRAIN MEASUREMENTS

Strain is defined as the ratio of deformation in dimensional properties to the actual dimension. It is the fundamental property which has no unit. Strain can be tensile (+ve) or compressive (-ve).

There are various methods of strain measurements out of which here "Mechanical strain gauge" is selected because of its operational convenience.

1.5.1 Mechanical Strain Gauge

There are many types of mechanical strain gauge available in market with different gauge length. Berry type strain gauges are rugged, simple to use and sufficiently accurate in structural applications where the strain distribution is approximately linear over 200 mm gauge length. Fig. 1.4 shows Berry type mechanical strain gauge.

Fig. 1.4 Berry Type Mechanical Strain Gauge

1.6 PROCEDURE OF STRAIN MESUREMENT WITH BERRY STRAIN GAUGE

- The DEMEC (Demounted Mechanical) strain gauge consists of a standard or a digital dial gauge attached to an Invar bar.
- A fixed conical point is mounted at one end of the bar, and a moving conical point is mounted on a knife edge pivot at the opposite end. The pivoting movement of this second conical point is measured by the dial gauge.
- A setting out bar is used to position pre-drilled aluminum discs which are attached to the structure using a suitable adhesive.
- Each time a reading has to be taken, the conical points of the gauge are inserted into the holes in the discs and the reading on the dial gauge noted. In this way, strain changes in the structure are converted into a change in the reading on the dial gauge.

- Reading obtained from the dial gauge is then converted in to mm by multiplying least count with the reading.

1.7 DEFLECTION MESUREMENTS

Deflection is change of dimensional properties in the direction of applied load. It is measured in linear dimensions. In general deflection varies linearly with respect to load but after first crack i.e. after elastic limit, it increases comparatively faster. Deflection is measured with the help of table mounted dial gauges.

1.8 SCOPE AND OBJECTIVE

As a present scenario, design of R.C.C./Fibrous Moderate Deep Beams and Deep Beams are yet not covered by many codal provisions. The research works available for shear predominant members are very less as compared to the literature and codal provisions available for flexure members. The current procedures for shear design of reinforced concrete members especially Moderate Deep Beams are not considered to be fully satisfactory. The shear deformational behavior of beams covering the entire range of transition; from Shallow Beam to Deep Beam has not completely been covered in any research work. The behavior of Moderate Deep Beams and Deep Beams is different from that of the more slender flexural members having relatively large values of span-to-depth (L/*D*) ratios. This difference in behavior is mainly attributable to the significant effect of normal stresses and shear stresses which make the exact analysis of reinforced concrete Moderate Deep and Deep Beams complex.

As compared to tensile and compressive strength, the research carried out on shear strength of Moderate Deep Beam using fibers is comparatively less. The research work on the shear strength of reinforced concrete began in the nineteenth century and up to now large numbers of investigations were carried out to design the beam for shear. At this stage the fundamental shear strain deformational behavior of Fibrous Concrete Moderate Deep Beams and Deep Beams failing in shear remains to be fully explained for the complex condition.

The prime objective of this research investigation is to undertake the comprehensive study of the micro mechanical measurement of strain for the evaluation of various shear parameters in R.C.C./Fibrous Concrete Moderate Deep Beam across its width and depths throughout its whole shear zone. The other objective is to study the cracking characteristics and shear behavior of Fiber Reinforced Concrete Moderate Deep Beams. Cracking characteristics mainly crack patterns and crack widths are also discussed in the present research investigation. The observation were taken for the first cracking load, deflection, modes of failure and ultimate load along with the measurement of maximum crack widths with their locations for developing empirical equations by way of modified available equations.

CHAPTER-2
LITERATURE REVIEW

2.1 GENERAL DESCRIPTION

Many investigations have been carried out and reports have been published so far for predicting the stress-strain behavior of RCC beams with stirrups under various load, support conditions and span-to-depth ratios. But very little work is done on Fibrous Concrete Moderate Deep Beams (without stirrups) to predict the ultimate shear strength.

For this research, numbers of published literatures were studied to get extract of all. A general review of published literature of some of the investigators on RCC/FRC Moderate Deep Beams/Deep Beams is briefly described.

2.2 LITERATURE SURVEY

Following are the several important researches with its brief abstract:

2.2.1. Fiber Concrete Deep Beams In Shear

By R. Narayanan and I.Y.S. Darwish[68]

In this paper the effect of three parameters was studied, namely the volume fraction of fibers, shear span to depth ratio and the concrete compressive strength. The effects of fiber incorporation on deflections, strains, crack widths, crack patterns, failure modes, cracking shear load, and ultimate shear load have been examined. Resistance to shear stress and spalling has been found to be improved by the inclusion of fibers. Based on this investigation, a rapid method of computing the ultimate shear capacity of a steel fiber concrete deep beam is suggested by author,

— — **..... (1)**

Where,

C1=An empirical coefficient equal to 1.05 for normal weight concrete and 0.75 for light weight concrete

C2= An empirical coefficient equal to 100 N/mm² for plain round bars and 225 N/mm² for deformed bars

Xe= effective clear shear span, mm

ha=effective height = h or l, whichever is smaller, mm

f_{spf}=split cylinder strength, N/mm²

b= Breadth of the beam, mm

A_{st}= Area of the individual web bar (for the purpose of this equation, the main longitudinal bars are considered as web bars), mm²

y= Depth of the bar measured from the top of the beam,mm

α = Angle between the line joining load & support with horizontal

..... (2)

Where,

f_{cuf}= Cube strength of fiber reinforced concrete, N/mm²

A= a non-dimensional constant having a value of

B= a dimensional constant having a value of 0.7 N/mm²

C= a dimensional constant having a value of 1 N/mm²

..... (3)

Where,

—**=** fiber aspect ratio

ρ_f= fiber volume fraction in the mix

β=bond factor (based on large series of pullout test β has been assigned a relative value of 0.5 for fiber having circular cross section, 0.75 for crimped or hooked fibers, 1.0 for indented fibers).

To investigate the above statement the author tested 12 reinforced concrete deep beams, including 11 containing steel fibers.

From an analytical study presented in this paper, the following conclusions were drawn by the authors:

1. The inclusion of steel fibers in concrete deep beams resulted in enhanced stiffness and increased spall resistance at all stages of loading up to failure and reduced crack widths.
2. Deep beams of fiber concrete under shear loading develop zones of approximately zero stress in many cases over a height of 0.15 to 0.3 h.
3. In general, the primary cause of failure was diagonal cracking, which led to the splitting of the beam along the diagonal cracks.
4. Both shear cracking load Vfo and ultimate shear load Vuo were influenced by the fiber factor F, a/h ratio and the concrete cube strength. The maximum increase in ultimate shear load considering the increase in F value from 0 to 0.75 was 25 percent for specimen D5 and the maximum increase in shear cracking load considering the increase in F value from 0 to 0.94 was about 100 percent for specimen D6.

   Ultimate loads in shear could be estimated by the equation (1) in which fiber concrete strength is represented by the calculated split cylinder strength fspf given by equation (2).

2.2.2. Shear Characteristics Of Reinforced Fiber Concrete

By Dr.C.B.Kukreja, Dr.S.K.Kaushik, Dr.M.B.Kanchi, and Dr.O.P.Jain[76]

As per this paper, fibrous concrete is a matrix with evenly distributed closely spaced fibers. This paper clearly states that steel fibers can be successfully used as partial shear reinforcement but the selection of fiber and its aspect ratio is very important.

The formula used for the theoretical investigation of ultimate shear strength offered by fibers is as below.

Where,

= Ultimate shear strength offered by fibers

=Constant derived by regression analysis

= Width of rectangular section.

D = Overall depth of rectangular section

To investigate above statements author had tested steel beam moulds 10.16cm x 15.24cm in cross section and 122 cm long. There were 11 series of beams, the first series was for reinforced concrete but without fibers and the remaining series for reinforced concrete with steel fibers and the last series was with reinforced concrete without fibers but with shear stirrups. Physical properties of 11 series of beams tested in this investigation are tabulated in this paper.

Crack width at working loads in reinforced fiber concrete beams are 50% of crack widths in beams without fibers and the inclination of diagonal tensile crack with the horizontal tensile crack in beams containing fibers is nearly 45° which is the case for beams without fibers as stated by the author.

2.2.3. Formula For Shear Strength of Deep Beams

By S. T. Mau and Thomas T. C. Hsu [65]

In this paper an explicit formula is derived for the shear strength of deep beams using the three equilibrium equation from the truss model theory. The constants in the formula are calibrated utilizing test data available in the literature. The formula is dimensionless and contains four variables that express the horizontal and vertical reinforcement ratios, the concrete strength and the shear span ratio.

The formula suggested by the author for ultimate shear strength of deep beams is as below:

Where,

V = Shear strength in shear span

fc’ = Cylindrical compressive strength of concrete

K = Ratio of the effective compressive stress in transverse direction to the effective tensile stress in the shear element

ωh = Reinforcement indexes in horizontal direction

ωv = Reinforcement indexes in vertical direction

C = Constant

From an analytical study presented in this paper, the following conclusions were drawn by the authors:

1. The equation is based on the equilibrium conditions of the effective shear element in a shear span. The final form of the formula is dimensionless and each variable in the formula has a clear physical meaning.
2. The formula expresses explicitly the contributions of the shear span ratio a/h (through K), horizontal reinforcement ωh, vertical reinforcement ωv and concrete strength fc′.
3. The proposed formula is calibrated with data conveying the following range on span-depth ratio, horizontal web reinforcement ratio and vertical web reinforcement ratio: $0.95 \le L/d \le 3.3$, 0 ≤ ≤0.0091, and $0.0018 \le \rho v \le 0.0245$ respectively. The compression steel ratio is within 0.92 percent. The concrete cylinder strength compression strength is close to 3000 psi (21MN/m²). Within these ranges, the proposed formula is accurate in predicting the shear strength of simply supported deep beams.

2.2.4. Ultimate Strength of Steel Fiber Reinforced Concrete Deep Beams

By Indradatta I. Pandya and Shreeram K. Damle [70]

As per this paper the experimental investigations carried out on fifteen deep beams consisting of plain and fiber reinforced concrete. The beams contained conventional tensile steel reinforcement and web reinforcement. The first cracking load, crack patterns, ultimate load and modes of failure are reported. On the basis of these investigations, empirical formulae are proposed for estimating the first cracking load and ultimate shear strength of beams. The addition of steel fibers in reinforced concrete resulted in a significant increase in the ultimate shearing capacity of beams.

The formula suggested by the author for ultimate shear capacity of deep beams is as below.

Where,

Vu2 = Ultimate shear capacity

f_t = Concrete split cylinder strength

fy = Yield stress of reinforcement

b = Width of beam

d = Effective depth of beam

–= Variation of strain in the web steel

α = Angle of horizontal to principal plane

A = Area of longitudinal or transverse reinforcement

From an analytical study presented in this paper, the following conclusions were drawn by the authors:

1. Addition of steel fibers in concrete deep beams resulted in significant increase of ultimate load capacity of the beams.
2. The larger area under the load deflection curves, especially for fiber reinforced concrete deep beams indicates a more ductile type behavior.

   The equation proposed in the present investigation is quite general and can predict satisfactorily the ultimate strength of fiber reinforced concrete deep beams for two point loading having span/depth ratio in the range of 1 to 1.5. Calculation of ultimate load, on the basis of formulae proposed, give values which are about ±15 percent of the observed values.

2.2.5. Shear Strength of Reinforced High Strength Concrete Beams with Shear Span-To-Depth Ratio Between 1.5 And 2.5

By Sung-Woo Shin, Kwang-Soo Lee, Jung-Lee Moon and S.K. Ghosh [45]

In this paper authors tested thirty high-strength concrete beams under concentrated loads at mid span to determine their diagonal cracking strength and nominal shear strength. The test variables were the compressive strength of concrete, the shear span-to-depth ratio, and the vertical shear reinforcement ratio. The effect of each test variable studied separately. Test results were compared with strengths predicted using ACI 318-95. It was found that for beams with shear span-to-depth ratios between 1.5 and 2.5, ACI Eq. (11-30) generally underestimates the shear strength contributed by the vertical shear reinforcement. New equations are presented for a more accurate prediction of the diagonal cracking strength and the nominal shear strength of reinforced concrete deep beams.

The formulas suggested by the author for ultimate shear capacity of deep beams without stirrups are as below.

Where,
Vcr = Shear strength values obtained from tests.
f'c = Compressive stress of concrete
ρ = Longitudinal reinforcement ratio
d = Shear depth
a = Shear span

From an analytical study presented in this paper, the following conclusions were drawn by the authors:

1. The mode of failure was mainly affected by the shear span-to-depth ratio *a/D*, rather than the shear reinforcement ratio; shear compression failure tended to change to shear tension failure at *a/D*= 2.0
2. For beams with shear span-to-depth ratios between 1.5 and 2.5, ACI 318-95 Eq. (11-30) generally underestimates the shear strength contributed by the vertical shear reinforcement.

3. Based on the test results, regression equations for diagonal cracking strength and nominal shear strength of beams having shear span-to-depth ratios between 1.5 and 2.5 are given above.

2.2.6. Shear Strength Prediction for Deep Beams

By Shyh-jiann Hwang, Wen-Yao Lu, and Hung-Jen Lee [43]

In this paper, a softened strut-and-tie model for determining the shear strengths of deep beams is proposed. The proposed model originates from the strut-and-tie concept and satisfies equilibrium, compatibility, and constitutive laws of cracked reinforced concrete. The shear strength predictions of the proposed model and the empirical formulas of the ACI 318-95 Code are compared with the collected experimental data of 123 deep beams. The comparison shows that the performance of the softened strut-and-tie model is better than the ACI Code approach for all the parameters under comparison. The parameters reviewed include the ratios of horizontal and vertical reinforcement, concrete strength, and the shear span-depth ratio. The softened strut-and-tie model can be further developed to improve the current deep beam design procedures by incorporating the actual shear resisting mechanisms in predicting shear strength supply of deep beams.

The formulas suggested by the author for ultimate shear capacity of deep beams of strut and tie method of ACI as below,

Where,

Vertical beam shear force

Horizontal beam shear force

D = Compression force in diagonal strut

Tension force in horizontal ties

Tension force in vertical ties

θ = Angle of inclination of h-axis with respect to d-axis.

From an analytical study presented in this paper, the following conclusions were drawn by the authors:

1. The softened strut-and-tie model consistently reproduced 123 deep beam measured shear strengths with reasonable accuracy for a wide range of horizontal and vertical web reinforcement ratios, concrete strengths, and shear span-to-depth ratios.
2. The ACI 318-95 Code empirical equations were found to underestimate the contribution of concrete and overestimate the contribution of web reinforcement on the shear strength of deep beams.
3. In general, the ACI Code's predictions are conservative for the selected test results in this paper and more pronounced conservatism can be found for deep beams without web reinforcement and with high-strength concrete and a low *a/D* ratio.

The proposed model can provide valuable insights into the shear strength and behavior of reinforced concrete deep beams and may be incorporated into current deep beam design methods.

2.2.7. Shear Capacity of Reinforced Concrete Deep Beams

By A. F. Ashour [42]

In this paper, a mechanism analysis of shear failure of simply supported reinforced concrete deep beams is presented. Concrete and steel reinforcement are modeled as rigid perfectly plastic materials. The failure modes are idealized as an assemblage of rigid blocks separated by failure zones of displacement discontinuity. The shear strength of deep beams is derived as a function of the location of the instantaneous center of relative rotation of moving blocks. Minimization of the developed function gives the shear capacity of deep beams. Comparisons of the predicted shear capacity of numerous deep beams show good agreement with results obtained from experiments. A parametric study of main variables affecting shear strength of deep beams is conducted. The present model shows that the shear-span-to-depth ratio has more influence on the shear capacity than the span-to-depth ratio and as the former increases, the shear strength decreases. Increasing main longitudinal bottom reinforcement increases the shear capacity up to a certain limit beyond which no shear strength improvement could be achieved. The relative effectiveness of horizontal and vertical web reinforcement on the load capacity is mainly influenced by the shear-span-to-depth ratio; the deeper the beam, the more effective the horizontal web reinforcement and the less effective the vertical web reinforcement.

2.2.8. Behavior of Fiber Reinforced Concrete Deep Beams

By A. K. Sachan and C. V. S. Kameswara Rao [63]

In this paper, Authors describes an experimental investigation to study the strength and behavior of steel fiber reinforced concrete deep beams. In total 14 beams were tested. The effects of fiber content, percentage reinforcement and type of loading were studied. The ultimate load-carrying capacity, modes of failure and load-deflection behavior reported. A simple model is proposed to predict the load carrying capacity of the beams. The addition of steel fibers to concrete results in a significant increase in ultimate strength of deep beams. It is also observed that the failure of Fiber Reinforced Concrete beam was more ductile and gradual compared with the failure of plain and RCC beams.

2.2.9. Shear Strength of Reinforced Concrete Deep Beams

By Wei Wang, Da-Hua Jiang and Cheng-Tzu Thomas Hsu [61]

In this paper, Formulas to predict the ultimate shear strength of reinforced concrete deep beams are proposed. The derived equations are based on limit analysis theorems and associated flow rule. The lowest upper-bound solution is achieved through the work equation. With the effective strength concept, the material are assumed to be perfectly rigid-plastic. A special constant is introduced to consider the structural effect on the effectiveness strength factor of concrete. For deep beams, this constant is equal to 1.25-0.25λ, where λ is the shear-span ratio of deep beam. The interaction between horizontal and vertical web reinforcement is carefully analyzed. It is found that the yield condition of horizontal and vertical web reinforcement depends on the ratio of and , or the degree of horizontal and vertical web reinforcements. Comparisons with experimental work are performed, and they show good agreement between the proposed equations and test results.

2.2.10. Shear Strength Of Steel Fiber Reinforced Concrete UHPC Beams Without Stirrups

By Yen Lei Voo, Wei Keat Poon and Stephen J. Foster [15]

As per this paper, the database of tests on shear in reinforced concrete members without stirrups is extensive; the pool of test data for fiber-reinforced specimens is limited. Fewer still are tests undertaken on high performance fiber reinforced concrete members with the fiber concrete designed to carry the full shear capacity. This paper reports the results of a testing program on ultra-high performance steel fiber reinforced concrete beams. Eight pre-stressed concrete beams were tested in shear with the test variables being the shear span-to-depth ratio and the quantity and type of steel fibers. The results of the tests, together with additional tests reported in the literature, are compared to the values derived from the PSM-VEM predictive model for the determination of shear strength of steel fiber reinforced concrete beams. A good correlation is observed with a mean model to experimental strength ratio of 0.92 and coefficient of variation of 0.12.

2.2.11. Shear Failure Of Deep Fiber Reinforced Concrete Beams

By T. M. Roberts and N. L. Ho [78]

In this paper, the results of a number of tests on deep fiber reinforced concrete beams are presented. The beams contained conventional tensile steel reinforcement but different percentage of steel fiber in place of conventional shear reinforcement. All beams were simply supported and loaded to failure by a central load distributed through two bearing plates. The results confirm that steel fiber can prevent shear failure in deep beams, and also indicate the various modes of failure of deep beams.

2.2.12. Evaluation Of Shear Strength Of Fiber-Reinforced Concrete Beams

By S.A. Al-Ta’an & J. R. Al-Feel [64]

In this paper, method is proposed to calculate the ultimate shear strength of fiber-reinforced concrete rectangular beams without stirrups. The method shows good agreement with published test results of 89 beams which failed in shear. The published data were also used in a regression analysis to identify the factors influencing the shear strength of fiber concrete beams. These factors were found to be the shear span-to-depth ratio, main reinforcement ratio, compressive strength of concrete and the fiber volume, dimensions, and type. Two formulae are given by authors to predict the cracking and ultimate shear strength.

2.2.13. Experimental Evaluation Of Design Procedure For Shear Strength Of Deep Reinforced Concrete Beams

By Gerardo Aguilar, Adolfo b. Matamoros, Gustavo J. Parra-Montesinos, Julio A. Ramfrez and James K. Wight [39]

In this paper, results from the monotonic testing of four reinforced concrete deep beams are presented. The behavior of the deep beams is described in terms of cracking pattern, load-versus-deflection response, failure mode, and strains in steel reinforcement and concrete. Despite different failure modes, the failure loads and corresponding ultimate deflections were similar in all four specimens. Yielding of both longitudinal and transverse reinforcement occurred prior to failure. Based on the test results, the shear design procedures contained in the ACI 318-99 Code and Appendix A of the ACI 318-02 Code were evaluated. Both design procedures yielded conservative predictions of the shear strength of the single-span deep beams.

2.2.14. Shear Strength Of Normal And High Strength Fiber Reinforced Concrete Beams Without Stirrups

By Madhusudan Khuntia, Bozidar Stojadinovic, and Subhash C. Goel [47]

In this paper, a general method of predicting the ultimate shear strength of FRC beam was proposed. A design equation was suggested for evaluating the ultimate shear strength of FRC beams based on the basic shear transfer mechanisms and numerous published experimental data on concrete strength up to 100 MPa. In addition to concrete strength, the influence of other variables such as fiber factor, shear span-to-depth ratio, longitudinal steel ratio, and size effect was considered. This method can be applied across a practical range of concrete strengths (20-100 MPa), fiber factor values (0.25-2.0), and shear span-to-depth ratios (more than 0.5).

Author has expressed the ultimate shear resistance of FRC beams as

Where,

= arch action factor = 2.5 for *a/D*< 2.5

= 1 for *a/D* ≥ 2.5

F_1 = fiber factor =

β = bond factor considering shape and surface characteristics of fiber

f_c' = compressive strength of FRC, MPa.

2.2.15. Steel Fibers Replacement Of Web Reinforcement For R.C.C. Deep Beams In Shear

By S.K. Madan, G. Rajesh Kumar and S.P. Singh [88]

Test data are presented on the shear strength of a series of Reinforced Cement Concrete (RCC) deep beams with three steel fiber volume fractions (0, 1.0 and 1.25%), three shear span to effective depth ratios (0.75, 1.0 and 1.25) and three combinations of web reinforcement. A total of 18 beams were tested to failure under two-point top loading. The test results indicate that the fibers have significant influence on the shear strength of a longitudinally reinforced concrete beams. Shear strength increases with increasing fiber volume and decreasing shear span to-effective depth ratio. Steel fibers can replace the conventional web reinforcement in RCC deep beams.

Based on the test results presented in this study the following conclusions can be drawn.

1. The inclusion of short steel fibers in concrete mix provides effective shear reinforcement in deep beams and provides better crack control and deformation characteristic of beams.
2. Both the first crack strength and ultimate strength in shear increase with the provision of web reinforcement. More significant increase was found for the fiber reinforced beams because of their increased resistance to propagation of cracks.
3. Shear strength increases with increasing fiber content and decreasing a/D ratio.
4. The theoretical prediction of ultimate shear strength on the basis of methods used in the study gives results close to the observed values in most of the beams tested.
5. Maximum increase of 56 percent in first cracking load for beam containing 1.25 percent of fibers was observed when compared with beam containing no web reinforcement. Also for all the beams tested in this program maximum shear strength was attained in beams reinforced with steel fibers followed by beams containing web reinforcement. These results support the use of steel fibers as an alternative to conventional web reinforcement is deep beams.

2.2.16. Crack and Deformation Characteristics of SFRC Deep Beams

By Prof R. H. Shah, S. V. Mishra [32]

In this paper, author investigates the effect of inclusion of steel fibers in concrete on crack and deformation characteristics of deep beams for various span-to-depth ratios. The complete load-deflection response, along with cracking characteristics, modes of failure, tensile strain in the main steel bar and ductility of beam were investigated experimentally. The modes of failure include flexure, flexural shear and shear. An effort was also made to investigate the effect of steel fibers and bar reinforcement on flexure and shear cracks as well as on strength parameters, such as, the first crack load, yielding of the beam, reserve strength and ultimate failure load of the beam. Twelve beams were tested and the results indicate that the inclusion of steel fibers significantly reduces the cracking and deforming behavior of plain concrete deep beams by resisting tensile stresses. Comparisons were also made among the beams of three series as well as among the varied span to depth ratio of beams within the same series.

2.2.17. Shear Strength of Steel Fiber Reinforced Concrete

By Amir A. Mirsayah and Nemkumar Banthia [37]

The shear behavior of fiber-reinforced concrete was studied using direct shear tests. Two 50 mm-long steel fibers, one with flattened ends and a circular cross section and the other with a crimped geometry and a crescent cross section, were investigated at fiber volume fractions varying between 0 and 2%. Direct comparison was made with flexural toughness determined as per the ASTM C 1018 procedure. It was found that both fibers provided significant improvements in shear strength as well as shear toughness and these improvements were greater at higher fiber dosage rates. Between the two fibers, the fiber with flattened ends was seen to be more effective than the one with crimped geometry. For the flattened-end fiber, an almost linear increase in the shear strength was noted with an increase in the fiber volume fraction. For the fiber with crimped geometry, on the other hand, shear strength approached a plateau value beyond which no increases in shear strength occurred with an increase in the fiber volume fraction. While plain concrete failed at a low equivalent shear strain of 0.4%, fiber-reinforced concrete supported as high as 10% strain in shear. When the shear toughness of steel fiber-reinforced concrete was compared with its flexural toughness, there appeared to be a direct correlation. However, given the subjectivity of this type of comparison and the limited data generated in this study, much further research is needed to fully understand and establish this correlation.

2.2.18. Theoretical Prediction of Shear Strength And Failure Mode Of Reinforced Concrete Beams

By Fumio Watanabe and Jung-Yoon Lee [49]

An incremental analytical method capable of tracing the response of beams to shear was proposed by authors. The model is based on truss mechanism. The compatibility of strains and the equilibrium of stresses of the cracked concrete and shear reinforcement were applied to the shear model using constitutive laws of materials, taking into account the effect of aggregate interlocking. This model is capable of predicting the shear strength and also the shear failure mode by adopting an incremental analytical method.
Authors have classified shear failure into the following three failure modes as:

1. STF —Just after the yielding of shear reinforcement, the beam shows its maximum strength due to excessive widening of diagonal cracks without crushing of diagonally compressed concrete.
2. SYCF —after the yielding of shear reinforcement, the resisting shear of the beam increases due to the aggregate inter locking. The beam reaches its maximum shear strength due to crushing of diagonally compressed concrete.
3. SCF —after forming diagonal cracks, the beam reaches the maximum shear strength due to crushing of diagonally compressed concrete without the yielding of shear reinforcement.

The proposed analytical method was verified by comparing with the test results of total 96 beams. Only beams which failed in shear prior to the yielding of longitudinal reinforcement without bond splitting failure were considered and it was concluded by the authors that the shear strength predicted by the proposed method showed a good agreement with the test results. On the other hand, the ACI Code is conservative for the test results and the AIJ-A Method is unsafe for higher V_{exp}/V_f than 0.45. Most of the predicted failure modes: STF, SYCF and SCF, agree with the observed failure modes. The shear force-deformation response predicted by the proposed method show a good agreement with the test results until the beams reach their maximum shear forces.

2.2.19. Initiation of Shear Cracking In Reinforced Concrete Beams with No Web Reinforcement

By Woo Kim and Richard N. White [62]

A hypothesis was proposed for the shear cracking mechanism in point loaded reinforced concrete beams, with no web reinforcement. The hypothesis resulted from an approximate analytical approach based on the observation that flexure-shear cracking results from a severe localization of internal stress after the onset of flexural cracking. This local stress concentration is associated with the nature of bond between concrete and flexural reinforcement, and the development of arch action in the end region (shear span) of the beam. Analytical expressions were developed for predicting the shear cracking load and the corresponding location of the critical shear crack. The adequacy of these expressions was then established by comparison with published test data.

The equation was presented as

$$V_{cr} = 9.4\,[\sqrt{p}\,(1 - \sqrt{p})^2\,(d/a)]^{1/3}\sqrt{f_c'}\;b\,d$$

Where,

ρ = steel ratio

f_c' = compressive strength of concrete.

To check the applicability of above equation more than 100 test beams were examined and the results compared with those calculated by the ACI formula and Zsutty's formula. Both the mean value and the standard deviation showed that good correlation existed between the predicted and the measured values.

From the analytical and experimental study authors have concluded that in ordinary rectangular reinforced concrete beams (with no web reinforcement) failing in shear, inclined shear cracking starts after the development of nearby flexural cracks, near the middle of the shear span and just above the longitudinal reinforcement. The primary factor in the initiation of the inclined shear crack at a relatively low conventionally calculated shear stress is the magnification of actual shear stress produced by the following two distinct stress concentration effects arising from the formation of the nearby flexural crack(s):

1. Concentration of bond stress along the longitudinal reinforcement near the middle of the shear span by the nature of bond after flexural crack forms nearby, and
2. Amplification of steel tension force near the middle of the shear span by the reduction of the internal moment arm length due to the development of arch action as flexural cracks extend.

These effects combine to produce a critical-zone shear stress that is at least three times larger than the average shear stress calculated from *V/bd*. The equations for predicting shear cracking loads and corresponding crack positions are based to a large extent on analytical premises and give satisfactory correlation between theoretical values and numerous published test results. No equation has been found previously for predicting shear crack locations.

2.2.20. The Influence of Shear Span Ratio on Load Capacity of Fiber Reinforced Concrete Elements With Various Steel Fiber Volumes

By Remigijus Šalna, Gediminas Marčiukaitis [21]

This paper analyses the influence of steel fiber volume and shear span ratio on the strength of fiber reinforced concrete elements in various states of stress. 36 beams with three different shear spans (*a/h* = 1, 1.5 and 2 %) and three different fiber volumes (1, 1.5 and 2 %) were tested to examine how these factors influence the behavior of such elements. Test results suggest that steel fiber volume and shear span can increase load capacity, plasticity and cracking. Experimental research showed that steel fiber volume has different influence at different shear span ratios. Regression analysis of experimental data was carried out and empirical approach showing different effect of these factors was proposed. Furthermore, test results were compared with different theoretical and empirical approaches of other authors.

2.2.21. Shear Strength of Steel Fiber-Reinforced Concrete Beams without Stirrups

By Yoon-KeunKwak, Marc O. Eberhard, Woo-Suk Kim, and JubumKim [38]

In this paper, authors were tests conducted on 12 Reinforced Concrete beams with three steel fiber-volume fractions (0, 0.5 and 0.75%), three shear span-depth ratios (2, 3 and 4) and two concrete compressive strengths (31 and 65 MPa). The results demonstrated that the nominal stress at shear cracking and the ultimate shear strength increased with increasing fiber volume, decreasing shear span-depth ratio, and increasing concrete compressive strength. As the fiber content increased, the failure mode changed from shear to flexure. The results of 139 tests of fiber-reinforced concrete beams without stirrups were used to evaluate existing and proposed empirical equations for estimating shear strength. The test population included beams with a wide range of beam properties, but most of the beams were small. The evaluation indicated that the equations developed by Narayanan and Darwish and the equations proposed herein provided the most accurate estimates of shear strength and the onset of shear cracking.

2.2.22. Flexural Response of Hybrid Fiber-Reinforced Cementitious Composites

By Nemkumar Banthia and Sayed Mohamad Soleimani [25]

In Fiber-Reinforced Concrete (FRC), fibers can be effective in arresting cracks at both macro and micro levels. Most of the FRC used today involves the use of a single fiber type. This implies that a given fiber can provide reinforcement only at one level and within a limited range of strain or crack opening. For an optimal response, therefore, different types of fibers may be combined to produce hybrid fiber-reinforced concrete (HFRC). The influence was quantified of various hybrid fiber combinations on fresh properties of concrete (that is, workability) and on hardened properties such as compressive strength. The main objective of this research, however, was to investigate the flexural toughness properties of hybrid fiber-reinforced concrete and to identify synergistic effects between fibers, if present. It was noted that some hybrid composites demonstrated some synergy between fibers.

2.2.23. Strength of Struts In Deep Concrete Members Designed Using Strut-And-Tie Method

By Carlos G. Quintero-Febres, Gustavo Parra-Montesinos, and James K. Wight[24]

Results from an experimental investigation aimed at evaluating the adequacy of the strength factors for concrete struts in strut-and-tie models given in Appendix A of the 2002 ACI Building Code are presented. The main design variables considered were: the angle between primary strut-and-tie axes, amount of reinforcement crossing the strut, and concrete strength. A total of 12 deep beams were tested, eight with normal strength concrete and four with high-strength concrete. The ratio between experimentally obtained failure loads and the strengths predicted using the strut strength factors given in Appendix A of the ACI Code ranged between 1.00 and 1.22, and between 0.91 and 1.02 for normal and high-strength concrete beams, respectively. Inconsistencies were found in the provisions for minimum reinforcement crossing a strut in Sections A.3.3 and A.3.3.1 when applied to the test specimens, with the former leading to substantially larger reinforcement ratios. The use of a strut strength factor $\beta s = 0.60$ in high-strength concrete bottle-shaped struts without web reinforcement led to strength predictions approximately 10% higher than the experimental failure loads. The limited test results suggest that, as a minimum, an effective reinforcement ratio of 0.01, calculated according to ACI Code, Section A.3.3.1, should be provided in high-strength concrete members when a strength factor $\beta s = 0.60$ is used. Additional test data, however, are required before a definite recommendation can be made in this regard.

2.2.24. Effect of Web Reinforcement on High-Strength Concrete Deep Beams

By Kang-Hai Tan, Fung-Kew Kong, Susanto Teng, and Li-Wei Weng[50]

Effect of Web Reinforcement on High-Strength Concrete Deep Beams Results of an experimental investigation on the behavior and ultimate shear strength of 18 high strength concrete deep beams are summarized. The concrete cylinder compressive strength fc′ ranges from 55 to 86 MPa (approximately 8000 to 12,500 psi). The test specimens are divided into three series based on the shear-span-to-overall-height ratio a/h. Each series consists of six beams with different arrangements of horizontal and vertical web reinforcements, i.e., the main variables are the horizontal and the vertical web steel ratios. Observations are made on mid-span deflections, crack widths, failure modes and ultimate strengths. The test results show that for deep flexural members with a/h exceeding 1.00 (or shear span- to-effective-depth ratio a/d ≥ 1.13), the vertical web reinforcement is more effective than the horizontal web reinforcement. It is also shown that orthogonal web reinforcement comprising both vertical and horizontal reinforcements is the most efficient in increasing the beam stiffness, restricting the diagonal crack width development and enhancing the ultimate shear strength. The test results are then compared with the ultimate strength predictions obtained using the current ACI Code, the Canadian Code, and the UK CIRIA Guide. The deep-beam provisions in the ACI Code overestimate the contribution of the horizontal web steel to shear strength. Based on the test results, a revision to ACI Eq. (11-31) for web steel contribution is suggested. The Canadian Code shows the most consistent and yet conservative predictions of the test beams with different web reinforcements, while the UK CIRIA Guide is un conservative for beams with horizontal web reinforcement.

2.2.25. High-Strength Concrete Deep Beams With Effective Span And Shear Span Variations

By Kang-Hai Tan, Fung-Kew Kong, Susanto Teng, and Lingwei Guan [56]

Nineteen reinforced concrete deep beams with compressive strengths in the range of 41 MPa ≤ fc′ ≤ 59 MPa (6000 psi ≤ fc′ ≤ 8600 psi) were tested under two-point top loading. All the beams were singly reinforced with main steel percentage ρ = 1.23 percent and with nominal percentage of shear reinforcement ρv = 0.48 percent. The beams were tested for seven shear span-depth ratios a/d, ranging from 0.27 to 2.70, and four effective span-depth ratios le/d, ranging from 2.15 to 5.38. Test results indicate that le/d has little influence on the magnitude of the failure load. But for beams with a/d ≥ 1.00, the flexural failure mode becomes dominant with increasing le/d. The test results are compared with predictions based on the current ACI Building Code. The comparisons reported in this paper will provide an added assurance to designers that the deep-beam provisions in the ACI code, though essentially based on concrete strengths of less than 41 MPa (6000 psi), will insure safe designs for higher strength deep beams. However, the ACI code tends to be rather conservative, as shown by comparison to the Deep-Beam Design Guide issued by the Construction Industry Research and Information Association, London. Nevertheless, the ACI code has the important advantage of being easy to use.

2.2.26. Strut-And-Tie Model For Deep Beam Design

By James k. Wight and Gustavo j. Parra-Montesinos [36]

It is a new concept for many structural engineers in the U.S. Procedures and recommendations for the use of STM to design reinforced concrete members were discussed in a State-of-the-Art Report from Joint ACI-ASCE Committee 445. Specific code requirements were not incorporated into the ACI Building Code until the 2002 edition. To help U.S. engineers improve their ability to use STM for analysis and design of concrete members, Joint ACI-ASCE Committee 445 and ACI Committee 318-E, Shear and Torsion, recently completed a publication that contains a variety of STM examples. The STM model used here for the analysis and design of a deep beam is not unique. It should be noted that the STM procedure in Appendix A of the ACI Building Code (referred to as the Code) is a strength limit-state design approach. Serviceability limit-states (for example, deflections and reinforcement distribution) defined in the main body of the Code must also be checked.

2.2.27. Behavior of Large-Scale Reinforced Concrete Beams With Minimum Shear Reinforcement

By Robert J. Frosch [41]

Research has indicated that as the depth of a beam increases, a decrease in the shear strength of the section can be expected. This trend has often been termed a size effect. Testing of specimens unreinforced in shear has also demonstrated that it is possible for the shear strength to fall below that commonly assumed in design. Most sections, however, contain at least minimum transverse reinforcement as required by the building code. Therefore, it is important to understand the behavior of these structures as they may also be affected by a size effect. Two duplicate large-scale beams containing minimum shear reinforcement were tested. The tests were conducted to investigate the effect of size on the shear strength provided by the concrete as well the shear strength provided by the transverse reinforcement. The specimens were subjected to constant shear, and the test results were analyzed. Based on these analyses, conclusions and concerns regarding the shear strength of transversely reinforced sections are presented.

2.2.28. Design Of Simply Supported Deep Beams Using Strut-And-Tie Models

By Adolfo B. Matamoros and Kuok Hong Wong [34]

A procedure to calculate the amount of reinforcement and the strength of deep beams based on strut-and-tie models is presented. The proposed design equations were calibrated using experimental results from 175 simply supported beams found in the literature with a maximum shear span-to-depth ratio of 3. The strength reduction coefficient for concrete in the main strut was found to decrease with the angle of inclination of the strut, resulting in lower values than those stated in Appendix A of the 2002 edition of the ACI 318 Building Code for beams with shear span-to-depth ratios greater than 1.

2.2.29. Shear Behavior of Large Reinforced Concrete Deep Beams And Code Comparisons

By K. H. Tan and H. Y. Lu [44]

In this paper, an experimental program on the size effect in reinforced concrete deep beams is described. A total of 12 large- and medium-sized specimens with overall height h ranging from 500 to 1750 mm and effective span le from 1500 to 4520 mm were tested to failure under two-point symmetric top loading. The beams had compressive cylinder strengths fc' of about 40 MPa and main steel ratio of 2.60 percent. Test results reveal that the ultimate shear stress is size-dependent and that Bazant's law can best describe this size effect. On the other hand, the diagonal cracking stress is hardly size-dependent. Besides the shear span to-height ratio a/h, the size effect h also has a significant influence on the failure mode; larger deep beams are more brittle in comparison with smaller ones. Some plausible explanations are given to the source of size effect in deep beams. It may arise from different rates of release of fracture energies associated with crack propagation in beams of different sizes. This is demonstrated from the crack patterns of geometrically similar beams at the same nominal shear stress, where it is obvious that crack development was more extensive in larger specimens. The 12 test results are then compared with predictions from the current ACI Code, the UK CIRIA Guide-2, and the Canadian CSA Code. Comparison study shows that while the ACI Code predictions do not have uniform safety margin, and estimations from CIRIA are generally unsafe for large deep beams, the strut-and-tie-model predictions in the Canadian Code yield uniform safety margin.

2.2.30. Cracking Characteristics of Reinforced Steel Fiber Concrete Beams Under Short- And Long-Term Loadings

By Kiang-Hwee Tan, P. Paramasivam, and Kah-Chai Tan [58]

In this paper, an analytical method for the prediction of maximum crack width in reinforced steel fiber concrete (SFC) beams under short term loading is first presented. The method accounts for the enhanced cracking strength, restraint against crack growth, and reduced tensile steel strains due to the presence of steel fibers. Based on a correlation analysis, a semi empirical formula for the long-term crack widths in reinforced SFC beams under sustained loads is also proposed. Tests were carried out on 10 beams to investigate the effect of steel fiber content on the cracking characteristics in both the short and long-term. The results indicated that the use of steel fibers greatly reduced the maximum crack widths in reinforced concrete beams. Good agreement was generally obtained between the analytical predictions and test results.

2.2.31. Correlations Among Mechanical Properties of Steel Fiber Reinforced Concrete

By B.W. Xu, H.S. Shi [17]

In this paper, applicability of previously published empirical relations among compressive strength, splitting tensile strength and flexural strength of normal concrete, polypropylene fiber reinforced concrete (PFRC) and glass fiber reinforced concrete (GFRC) to steel fiber reinforced concrete (SFRC) was evaluated; moreover, correlations among these mechanical properties of SFRC were analyzed. For the investigation, a large number of experimental data were collected from published literature, where water/binder ratio(w/b), steel fiber aspect ratio and volume fraction were reported in the general range of 0.25–0.5, 55–80 and 0.5–2.0%, respectively, and specimens were cylinders with size of U 150 _ 300 mm and prisms with size of 150 _ 150 _ 500 mm. Results of evaluation on these published empirical relations indicate the in applicability to SFRC, also confirm the necessity of determination on correlations among mechanical properties of SFRC. Through the regression analysis on the experimental data collected, power relations with coefficients of determination of 0.94 and 0.90 are obtained for SFRC between compressive strength and splitting tensile strength, and between splitting tensile strength and flexural strength, respectively.

2.2.32. Experimental Studies on Shear Strength of Steel Fiber Reinforced Concrete

By Urano Toshio, Shimoda Seiya, Mur Kiyoshi, Mitsui Yoshiyuki [48]

A total of nine beams have been tested to investigate the influence of fiber reinforcement on the mechanical behavior of reinforced concrete beams in shear. The major test variables are the volume fraction of steel fibers and the ratios of stirrups to the required shear reinforcement. The test results show that the first crack shear strength increases significantly as fiber content increases and the improvement in ultimate shear strength is also achieved. The present study indicates that fiber reinforcement can reduce the amount of shear stirrups required and that the combination of fibers and stirrups may meet strength and ductility requirements. An analytical method to predict the shear strength of reinforced concrete beams containing steel fibers is proposed and comparisons made with the present test data as well as other data.

2.2.33. Shear Strength of Reinforced Concrete Deep Beams

By V. K. M. SELVAM [89]

The major difficulties in obtaining a theoretical solution for the shear strength of reinforced concrete deep beams are due primarily to the complex internal force system at failure, the non-homogeneity of concrete, and the inherent non-linear stress and strain distributions over the cross section. This paper attempts at providing a method for estimating the ultimate capacity of the beams by considering the contribution of longitudinal steel to the strength of the beams. In this paper a hypothesis of the mechanism of shear failure is developed from studies of the crack pattern at failure. Considering the strength of the concrete in compression and tension and recognizing the effect of reinforcement, an equation is developed for the ultimate capacity with the aid of the equilibrium conditions. Prediction by this equation shows that the method is effective for beams with a wide range of depth to span ratios.

2.2.34. Experimental and Analytical Study on RC Deep Beams

By Mohammad Reza Salamy, Hiroshi Kobayashiand Shigeki Unjoh [30]

A study on RC deep beams behavior is conducted in this paper by means of finite element analysis along with experimental evaluation of analytical simulation. The beams have shear span to depth ratio between 0.5 and 1.5 and effective depth from 400 mm to 1400 mm. Lateral reinforcement ratio varies by 0.0%, 0.4% and 0.8% in shear span. A fracture type analysis is employed to simulate RC members through smeared rotating crack approach. The results showed reliability of analysis in predicting deep beams behavior in terms of failure load, failure mode as well as crack propagation. The objective of this study is to investigate capabilities of the finite element simulation for further study on deep beam behavior instead of conducting expensive time consuming experimental works. This includes particularly members with possibilities of failing in shear as well as size effect by means of large-scale structures numerical simulation.

2.2.35. Ultimate Strength Analysis of Structural Concrete Deep Beams Using Strut-And-Tie Models

By Young Mook Yun [33]

This paper presents an ultimate strength analysis of two reinforced and one pre-stressed concrete deep beams tested to failure. A nonlinear strut-tie model approach implementedwith an interactive computer graphics program was utilized to evaluate the ultimate strength and nonlinear behavior of the beams. Different types of strut-tie models for the beams wereselected based on the principal compressive stress trajectories, actual specimen detailing,and loading and support conditions. The present study shows that the nonlinear strut-tie-model approach can provide simple and effective solutions for a large number of analysissituations by describing the essential structural behavior aspects and evaluating the strengthof structural concrete. It also allows for the conceptual representation of the complex concrete and reinforcing steel interactions, and permits the study of localized effects throughthe bearing capacity evaluation of nodal zones. The framework provided by the nonlinear strut-tie model approach for considering combined actions is strongly suggested in the ultimate strength analysis of structural concrete deep beams.

2.2.36. A Codified Comparative Study on RC Deep Beams Behavior With Small Shear Span To Depth Ratio

By Mohammad Reza Salamy, Shigeki Unjohand Hiroshi Kobayashi [29]

A comparative study on RC deep beams behavior is conducted in this paper by means of Japanese design codes (JSCE and JRA) prediction and finite element analysis and those results are evaluated by experimental observation. The beams have shear span to depth ratio between 0.5 and 1.5 and effective depth size from 400 mm to 1400 mm. Lateralreinforcement ratio varies by 0.0%, 0.4% and 0.8% in shear span. Estimated shear capacity by JSCE was around shear crack load while JRA code and Finite Element analysis have had closer results to experiment.

2.2.37. Prediction of Behavior And Shear Strength of Reinforced Concrete Beams Using Non-Linear Strut-Tie Model Approach

By Young Mook Yun, And Chang-Geun Cho [26]

Numerous analytical techniques, analytical theories, and analytical/design models have been proposed for the rational shear designs and shear behavior examinations of RC Beams. Accordingly, much attention has been focused on the development of general and consistent model for method. In this study, the strength and behavior of four R C beams tested to shear failure were estimated using a nonlinear strut-tie model approach. Based onthe strut –tie model analysis results, the validity of the nonlinear strut-tie model approach in the reasonable design of reinforced concrete beams and in the accurate examination of many shear related phenomena was evaluated.

2.3 SUMMARY

To identify the clear objective of present research work and its scope, we have summarized and reviewed the critical observations of some of the researchers/investigators are as under. The summary will provide perfect platform for carried out research work in the area of Deep beams and Moderate Deep beams.

It was observed that the major research work was carried out to determine the shear capacity with and without stirrup using various types of fibers namely steel fibers and polypropylene fibers. Some of the research work was carried out with specific objective of a/D ratio in the range of 0.5 to 4 along with L/D ratio in the range of 1 to 6. The distinct demarcation between Deep

Beam and Moderate Deep beam was partially reflected in earlier research work published by researchers namely Narayan, Darwish, Kukreja, Ashour etc.

The critical observations and conclusions drawn by different researcher have suggested the critical behavior of beam for a/D ratio less than 1.0 and L/D ratio less than 2.0. As per cracking patterns & Modes of failure, they have concluded that such beams are shear predominant members. Few research works carried out by researchers namely Ghosh, Kameshwarrao, Sachan, Nemkumar banthia have highlighted that a/D greater than 2.0 or L/D greater than 6.0 are failing in flexural mode which were identified as flexural predominant members. Most of cracks were observed in the zone of maximum moment leading to flexural failure of the beams. Very few researchers have carried out research in the range of a/D ratio 1 to 2.5 and L/D ratio between 2 to 6, where they have observed the combined mode of failure i.e. flexural and shear both. Such variation was observed due to complex mechanism of transfer of stresses with respect to a/D and L/D ratio.

To generate the clear understanding of this complex behavior, in the present research work, the critical observations related to shear parameters in Moderate Deep beams using steel and Polypropylene fibers was carried out. The nomenclature of the beams having a/D ratio 1 to 2.5 and L/D ratio 2 to 6 are generalized as Moderate Deep Beams. Due to complex behavior in this range and to set up a perfect platform of understanding, the flexural & shear capacity of such section were evaluated as per their modes of failure.

As per track proven research, Steel fibers play vital role in enhancement of strength. Considering the strength aspect, we have added optimum volume of fibers as 1% by volume of concrete in our research work as suggested by Swami, Kukreja etc. We have also considered the significant role of Polypropylene fibers which impart the strain enhancement by transferring stresses and providing good control over cracking. Due to less density of Polypropylene fibers, we have reduced volume of Polypropylene fibers from 1% to 0.75% which can allow appropriate mixing and compaction in the given volume of concrete. In the present research work, we have focused the strength and strain enhancement concept as an innovative hybrid combination looking to the present need of structural members having effectiveness of fibers towards strength and strain both hence we have adopted this hybrid combination of steel and polypropylene fibers.

CHAPTER-3
EXPERIMENTAL SEQUENCE

3.1 GENERAL DESCRIPTION

This research investigation is undertaken to carry out a comprehensive study of the micro mechanical measurement of strain for the accurate evaluation of various shear parameters in a Fiber Reinforced Concrete Moderate Deep Beam across its width and depths throughout its whole shear zone. Along with this, cracking characteristics such as crack patterns and crack width profile is studied for Moderate Deep Beams using different types of fibers. During course of this investigation, failure behavior is compared for different types of fibrous beam with respect to nature of failure & cracking characteristics.

In the present investigation, Critical parameters such as Deflection, Concrete surface strain using delta rosette for determination of shear parameters, initiation of crack, First cracking load, Ultimate load, Modes of failure, Crack patterns and Crack width profiles were recorded in detail.

3.2 DESCRIPTION OF TEST SPECIMENS

The test specimens consist of 88 (Eighty Eight) numbers of beams. The beams were divided in 12 (twelve) series having different depths of 300 mm, 400 mm, 500 mm and 600 mm with four beams in each series ranging L/D ratio 2, 2.4, 3 and 4. The span and width of all the beams were kept constant having overall span of 1300 mm, effective span of 1200 mm and width of 150 mm.

The each series was designated using type of concrete, loading condition i.e. single central point load or two point load as described below:

1) **RCC (w/s)-1P/2P**= RCC beam with stirrup with one point load/two point load

2) **RCC (w/o/s)-1P/2P**= RCC beam without stirrup with one point load/two point load

3) **PPFRC(MT)-1P/2P**= Polypropylene Fiber (Monofilament type) Reinforced Concrete beam without stirrup with one point load/two point load

4) **PPFRC (FT)-1P/2P**= Polypropylene Fiber (Fibrillated type) Reinforced Concrete beam without stirrup with one point load/two point load
5) **SFRC (CCT)-1P/2P**= Steel Fiber (Circular Corrugated type) Reinforced Concrete beam without stirrup with one point load/two point load
6) **HFRC(MT+CCT)-1P/2P**= Hybrid Fiber (Monofilament type + Circular Corrugated type) Reinforced Concrete beam without stirrup with one point load/two point load

RCC(w/s)-2P, PPFRC(MT)-2P, PPFRC(FT)-1P, SFRC(CCT)-1P and SFRC(FCT)-2P series contains three beams having same depth but with concrete strain measured through holes made having the depth of 0 mm (i.e., at surface), 50 mm and 75 mm from the surface across its width of total 150mm. While in RCC(w/s)-1P, RCC(w/o/s)-1P, RCC(w/o/s)-2P, PPFRC(MT)-1P, PPFRC(FT)-2P, HFRC(MT+CCT)-2P and HFRC(MT+CCT)-1P series, concrete strains were measured only on surface i.e. 0 mm from the surface across its width.

All the beams were kept simply supported and tested under two types of loading condition viz (i) Beams were tested under central point load condition so that beam was divided into two equal zones (ii) Beams were tested under two symmetrically loaded point load condition such that each beam was divided into three equal zones having central zone subjected to constant flexure and outer zones subjected to constant shear.

Steel plates having dimensions 150 mm × 100 x 6 mm thick mm were provided in beams being anchored in concrete with 8mmØ M.S. Bars welded with plates. The purpose of providing plate was to avoid stress concentration keeping bearing stresses within permissible limit and to avoid crushing of concrete at the points of application of load & at the points of support reactions. At the point of application of load, a special arrangement of plate and roller was done to transfer the load accurately at the load point of the beam as described in above loading condition (Fig. 3.7).

3.3 BEAM NOTATIONS

The beams were classified in two ways. First, according to its overall depth. According to this way each beams were classified into four beams of depths as 30 cm, 40 cm, 50 cm, and 60 cm respectively. Second, according to the depth at which concrete strain was to be measured across the width of the beam.. According to this way each beams were classified into beams with concrete strain measured at a same depth across its width

Thus according to first way the four series were D30, D40, D50 and D60 and as per second way the series were S 0.0 (i.e. at surface), S 5.0 (i. e at 5 cm from the surface across the width), S 7.5 (i.e. at 7.5 cm from the surface across the width).

Thus actual notations provided on beam are as given in example below:

D50 S5.0

- Depth of surface plane across the width of beam in cm at which concrete strain was to be measured
- Denotes surface plane across the width of beam
- Overall depth of beam in cm
- Denotes overall depth of beam

3.4 MATERIALS

3.4.1. Cement

O.P.C. of 53 grades was used for casting of all the specimens. Cement was stored in the closed dry place throughout its use.

3.4.2. Coarse And Fine Aggregates

Clean and dry river sand passing through 4.75 mm I.S. sieve having fineness modulus of 2.56 was used as a fine aggregate for preparation of concrete mix. Basalt gravel of 20 mm size having fineness modulus of 7.0was used as coarse aggregates in concrete mix.

3.4.3. Water

Clean potable water having Ph value 7.0 was used for mixing of concrete and for curing of all the specimens.

3.4.4. Reinforcement

High strength deformed steel bars conforming to IS 1786 were used as longitudinal tension reinforcement as well as anchor bars. Mild steel bars conforming to IS 432 (part I) were used as vertical shear reinforcement. 10 mm and 12 mm diameter HYSD of Fe 415 grade bars were used as tension reinforcement and 6 mm M.S. of Fe250 grade and 8 mm HYSD of Fe 415 grade diameter bars were used as shear reinforcement. Stirrups were not used in any FRC beams in the present research work.

3.4.5. Fibers

Table 3.1 Properties Of Polypropylene Fibers (FT & MT)

No.	Property	Polypropylene Fiber	
1.	Specific Gravity	0.91	0.91
2.	Denier	6	6
3.	Tensile Strength	570-660 N/mm^2	670 N/mm^2
4.	Modulus (Young's)	5000 N/mm^2	4000 N/mm^2
5.	Melt Point	>165 Celsius	>1650 Celsius
6.	Ignition Point	600 Celsius	6000 Celsius
7.	Absorption	Nil	Nil
8.	Density-Bulk	910 kg/m3 (approx.)	910 kg/m3 (approx.)
9.	Fiber cut length	38 mm	12 mm
10.	Form	**Fibrillated (FT)**	**Monofilament (MT)**
11.	Fiber content/beam	0.75% (by volume of concrete)	

Fig. 3.1Photographs Of Polypropylene Fibers (FT & MT respectively)

Table 3.2 Properties Of Steel Fibers (FCT & CCT)

NO.	Property	Steel Fiber	
1.	Cross section	Circular	rectangular
2.	Embedded length	36mm	50mm
3.	Equivalent Diameter	0.45mm	0.625/2mm wide
4.	Tensile strength	825 N/mm^2	825 N/mm^2
5.	Specific Gravity	7.85	7.85
6.	Modulus of Elasticity	2.0×10^5 N/mm^2	2.0×10^5N/mm2
7.	Aspect ratio	80	80
8.	Form	Circular Corrugated (CCT)	Flat Corrugated (FCT)
9.	Fiber content/beam	1% (by volume of concrete)	1% (by volume of concrete)

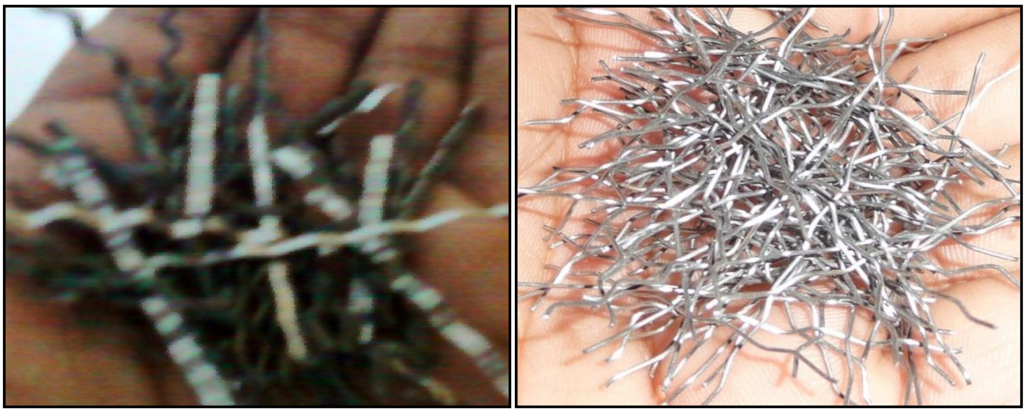


Fig. 3.2 Photograph Of Steel Fiber (FCT & CCT respectively)

3.5 CONCRETE MIX

Concrete mix was prepared with Cement: FA: CA ratio of 1:1.5:3 by weight having water cement ratio of 0.45 for all the specimens.

3.6 FORMWORK

The formworks were made from 12 mm thick good quality teak wood. Small angles (25mm x 25mm x 2mm) with nuts and bolts were used to hold the sides of formwork in position. Two wooden clamps at the top of sides of formwork were used to prevent it getting widened at the time of concreting. Before each casting the putty (laphi) was applied at all the joints of formwork to prevent the cement slurry coming out of the formwork. The oil was applied at all the inner faces of the formwork so that specimen can easily be taken out from formwork. Alternate formworks were made of 4 mm thick steel sheet & small angles (25mm x 25mm x 2mm). Three sides of formwork were welded & one side was kept open with adjustable depth provision. The nuts and bolts arrangement was used to hold the one adjustable side of formwork to prevent it getting widened at the time of concreting. The oil was applied at all the inner faces of the formwork before casting so that specimen can easily be taken out from formwork.

Fig. 3.3 Photographs of Formwork

3.7 MIXING, CASTING AND CURING

3.7.1 MIXING

As per the required type of concrete, batches were prepared by weight. All the ingredients were collected on dry, flat and non-porous platform and mixing was carried out in a dry condition by concrete mixer machine as shown in fig 3.7. First we added coarse aggregate in mixer machine and allowed it to rotate, then required amount of fine aggregates were added in to it by keeping mixer rotating. After this, Cement was added and allowed to mix properly. 50 % quantity of Fibers was added subsequent to the cement. Addition of fibers was done such a way that it can be spread uniformly during mixing to avoid balling & nesting of fibers. The partial quantity (70 %) of water and remaining 50 % fibers were added during mixing. At the end, remaining 30 % quantity of water was added. Mixing was generally carried out for about 3-5 minutes until homogeneous concrete was prepared.

3.7.2 CASTING

The inner surfaces of the moulds were oiled and placed on the vibration table. Vibration table was used for casting of beams. Mixed concrete poured gradually into moulds and formworks in successive layers, spread and compacted on vibration table for 2 to 3 minutes. Moulds and formworks had been kept undisturbed for 24 hours. The control specimens and test specimen were removed from the moulds after 24 hours.

3.7.3 CURING

The control specimens (Cubes and cylinders) were kept in water tank in fully immersed position. The test specimens (beams) were kept in partly immersed position in water in curing pond. The top surface of the test specimens was fully covered with the help of wet jute bags as shown in fig 3.4. Curing is carrying out for at least 28 days.

Fig 3.4 Photograph Of Curing Pond

Table 3.3 Sizes Of The Moulds And Formworks

Specimen	Size	
Cube	**Size of Mould** 150 mm X 150 mm X 150 mm	
Cylinder	**Diameter** 150 mm	**Height** 300 mm
Beam	**Size of Formworks**	
	1300 mm x 300 mm x 150 mm	
	1300 mm x 400 mm x 150 mm	
	1300 mm x 500 mm x 150 mm	
	1300 mm x 600 mm x 150 mm	

3.8 PRE TESTING ARRANGEMENTS

Prior to testing, beams were carried out from curing pond and surfaces were made clean with the help of wire brush, air blower and trowel. All surfaces were white washed. White wash (lime) acts as a thin film coated over concrete which immediately reflects and amplifies the crack induced in concrete. The markings and notations of the beam on the surface are distinctly visible due to white wash. The DEMEC points were fixed on the surface or in depth by proper adhesive to guide the pointer of strain gauge. Beam notations were written on top right corners for visible identification.

3.9 INSTRUMENTATION

3.9.1 Universal Testing Machine

All the beams were tested in Universal Testing Machine as shown in fig. 3.5 having 200 tones direct compression capacity and 100 tones bending capacity. The machine is manufactured by VEB WERKSTOP MACHINE, LEIPZIG, East Germany. The machine scale has different loading ranges given as under.

Table 3.4 Range And Least Count Of Different Scales Of UTM

Scale	Range (tone)	Least Count (tone)
A	0-50	0.1
B	0-100	0.2
C	0-200	0.5

Fig. 3.5 Photograph Of Universal Testing Machine

3.9.2 Conveyance

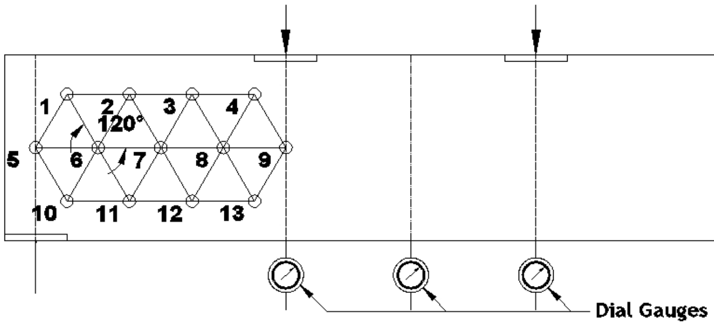
After completion of curing period, beams were conveyed from curing pond to Universal Testing machine. Manually operated crane having 5.0 Tone capacity was used to lift and shift the beam specimens.

3.9.3 Deflection Gauge

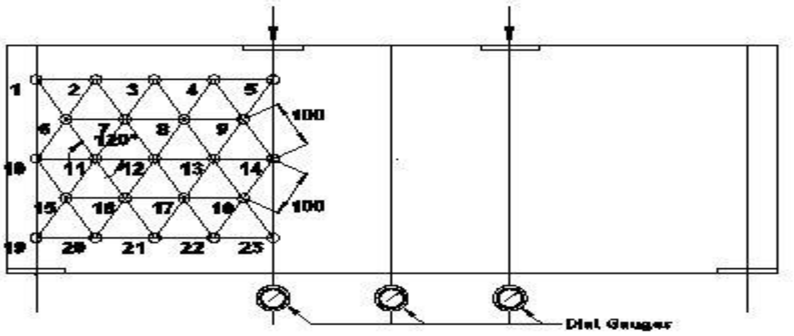
Beam tends to deflect in the direction of load. The deflections were measured at three various points below the beam as shown in figure 3.14 &3.15. The deflection readings were recorded at an interval of every 0.5 Tone load with the help of dial gauges. Dial gauges are having least count of 0.01 mm and range of 10 mm.

3.9.4 Strain Measuring Assembly

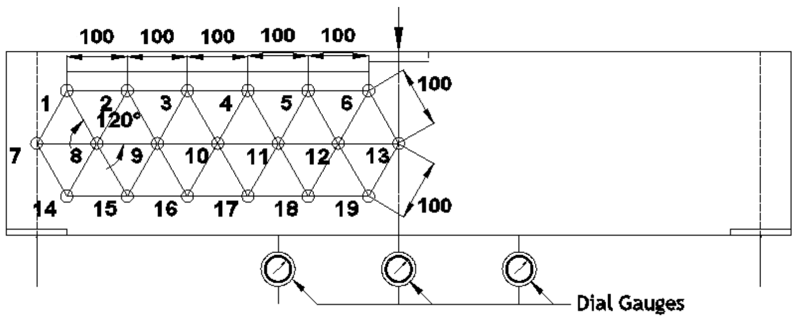
For the measurement of strain, a symmetrical grid of DEMEC target points for 1 point and 2 point loading was arranged in one shear zone of specimen as shown in fig. 3.6. As per that grid 10mm Ø hollow aluminum discs were fixed as a DEMEC targets to measure the strain. Mechanical type strain gauge with gauge length 200mm, least count 0.01 mm and range of 30mm was used.



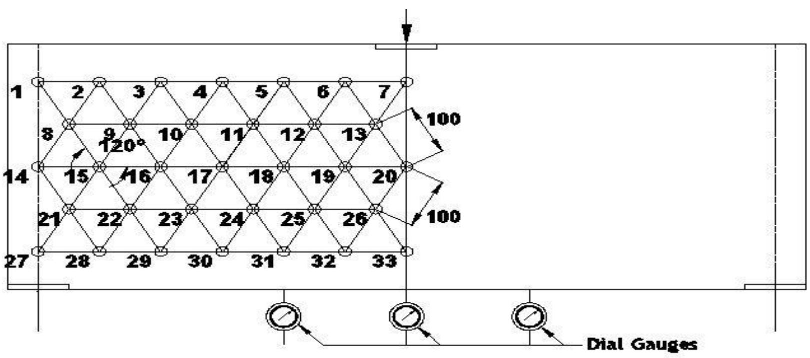
(D 30/D 40)- 2P



(D 50/D 60) - 2P



(D 30/D 40) - 1P



(D 50/D 60) - 1P

Fig. 3.6 Arrangement Of Demec Target

3.10 TESTING PROCEDURE

All the beams were simply supported with an effective span of 1200 mm. Beams were centered on platform and leveled horizontally and vertically by adjusting the bearing plates. Load was applied gradually up to failure of specimen. Load was applied as central point load as shown in fig 3.7. Load was also applied as two point loads symmetrically placed as shown in fig. 3.7.

Three dial gauges were used to measure the deflection at the three equidistance points as shown in fig 3.7. Delta rosette was used for measuring strains at different Demec target points in which three strains were required to calculate the shear strains and shear stresses at a point. Shear strains were calculated at Demec target points 6, 7 & 8 in D30 and D40 beams for both loading conditions. Shear strains were calculated at Demec target points at 7, 8, 11, 12, 13, 16, 17 in D50 and D60 beams for both loading conditions. Readings of strain and deflection were taken at proper load interval. Concrete surface strains and in-depth strains were measured in shear zones using mechanical strain gauge.

Crack propagations were traced by sketch pens and their tips were marked corresponding to the load readings. Cracks were named as A, B, C and D etc. as per order of formation during testing.

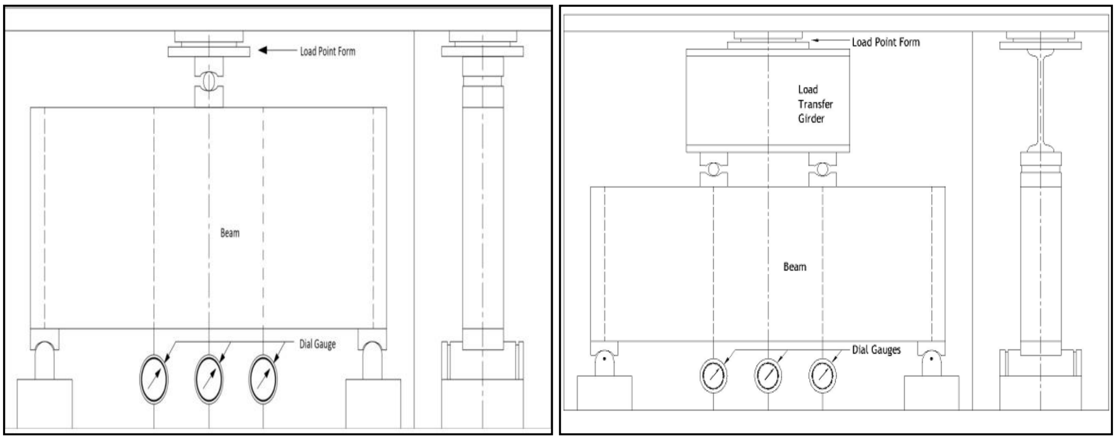


Fig. 3.7 Test Load Arrangement For One And Two Point Load

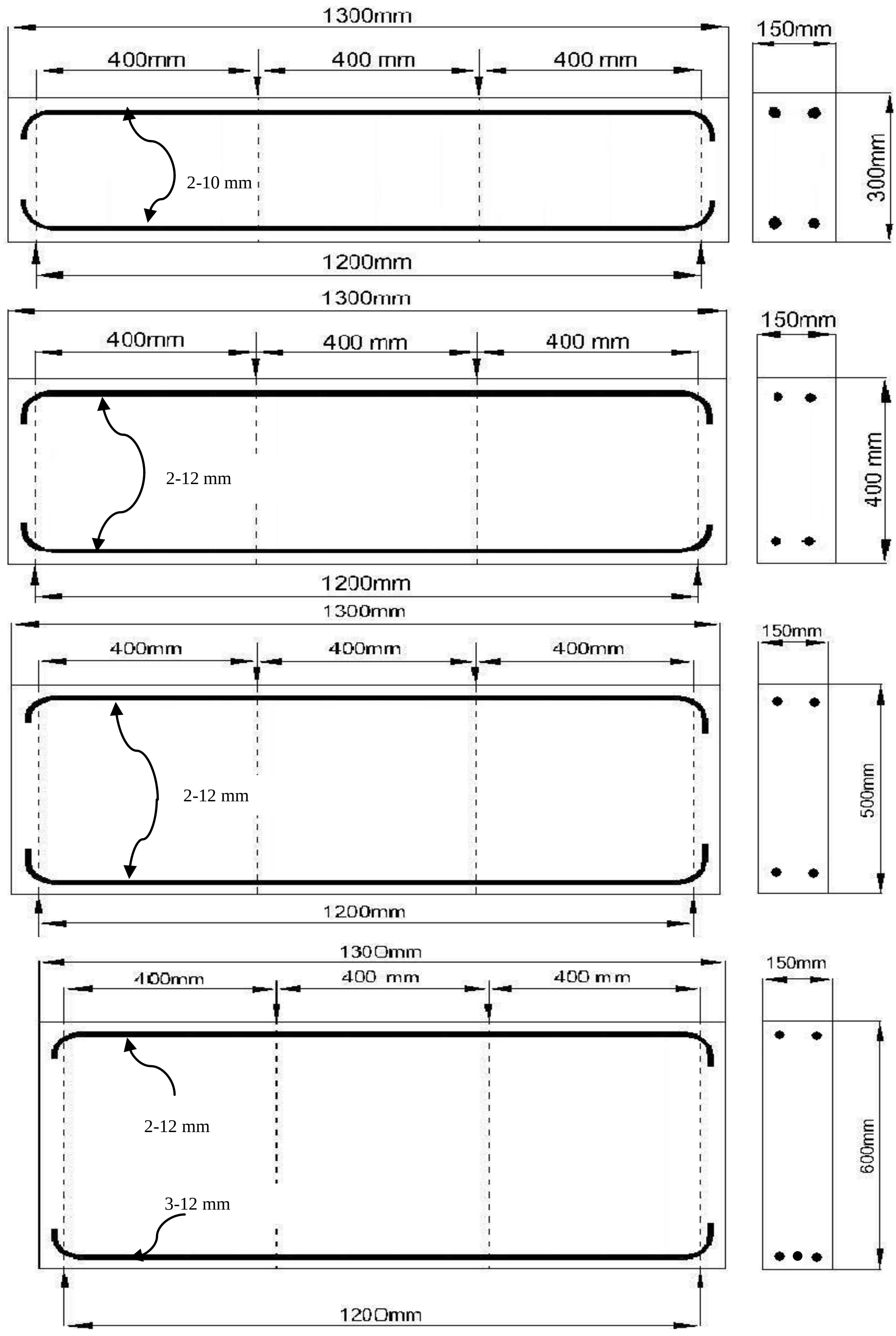


Fig. 3.8 Reinforcement Details Of Moderate Deep Beam Without Web Reinforcement

CHAPTER-4
PRESENTATION AND COMPARISON OF TEST RESULTS

4.1 GENERAL DESCRIPTION

This research program is mainly focused on the comprehensive study of strain to evaluate various shear parameters. An attempt is made here to use these parameters to develop empirical equation to satisfy the evaluated test results for ultimate shear strength of Fibrous Moderate Deep Beam using Polypropylene & steel fibers. The Ultimate strength of Fibrous Moderate Deep Beam is compared with that of RCC Moderate beam with stirrups and without stirrups. In the present research work, testing was carried out on sixteen (16) R.C.C. moderate deep beams with stirrups, Eight (8) R.C.C. Moderate Deep Beams without stirrups and sixty four (64) Moderate Deep Beams with different types of fibers without stirrups. Thus total Eighty Eight (88) numbers of Moderate Deep Beams were tested

The detailed observations related to deflection, shear strain, crack patterns, cracking characteristics, ultimate load, first crack load, modes of failure were accurately recorded. The results are compared in appropriate way to signify its relevant effect from strength aspect.

Observations related to deflection, shear strain, crack pattern, crack characteristics, ultimate load, first crack load, modes of failure were accurately recorded and compared.

4.2 GENERAL OBSERVATIONS

4.2.1. Reserved Strength

First cracking load for moderate deep beam and deep beam is not the ultimate shear capacity of the beam. Still there would be some reserved strength in the beam beyond first cracking load which can be termed as **reserved strength** of the beam.

It can be defined as the ratio of the difference of ultimate load to the first cracking load expressed in terms of percentage as *Reserve strength* = $\{(W_u - W_c) / W_c\} \times 100$.

The variation in percentage of reserve strength can be attributed to the strength of the concrete, type of web reinforcement, fiber characteristics and the geometry of the specimen. **Table group 4.2** gives the relevant percentage of reserved strength of the beams tested.

4.2.2. Deflection Characteristics

Deflection measurement was done at gradual load interval at three equidistance points to evaluate path of variation of deflection w.r.t. load. In **Table 4.1** deflection readings of all beams are tabulated for D30 series of beams and compared with the help of graphs. For D40, D50 and D60 series of beams, only the deflection graphs are shown **[Fig. 4.2-4.4]**. From the graphs of Deflection Vs Load it is observed that, during the first elastic stage the curve is almost linear and can be approximated by a straight line. After yielding of beam the curve changed its slope and it became more flat. There was a considerable deviation in load deflection curve after the yielding of beam, which can be attributed to the first cracking and yielding of beam which caused a sudden increase in deflection. A measure of the slope of the yielding portion can be given by the ratio of deflection at ultimate load to deflection at first crack load or yield load, which is called ductility. There was considerable deviation of the actual load deflection curve at beam yield, which is attributed to cracking and sudden increase in deflection.

4.2.3. Crack Patterns

Crack pattern is the important phenomena by which behavior of beam under applied static loading can be understood easily. Hence, it is essential to study the crack patterns carefully to understand the shear deformational behavior of beams which predominantly fails in shear.

In RCC members mainly three types of cracks are observed: flexure cracks, flexure-shear cracks and shear cracks. In shallow beams, the predominant crack is flexure crack. In Moderate Deep Beams, the predominant crack is flexure-shear crack. In Deep beams, the predominant crack is shear crack.

4.2.4 Modes of Failure

The modes of failure in moderate deep beam and deep beams containing fibers can be of different types such as flexure failure, flexure-shear failure, diagonal compression failure, local compression failure, anchorage failure at support and split & diagonal tension failures.

4.2.4.1 Flexure Failure

It is due to the yielding of longitudinal main steel bars. Flexure cracks appeared first in the region of maximum bending moment and initiated from the soffit of the beam. Flexural crack(s) will propagate upwards quickly. Generally, concrete is not crushed, and on continuous loading, the main bars might reach their hardened stage, so the flexure failure of normal section manifests a better ductility, and the flexural moment of specimen at ultimate load is larger than that at steel yielding, by 10-30%. The width(s) of diagonal crack will be very small.

4.2.4.2 Flexure-Shear Failure

In this case, as loading reached 20-25% of ultimate load value, short and small flexure cracks would occur from beam bottom. As the loading reaches 40-50%, the flexure cracks in shear span extend quickly towards the loading point(s) with width wider in bottom and narrow upwards. In this stage, the stressed state become gradually into an arch structure with main bar as tensile ties. The tensile stresses in longitudinal main bars increase quickly, but the flexure crack(s) in the span do not extend upwards until the yielding of main bars. The diagonal crack(s) also extend towards loading point. In this type of failure both flexural and inclined shear cracks are formed and well developed at the time of failure but major cause of failure is inclined shear crack.

4.2.4.3 Shear Failure

Shear failure is generally classified as diagonal tension failure and shear compression failure. Failure in such beams begins with the formation of diagonal tension cracks as a result of combined bending and shear stresses. In shear compression failure, parallel inclined cracks are formed. This gives beam a “strut like” appearance between the load point and the support. Here failure occurs by the destruction of this strut. Sometimes, it occurs simultaneously with the formation of second parallel inclined crack. In splitting failure, a diagonal crack suddenly originates from the inner edge of the supporting block and proceeds towards the outer edge of loading plate. After the formation of the diagonal crack, the beam fails by sudden splitting along the plane of this crack. The appearance of these types of diagonal cracks was often accompanied by a loud noise. The phenomenon of this failure is similar to that of concrete cylinder under diametrical compressive load i.e. Brazilian split test. In this case, some small flexural cracks at the bottom of beam would occur on loading. As loading is increased to 40-50% of ultimate value, a longer diagonal crack occurs in beam web in shear span and extends quickly towards support(s) and point(s) of load application respectively with the increase of loading, but the flexural cracks develops slowly. As the loading reaches 85-95% of ultimate value, by the external side of principal diagonal crack appears from loaded point towards support to form a stressed state of diagonal short column between support and load point. It follows by a quick enlargement of the width and the fast extension of the length of the external diagonal crack. Finally this concrete is crushed. In this case, generally the longitudinal main bars do not yield.

4.2.4.4 Local Compression Failure

At support and point of applied concentrated load, the value of vertical stress is very large; hence if there are no appropriate measures, a local compression failure may occur due to local crushing of concrete at the points of supports and/or application of load.

4.2.4.5 Anchorage Failure

After the stressed state of specimen forms an arch with ties, the tensile stress near support is very large. If their anchorage is not effective the steel bars are prone to slip from support to create an anchorage failure.

4.2.5 Principal strain and Shear Strain Variation

Graphs are shown for important selected beams only to get the idea about nature of shear strain variation along vertical axis **[Fig. 4.5-4.38]** and nature of principal strain variation along inclined axis **[Fig. 4.39-4.49]**.

TABLE 4.1 List Of Tested Beam Specimens

LIST OF TESTED BEAM SPECIMEN

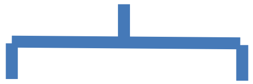
SR.	BEAM	D	L/D	a/D	TYPE OF BEAM	SR.	BEAM	D	L/D	a/D	TYPE OF BEAM
1.	 12 SAMPLE	30	4	1.33	RCC (W/S)	2.	 4 SAMPLE	30	4	2	RCC (W/S)
		40	3	1	RCC (W/S)			40	3	1.5	RCC (W/S)
		50	2.4	0.8	RCC (W/S)			50	2.4	1.2	RCC (W/S)
		60	2	0.67	RCC (W/S)			60	2	1	RCC (W/S)
3.	 12 SAMPLE	30	4	1.33	PPFRC (MT)	4.	 4 SAMPLE	30	4	2	PPFRC (MT)
		40	3	1	PPFRC (MT)			40	3	1.5	PPFRC (MT)
		50	2.4	0.8	PPFRC (MT)			50	2.4	1.2	PPFRC (MT)
		60	2	0.67	PPFRC (MT)			60	2	1	PPFRC (MT)
5.	 4 SAMPLE	30	4	1.33	PPFRC (FT)	6.	 12 SAMPLE	30	4	2	PPFRC (FT)
		40	3	1	PPFRC (FT)			40	3	1.5	PPFRC (FT)
		50	2.4	0.8	PPFRC (FT)			50	2.4	1.2	PPFRC (FT)
		60	2	0.67	PPFRC (FT)			60	2	1	PPFRC (FT)
7.	 12 SAMPLE	30	4	1.33	SFRC (FCT)	8.	 12 SAMPLE	30	4	2	SFRC (CCT)
		40	3	1	SFRC (FCT)			40	3	1.5	SFRC (CCT)
		50	2.4	0.8	SFRC (FCT)			50	2.4	1.2	SFRC (CCT)
		60	2	0.67	SFRC (FCT)			60	2	1	SFRC (CCT)
9.	 4 SAMPLE	30	4	1.33	MIX (MT + CCT)	10.	 4 SAMPLE	30	4	2	MIX (MT + CCT)
		40	3	1	MIX (MT + CCT)			40	3	1.5	MIX (MT + CCT)
		50	2.4	0.8	MIX (MT + CCT)			50	2.4	1.2	MIX (MT + CCT)
		60	2	0.67	MIX (MT + CCT)			60	2	1	MIX (MT + CCT)
11.	 4 SAMPLE	30	4	1.33	RCC (W/O/S)	12.	 4 SAMPLE	30	4	2	RCC (W/O/S)
		40	3	1	RCC (W/O/S)			40	3	1.5	RCC (W/O/S)
		50	2.4	0.8	RCC (W/O/S)			50	2.4	1.2	RCC (W/O/S)
		60	2	0.67	RCC (W/O/S)			60	2	1	RCC (W/O/S)

Table group 4.2 TABULATION OF OBSERVED DATA (W/C Ratio: 0.45 and Conc. Mix-1:1.5:3.)

TABLE 4.2.1 Comparison of Control Specimens, Deflection, Ductility & Reserve Strength At S 0.0 1P

TYPE	BEAM S 0.0	L/D RATIO	a/D RATIO	AVERAGE CUBE COMP. STRENGTH (N/mm2)	AVERAGE CYLINDER COMP. STRENGTH (N/mm2)	AVERAGE SPLIT CYLINDER STRENGTH (N/mm2)	FIRST CRACK LOAD (Wc) (T)	ULTIMATE LOAD (Wu) (T)	DEFLECTION AT FIRST CRACK LOAD (δy) (mm)	DEFLECTION AT ULTIMATE LOAD (δu) (mm)	DUCTILITY (μ) (δu/ δy)	RESERVED STRENGTH (Wu-Wc)/Wc X 100	MODE OF FAILURE
RCC 1P	**D 30**	4.0	2.0	33.25	26.60	4.10	4.70	11.50	1.12	7.01	6.25	144.68	Flexure
	D 40	3.0	1.5	34.30	27.45	4.08	8.40	17.20	0.75	3.97	5.30	104.76	Flexure-Shear
	D 50	2.4	1.2	33.60	26.85	4.02	12.20	27.30	0.78	3.24	4.15	123.77	Flexure
	D 60	2.0	1.0	33.75	27.00	4.10	21.30	45.70	0.88	4.48	5.09	114.55	Flexure-Shear
PPFRC (MT) 1P	**D 30**	4.0	2.0	34.95	27.95	4.15	6.30	11.00	0.91	5.02	3.52	74.60	Flexure
	D 40	3.0	1.5	34.90	27.90	4.15	9.70	16.50	0.54	3.14	5.81	70.10	Flexure-shear
	D 50	2.4	1.2	34.85	27.85	4.15	14.30	26.50	0.95	4.34	4.56	85.31	Shear-Flexure
	D 60	2.0	1.0	34.80	27.80	4.13	21.40	42.80	0.72	3.81	5.29	100.00	Shear
PPFRC (FT) 1P	**D 30**	4.0	2.0	34.85	27.88	4.14	6.00	9.50	0.57	3.40	5.96	58.33	Flexure-Shear
	D 40	3.0	1.5	35.15	28.15	4.18	7.30	15.50	0.74	3.90	5.27	112.33	Flexure
	D 50	2.4	1.2	34.60	27.70	4.12	13.40	27.10	0.96	7.16	7.46	102.24	Shear-Flexure
	D 60	2.0	1.0	34.90	27.95	4.14	22.60	40.90	1.19	5.62	4.72	80.97	Shear-Flexure
SFRC (CCT) 1P	**D 30**	4.0	2.0	35.10	28.10	4.17	5.00	8.90	0.94	3.12	3.39	118.00	Flexure
	D 40	3.0	1.5	34.90	27.90	4.15	8.50	16.90	0.90	3.75	4.16	98.82	Flexure
	D 50	2.4	1.2	34.70	27.75	4.13	11.70	27.30	0.39	2.02	5.18	133.84	Shear-Flexure
	D 60	2.0	1.0	35.30	28.25	4.19	20.50	43.70	0.81	3.64	4.49	113.17	Shear-Flexure
HFRC (MT+CCT) 1P	**D 30**	4.0	2.0	35.00	28.00	4.16	5.80	10.70	0.93	4.29	4.61	84.48	Flexure
	D 40	3.0	1.5	34.80	27.85	4.14	7.20	13.08	0.85	3.42	4.02	130.56	Flexure-shear
	D 50	2.4	1.2	34.75	27.80	4.14	16.30	27.15	0.56	3.63	6.48	66.56	Shear-Flexure
	D 60	2.0	1.0	35.40	28.50	4.20	19.10	43.80	0.78	4.43	5.68	129.32	Shear
RCC (W/O/S) 1P	**D 30**	4.0	2.0	34.40	27.50	4.90	3.0	6.2	1.56	6.2	3.97	106.66	Flexure
	D 40	3.0	1.5	35.90	27.10	4.15	4.0	9.9	1.51	6.8	4.5	134.00	Flexure-shear
	D 50	2.4	1.2	34.15	28.45	3.95	7.6	15.2	1.45	6.1	4.2	100.00	Shear-Flexure
	D 60	2.0	1.0	35.70	26.65	4.20	10.9	24.0	1.43	6.5	4.54	120.18	Shear

TABLE 4.2.2 Comparison of Control Specimens, Deflection, Ductility & Reserve Strength At S 0.0 2P

TYPE	BEAM S 0.0	L/D RATIO	a/D RATIO	AVERAGE CUBE COMP. STRENGTH (N/mm2)	AVERAGE CYLINDER COMP. STRENGTH (N/mm2)	AVERAGE SPLIT CYLINDER STRENGTH (N/mm2)	FIRST CRACK LOAD (Wc) (T)	ULTIMATE LOAD (Wu) (T)	DEFLECTION AT FIRST CRACK LOAD (δy) (mm)	DEFLECTION AT ULTIMATE LOAD (δu) (mm)	DUCTILITY (μ) (δu/ δy)	RESERVED STRENGTH (Wu-Wc)/Wc X 100	MODE OF FAILURE
RCC. (2P)	**D 30**	4.0	1.33	33.70	26.90	4.10	6.00	13.40	0.89	5.75	6.46	123.33	Flexure-shear
	D 40	3.0	1.00	33.50	26.80	4.02	11.00	29.50	0.59	3.90	6.61	168.18	Shear-Flexure
	D 50	2.4	0.80	33.80	27.05	4.06	20.50	46.00	0.65	5.02	7.72	124.39	Shear-Flexure
	D 60	2.0	0.67	34.20	27.35	4.10	25.30	63.75	0.74	4.71	6.36	151.97	Flexure-shear
PPFRC (MT) 2P	**D 30**	4.0	1.33	34.65	27.75	4.12	7.80	12.40	0.88	3.80	4.32	58.97	Flexure
	D 40	3.0	1.00	34.50	27.60	4.10	11.00	23.40	0.48	3.44	7.17	112.73	Flexure-shear
	D 50	2.4	0.80	34.75	27.80	4.14	16.00	40.00	0.79	3.21	4.06	150.00	Shear-Flexure
	D 60	2.0	0.67	35.60	28.50	4.22	19.40	53.20	0.38	2.35	6.18	174.23	Shear
PPFRC (FT) 2P	**D 30**	4.0	1.33	34.20	27.35	4.06	7.60	11.90	0.68	3.82	5.62	56.58	Flexure-shear
	D 40	3.0	1.00	35.20	28.15	4.19	12.80	22.30	0.71	4.54	6.39	74.21	Shear
	D 50	2.4	0.80	34.90	27.90	4.15	19.70	37.40	0.59	3.17	5.38	89.85	Shear-Flexure
	D 60	2.0	0.67	35.25	28.25	4.18	20.60	51.30	0.66	3.42	5.18	149.03	Shear
SFRC (FCT) 2P	**D 30**	4.0	1.33	34.70	27.75	4.12	7.40	12.50	0.49	2.75	5.61	68.91	Flexure-shear
	D 40	3.0	1.00	34.80	27.85	4.14	11.50	23.50	1.02	5.60	5.49	104.35	Flexure-shear
	D 50	2.4	0.80	34.75	27.80	4.14	15.00	39.76	0.68	3.95	5.81	165.00	Shear-Flexure
	D 60	2.0	0.67	35.10	28.08	4.16	17.60	53.90	0.62	3.20	5.16	206.25	Shear-Flexure
HFRC (MT+CCT) 2P	**D 30**	4.0	1.33	34.75	27.80	4.13	5.90	12.06	1.47	5.29	3.59	104.24	Flexure-shear
	D 40	3.0	1.00	35.25	28.20	4.19	14.20	23.90	0.71	4.34	6.11	68.31	Shear-Flexure
	D 50	2.4	0.80	34.00	27.20	4.05	23.80	39.80	0.79	3.25	4.11	67.23	Shear-Flexure
	D 60	2.0	0.67	35.40	28.35	4.20	27.70	50.90	0.68	3.38	4.97	83.75	Shear

TABLE 4.2.3 Comparison Of Control Specimens, Deflection, Ductility & Reserve Strength At S 5.0

TYPE	BEAM S 0.0	L/D RATIO	a/D RATIO	AVERAGE CUBE COMP. STRENGTH (N/mm2)	AVERAGE CYLINDER COMP. STRENGTH (N/mm2)	AVERAGE SPLIT CYLINDER STRENGTH (N/mm2)	FIRST CRACK LOAD (Wc) (T)	ULTIMATE LOAD (Wu) (T)	DEFLECTION AT FIRST CRACK LOAD (δy) (mm)	DEFLECTION AT ULTIMATE LOAD (δu) (mm)	DUCTILITY (μ) (δu/ δy)	RESERVED STRENGTH (Wu-Wc)/Wc X 100	MODE OF FAILURE
PPFRC (FT) 1P	**D 30**	4.0	2.0	34.20	27.50	4.06	4.80	9.00	0.62	3.31	5.34	88.00	Flexure
	D 40	3.0	1.5	35.00	28.00	4.16	10.70	16.20	0.68	3.41	5.01	51.00	Flexure-shear
	D 50	2.4	1.2	34.80	27.90	4.14	12.10	26.10	0.55	2.22	4.04	116.00	Shear-Flexure
	D 60	2.0	1.0	35.40	29.25	4.20	19.70	41.20	1.05	5.79	5.51	109.13	Shear-Flexure
SFRC (CCT) 1P	**D 30**	4.0	2.0	35.50	28.40	4.22	5.40	10.50	0.90	4.62	5.13	94.00	Flexure
	D 40	3.0	1.5	34.80	27.85	4.14	10.30	16.70	0.60	3.12	5.20	62.00	Flexure
	D 50	2.4	1.2	34.60	27.70	4.12	12.10	26.90	0.79	3.93	4.97	122.31	Shear-Flexure
	D 60	2.0	1.0	35.80	28.50	4.25	22.50	42.75	0.55	2.14	3.89	90.00	Shear-Flexure
R.C.C 2P	**D 30**	4.0	1.33	34.25	27.40	4.07	5.80	15.70	0.91	5.95	6.53	171.00	Flexure
	D 40	3.0	1.00	33.65	26.90	4.00	10.60	29.00	0.93	4.62	4.96	174.00	Flexure-shear
	D 50	2.4	0.80	33.70	26.95	4.01	20.20	45.50	1.14	5.94	5.21	125.25	Shear-Flexure
	D 60	2.0	0.67	34.20	27.35	4.06	23.60	52.20	0.95	5.38	5.66	121.18	Shear-Flexure
PPFRC (MT) 2P	**D 30**	4.0	1.33	34.90	27.95	4.14	7.20	12.30	1.20	4.85	4.04	70.83	Flexure
	D 40	3.0	1.00	34.55	27.65	4.11	11.60	24.20	0.97	4.89	5.04	109.00	Flexure
	D 50	2.4	0.80	35.50	28.50	4.23	16.80	37.40	1.01	4.62	4.57	123.00	Shear-Flexure
	D 60	2.0	0.67	35.25	28.25	4.18	18.40	52.20	0.87	3.68	4.22	183.69	Shear
SFRC (FCT) 2P	**D 30**	4.0	1.33	35.25	28.25	4.19	7.60	12.46	1.99	11.2	5.63	64.00	Flexure
	D 40	3.0	1.00	34.90	27.90	4.15	11.70	23.30	0.98	6.20	6.33	99.14	Flexure
	D 50	2.4	0.80	34.75	27.75	4.14	19.90	39.10	1.37	7.20	5.26	96.00	Shear-Flexure
	D 60	2.0	0.67	35.30	28.25	4.19	20.70	53.15	1.52	8.12	5.34	156.76	Shear-Flexure

TABLE 4.2.4 Comparison Of Control Specimens, Deflection, Ductility & Reserve Strength At S 7.5

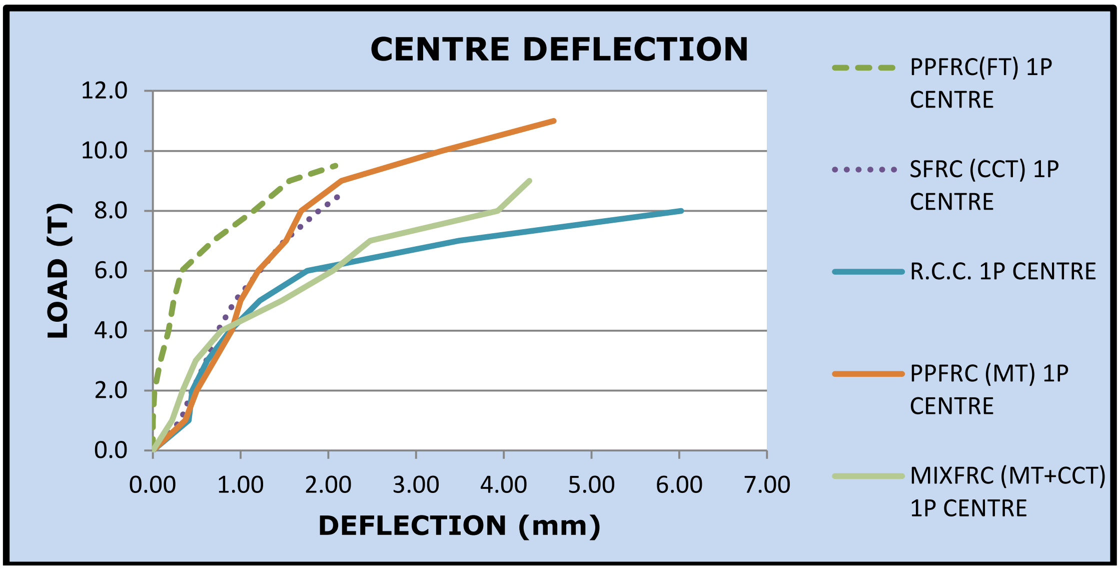
TYPE	BEAM S 0.0	L/D RATIO	a/D RATIO	AVERAGE CUBE COMP. STRENGTH (N/mm2)	AVERAGE CYLINDER COMP. STRENGTH (N/mm2)	AVERAGE SPLIT CYLINDER STRENGTH (N/mm2)	FIRST CRACK LOAD (Wc) (T)	ULTIMATE LOAD (Wu) (T)	DEFLECTION AT FIRST CRACK LOAD (δy) (mm)	DEFLECTION AT ULTIMATE LOAD (δu) (mm)	DUCTILITY (μ) (δu/ δy)	RESERVED STRENGTH (Wu-Wc)/Wc X 100	MODE OF FAILURE
PPFRC (FT) 1P	**D 30**	4.0	2.0	34.60	27.65	4.11	3.70	9.20	0.67	3.30	4.92	148.65	Flexure
	D 40	3.0	1.5	35.55	28.40	4.23	8.00	16.70	0.91	4.60	5.05	108.75	Flexure
	D 50	2.4	1.2	35.00	28.00	4.17	12.50	26.70	0.77	3.12	4.05	113.6	Shear-Flexure
	D 60	2.0	1.0	34.90	27.90	4.14	21.40	41.50	1.53	7.00	4.57	93.93	Flexure
SFRC (CCT) 1P	**D 30**	4.0	2.0	35.35	28.25	4.20	5.80	10.20	0.48	2.78	5.79	75.86	Flexure-shear
	D 40	3.0	1.5	35.10	28.10	4.17	8.70	16.10	1.02	6.78	6.64	85.05	Flexure
	D 50	2.4	1.2	34.80	27.85	4.14	13.70	26.86	0.59	2.91	4.93	95.99	Flexure-shear
	D 60	2.0	1.0	35.70	28.55	4.23	23.70	42.60	0.77	3.31	4.29	79.75	Shear-Flexure
R.C.C. 2P	**D 30**	4.0	1.33	33.50	26.80	3.98	5.00	16.10	0.77	5.98	7.76	222.00	Flexure
	D 40	3.0	1.00	34.20	27.35	4.07	10.10	28.90	0.43	3.80	8.84	186.14	Flexure-shear
	D 50	2.4	0.80	33.90	27.15	4..04	19.60	44.90	0.94	5.70	6.06	129.08	Shear-Flexure
	D 60	2.0	0.67	34.15	27.30	4.05	21.60	53.02	1.00	5.43	5.43	181.02	Shear
PPFRC (MT) 2P	**D 30**	4.0	1.33	35.45	28.35	4.21	8.00	12.15	1.14	5.25	4.60	51.88	Flexure-shear
	D 40	3.0	1.00	35.20	28.00	4.19	11.40	25.00	0.96	4.28	4.45	119.30	Flexure-shear
	D 50	2.4	0.80	34.80	27.75	4.14	19.80	40.40	0.85	4.09	4.81	104.04	Shear-Flexure
	D 60	2.0	0.67	35.00	28.15	4.15	24.80	53.05	0.75	3.70	4.93	113.91	Shear
SFRC (FCT) 2P	**D 30**	4.0	1.33	35.60	28.50	4.23	6.20	12.40	0.51	2.85	5.59	100.00	Flexure
	D 40	3.0	1.00	35.40	28.30	4.21	12.40	23.10	0.66	3.75	5.68	86.29	Flexure-shear
	D 50	2.4	0.80	34.80	27.85	4.14	14.80	38.86	1.27	7.20	5.67	162.50	Shear-Flexure
	D 60	2.0	0.67	35.25	28.25	4.18	21.80	52.98	1.38	7.50	5.43	142.89	Shear-Flexure
RCC (W/O/S) 2P	**D 30**	4.0	1.33	34.60	26.50	3.90	3.2	7.0	1.5	6.8	4.53	118.75	Flexure
	D 40	3.0	1.00	34.90	27.10	3.95	6.14	13.4	1.50	6.2	4.13	119.95	Flexure-shear
	D 50	2.4	0.80	35.15	28.50	4.10	10.0	20.4	1.72	6.5	3.78	104.0	Shear-Flexure
	D 60	2.0	0.67	34.70	26.90	4.12	14.5	30.0	1.68	6.3	3.75	106.89	Shear

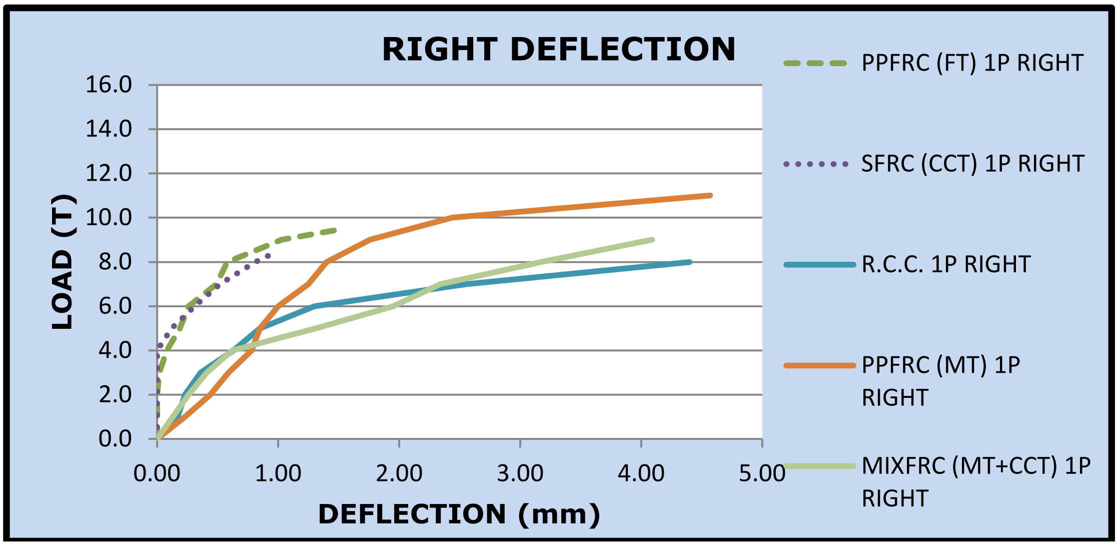
TABLE 4.3 COMPARISON OF DEFLECTION

TABLE 4.3.1 Comparison Of Deflection For D30

LOAD DEFLECTION READINGS FOR BEAM D30 S 0.0 (mm)																							
LOAD	**PPFRC (MT)**			**LOAD**	**PPFRC(FT)**			**LOAD**	**MIXFRC (MT+CCT)**			**LOAD**	**PPFRC (MT)**			**LOAD**	**SFRC(FCT)**			**LOAD**	**R.C.C.**		
	1P				**2P**				**2P**				**2P**				**2P**				**2P**		
(T)	**L**	**C**	**R**	**(T)**	**L**	**C**	**R**	**(T)**	**L**	**C**	**R**	**(T)**	**L**	**C**	**R**	**(T)**	**L**	**C**	**R**	**(T)**	**L**	**C**	**R**
0	0.0	0.0	0.0	**0**	0.0	0.0	0.0	**0**	0.0	0.0	0.0	**0**	0.0	0.0	0.0	**0**	0.0	0.0	0.0	**0**	0.0	0.0	0.0
2	0.4	0.5	0.4	**2**	0.3	0.4	0.3	**2**	0.6	0.5	0.5	**2**	0.6	0.4	0.4	**2**	0.6	0.4	0.4	**2**	0.3	0.4	0.4
4	0.8	0.9	0.8	**4**	0.5	0.6	0.5	**4**	1.2	1.2	1.2	**4**	0.8	0.7	0.7	**4**	0.8	0.7	0.7	**4**	0.4	0.5	0.5
6	1.0	1.2	1.0	**6**	0.8	0.9	0.8	**6**	1.4	1.5	1.3	**6**	1.0	1.0	0.9	**6**	1.0	1.0	0.9	**6**	0.6	0.7	0.7
8	1.4	1.7	1.4	**8**	1.4	1.5	1.3	**8**	1.8	2.3	1.9	**8**	1.4	1.4	1.3	**8**	1.4	1.4	1.3	**8**	1.2	1.4	1.2
10	2.4	3.3	2.4	**10**	1.7	1.9	1.7	**10**	2.5	3.1	2.4	**10**	1.9	1.9	1.8	**10**	1.9	1.9	1.8	**10**	2.2	2.8	2.7
11	4.6	4.6	4.6	**12**	2.0	2.2	2.1	**11**	4.2	5.3	4.2	**12**	2.9	2.9	2.6	**12**	2.9	2.9	2.6	**12**	4.2	4.2	3.8
				14	3.5	3.8	3.6					**13**	3.5	3.7	3.2	**13**	3.3	3.5	2.9				

LOAD DEFLECTION READINGS FOR BEAM D30 S 0.0 (mm)																							
LOAD	**MIXFRC (MT+CCT)**			**LOAD**	**R.C.C.**			**LOAD**	**R.C.C. W/O/S**			**LOAD**	**R.C.C. W/O/S**			**LOAD**	**PPFRC (FT)**			**LOAD**	**SFRC (CCT)**		
	1P				**1P**				**2P**				**1P**				**2P**				**2P**		
(T)	**L**	**C**	**R**	**(T)**	**L**	**C**	**R**	**(T)**	**L**	**C**	**R**	**(T)**	**L**	**C**	**R**	**(T)**	**L**	**C**	**R**	**(T)**	**L**	**C**	**R**
0	0.0	0.0	0.0	**0**	0.0	0.0	0.0	**0**	0.0	0.0	0.0	**0**	0.0	0.0	0.0	**0**	0.0	0.0	0.0	**0**	0.0	0.0	0.0
2	0.3	0.3	0.3	**2**	0.3	0.5	0.2	**2**	0.4	0.4	0.3	**2**	0.5	0.4	0.6	**2**	0.1	0.0	0.0	**2**	0.1	0.5	0.0
4	0.6	0.8	0.6	**4**	0.6	0.9	0.6	**4**	0.7	0.7	0.6	**4**	1.0	0.9	1.2	**4**	0.4	0.2	0.1	**4**	0.4	0.7	0.0
6	2.0	2.1	2.0	**6**	1.2	1.8	1.3	**6**	0.9	0.9	0.8	**6.2**	1.5	1.4	1.5	**6**	0.7	0.3	0.3	**6**	0.8	1.2	0.3
8	3.2	3.9	3.2	**8**	4.4	6.0	4.4	**7**	1.4	1.6	1.3					**8**	1.5	1.2	0.6	**8**	1.3	1.9	0.8
9	4.1	4.3	4.1													**9**	1.9	1.6	1.0	**8.5**	1.5	2.1	1.0
																9.5	2.4	2.1	1.5				





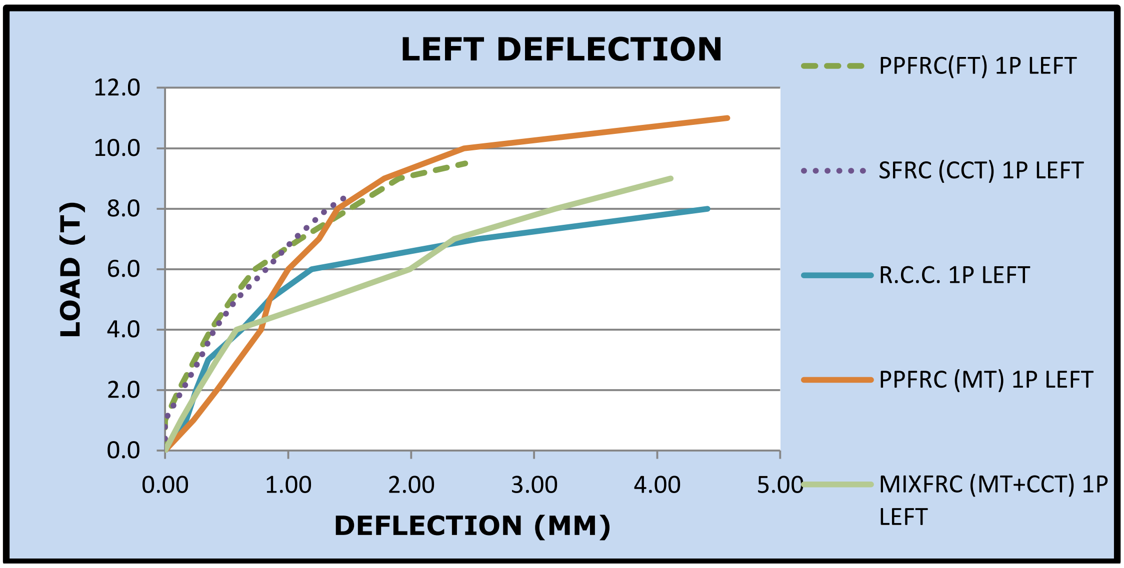
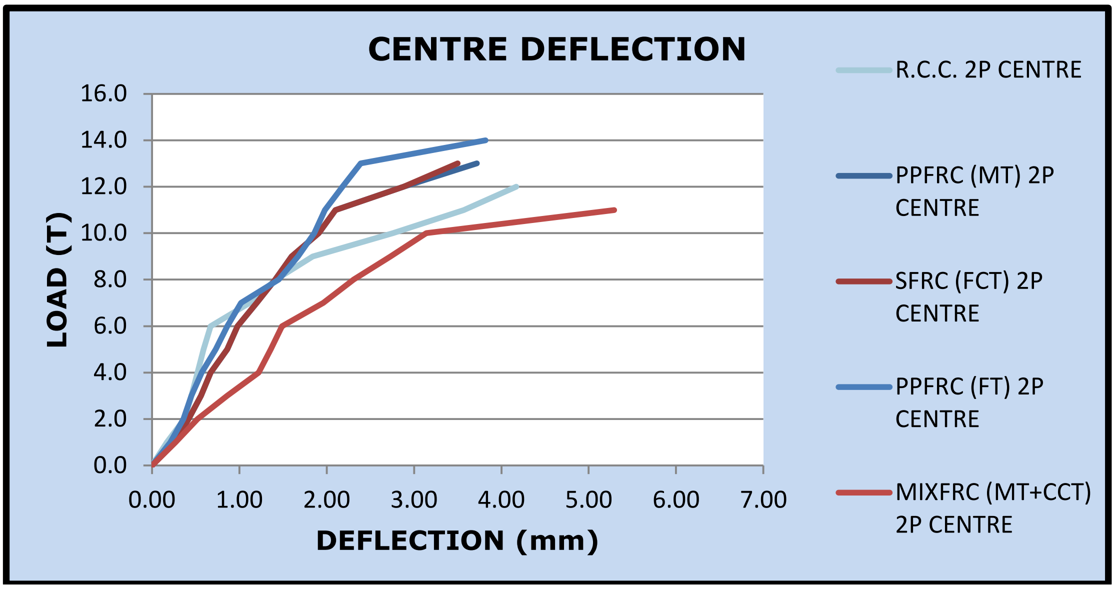
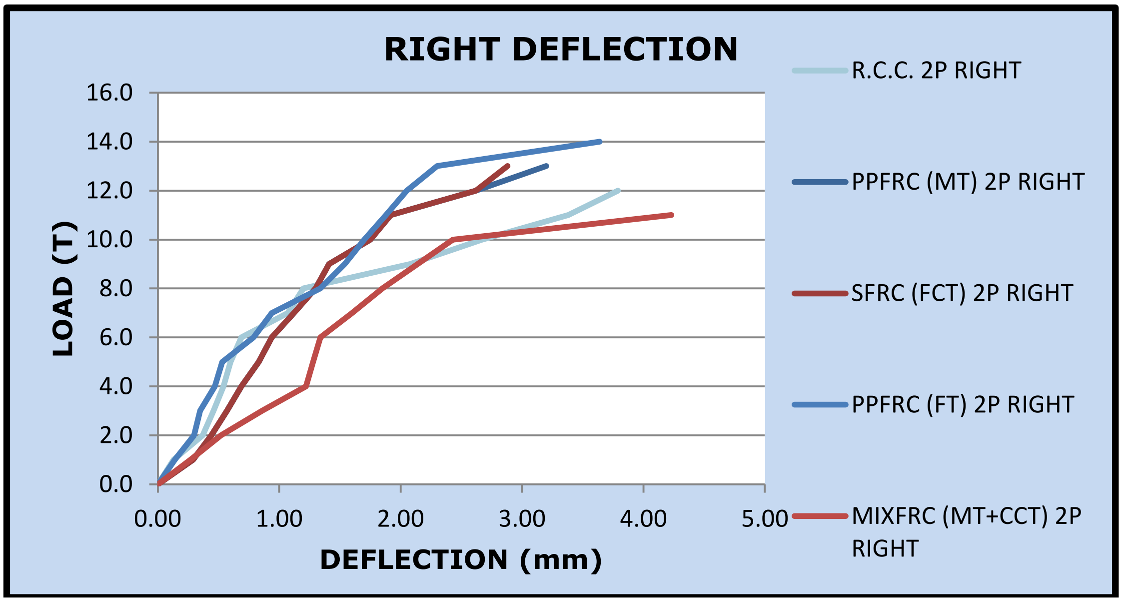


Fig.4.1a Load Vs Deflection Graphs Of D 30 S 0.0 for 1P





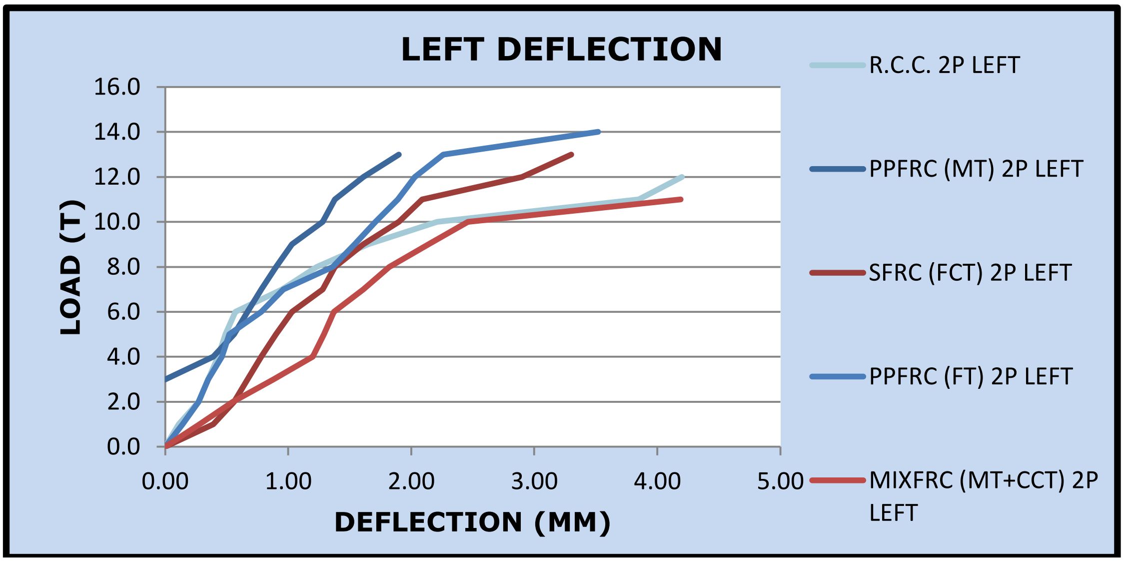
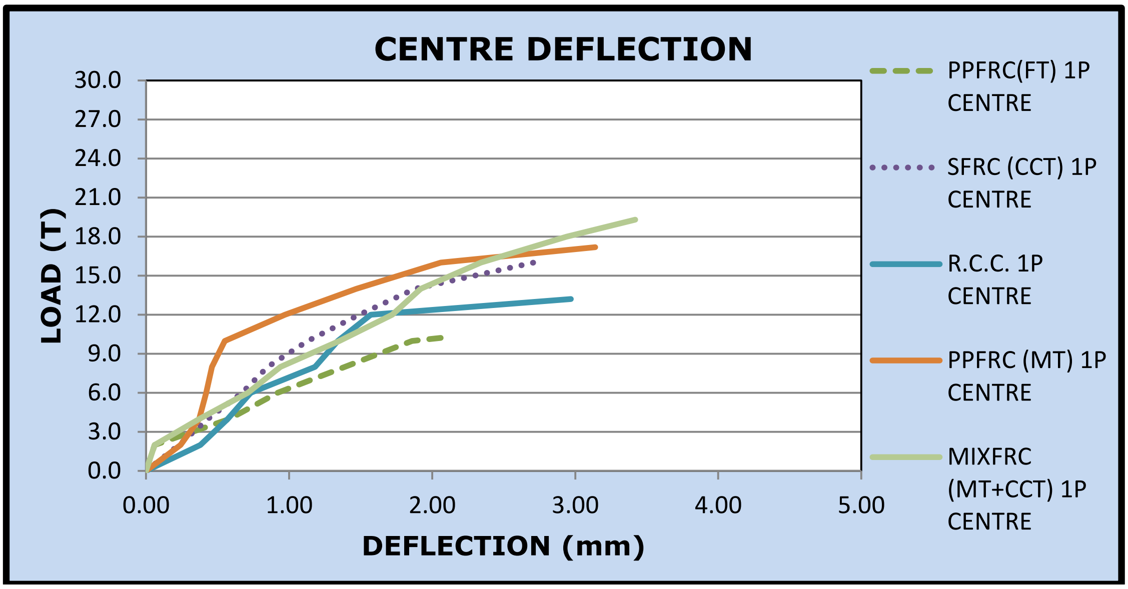
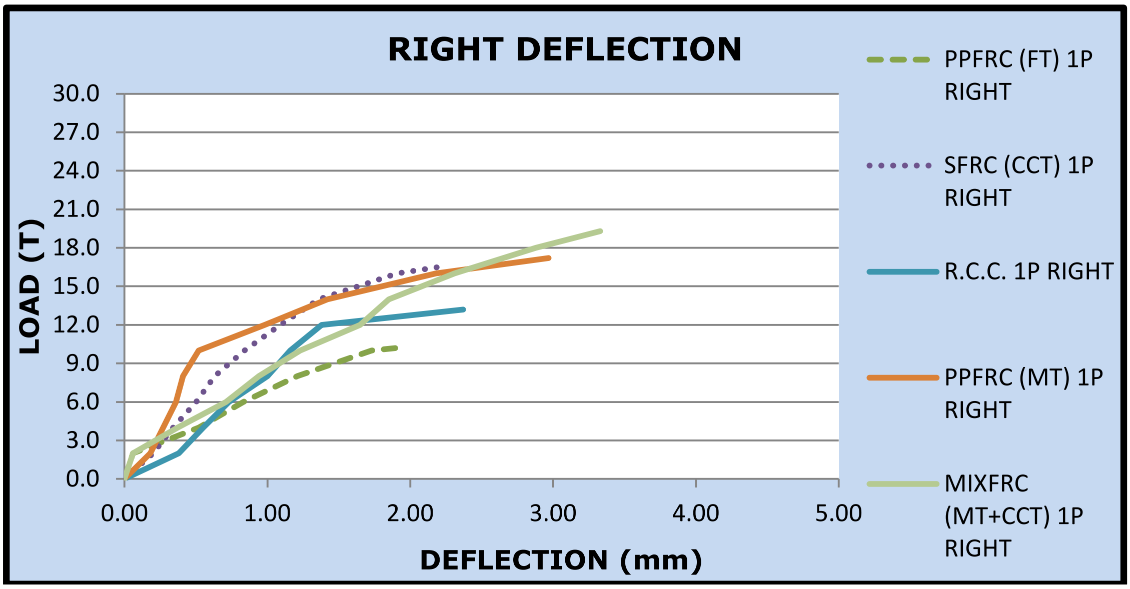


Fig.4.1b Load Vs Deflection Graphs Of D 30 S 0.0 for 2P





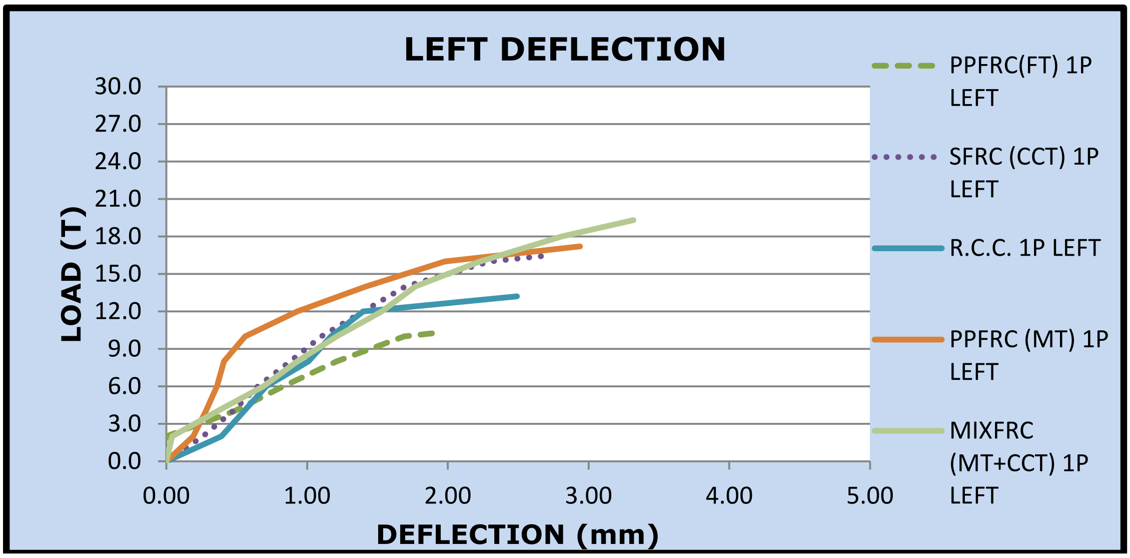
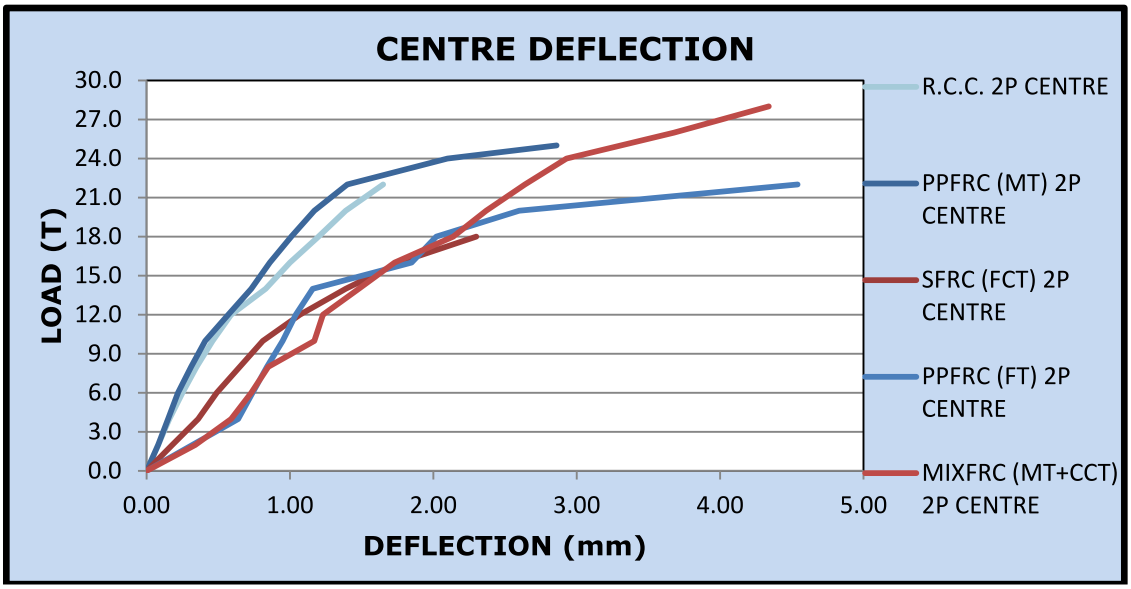
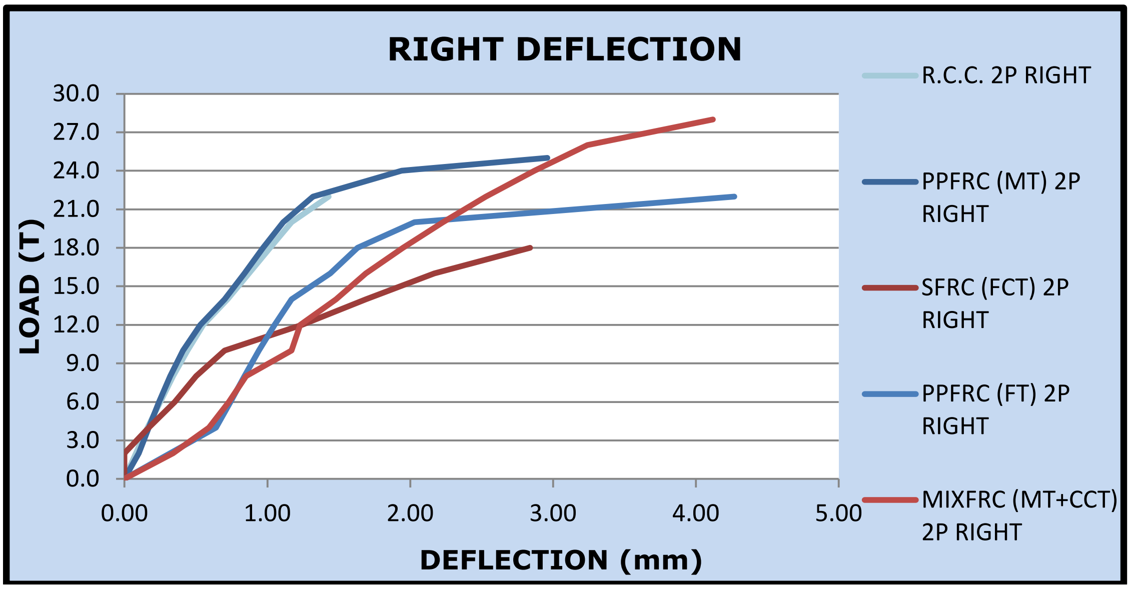


Fig.4.2a Load Vs Deflection Graphs Of D 40 S 0.0 for 1P





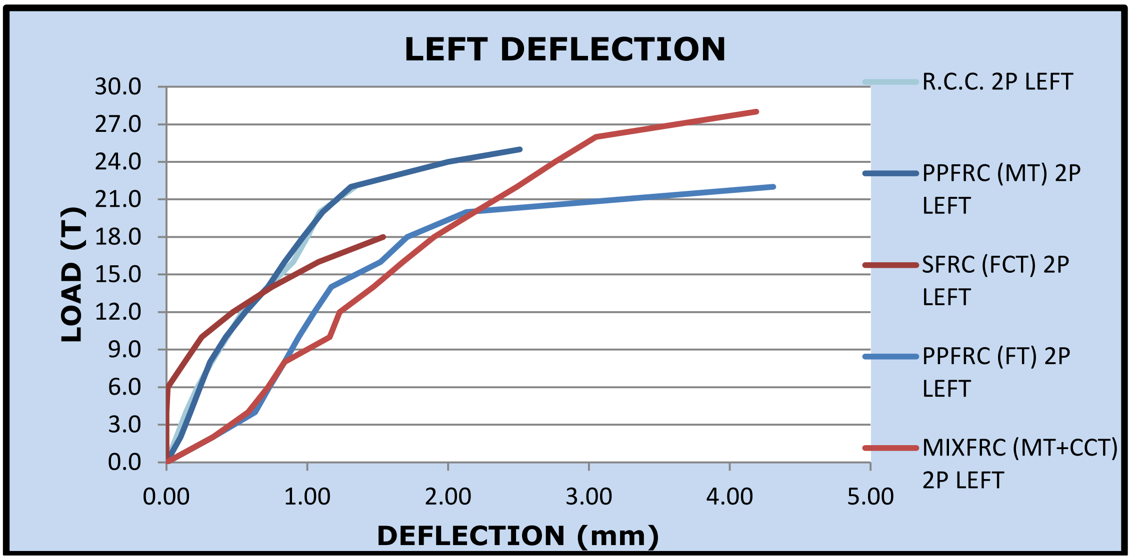
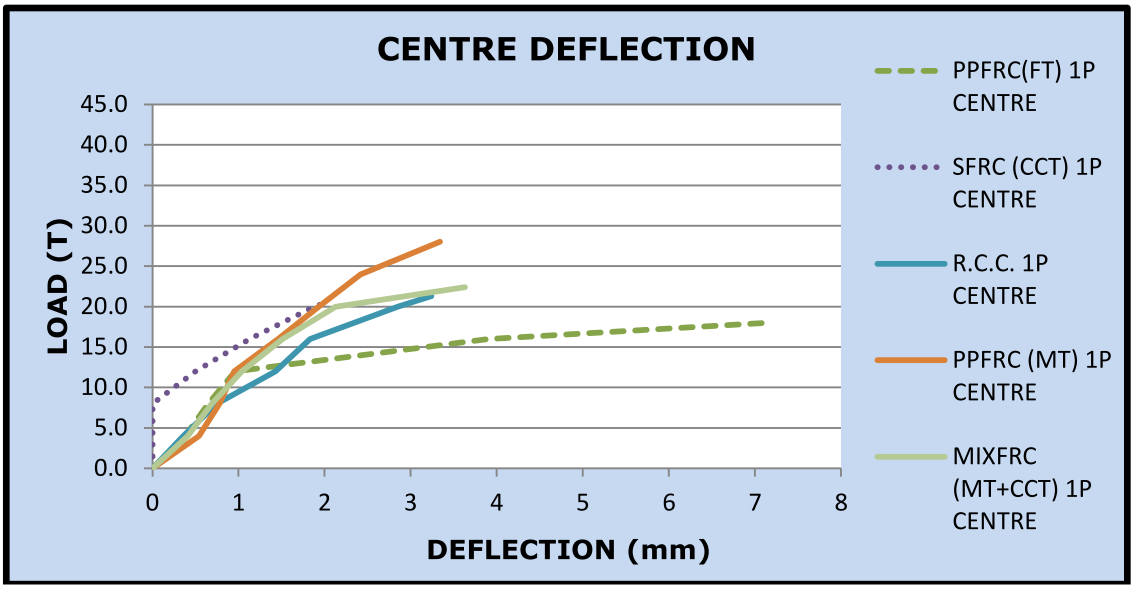
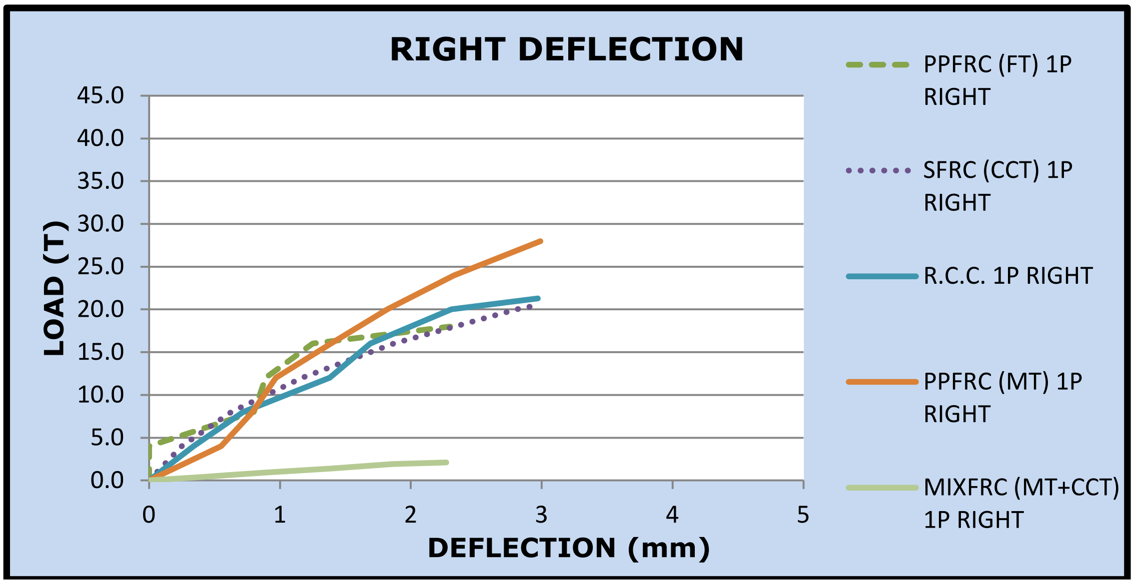


Fig.4.2b Load Vs Deflection Graphs Of D 40 S 0.0 for 2P





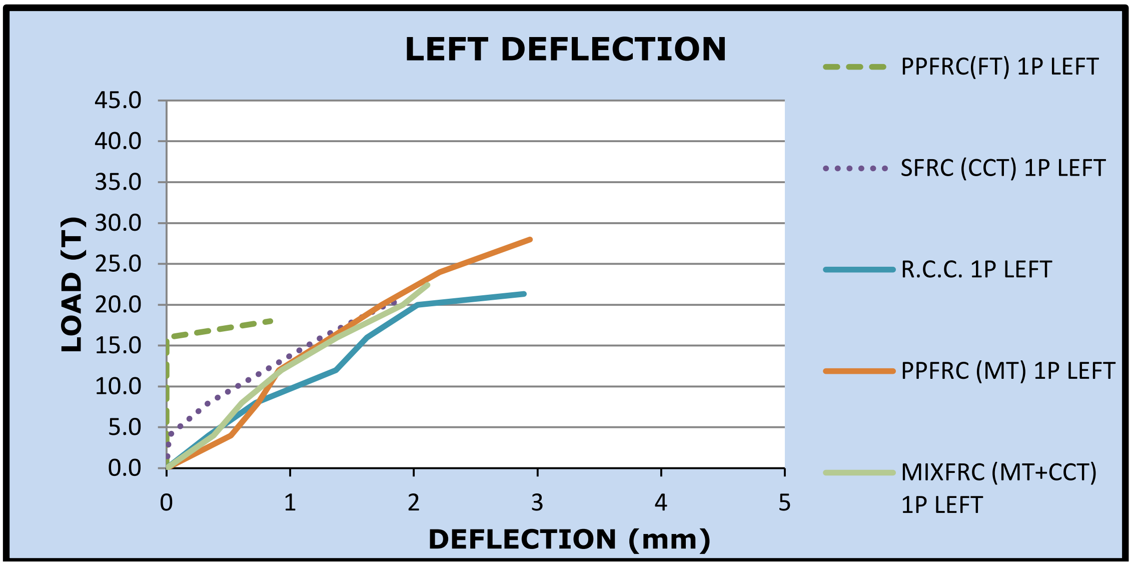
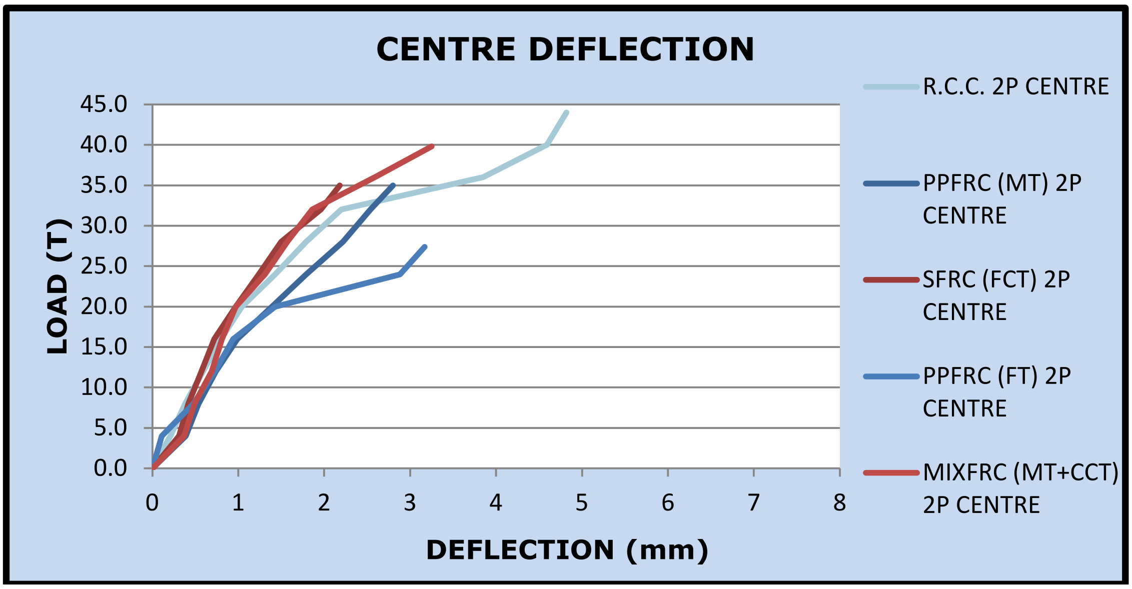
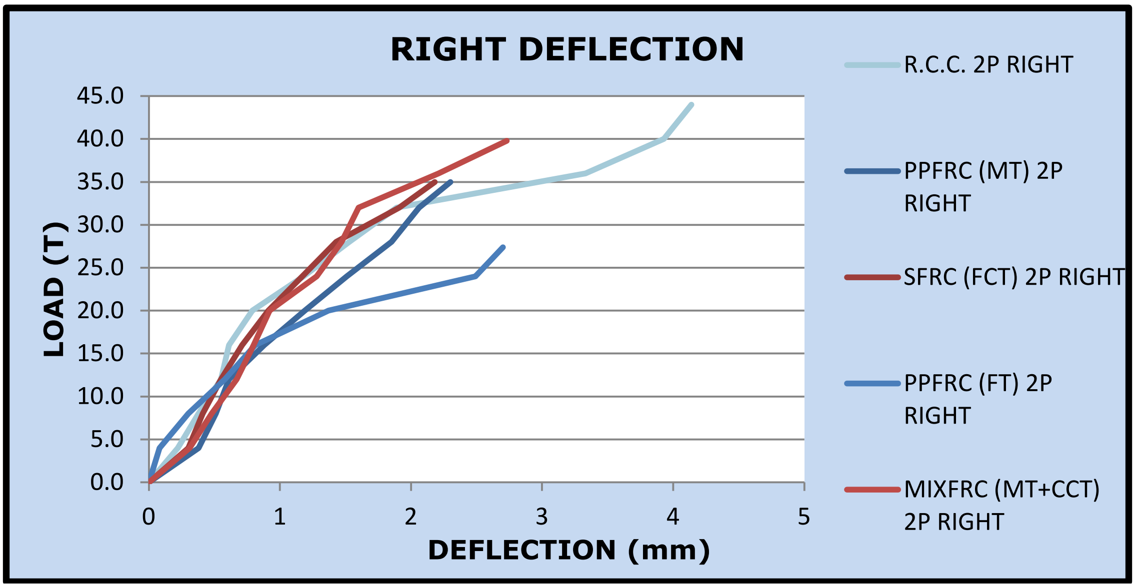


Fig.4.3a Load Vs Deflection Graphs Of D 50 S 0.0 for 1P





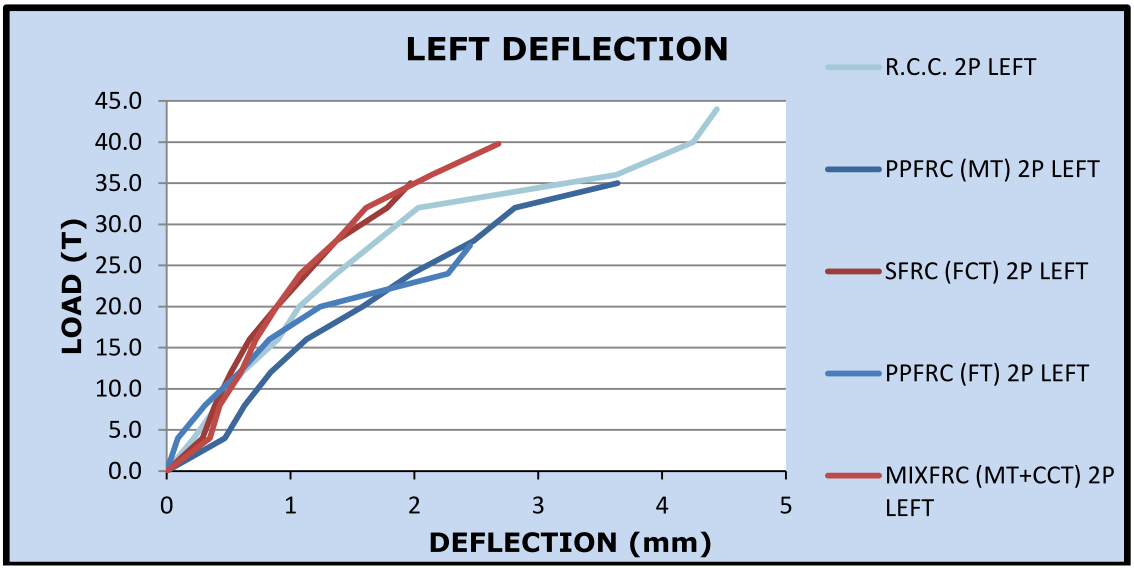


Fig.4.3b Load Vs Deflection Graphs Of D 50 S 0.0 for 2P

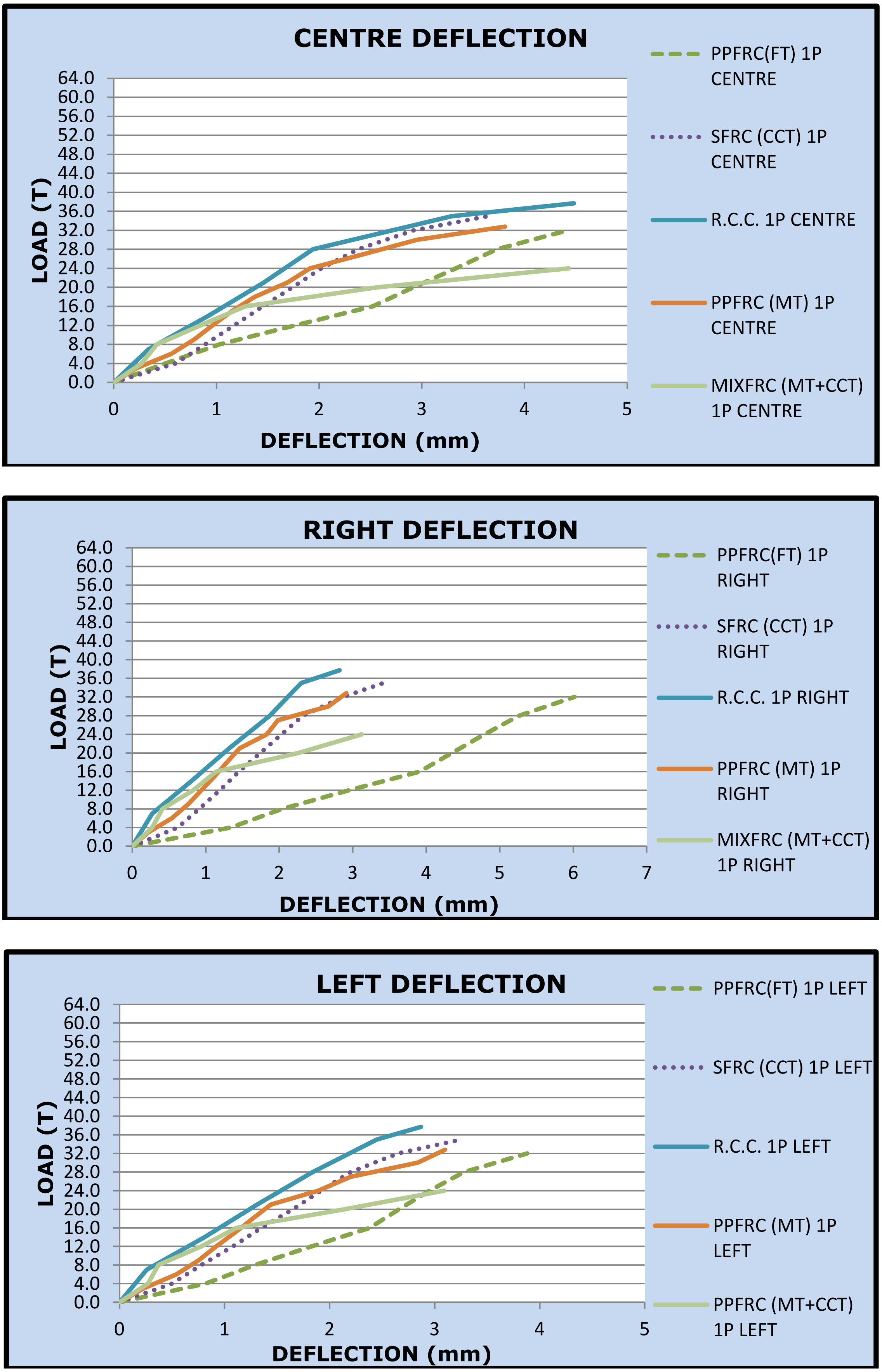
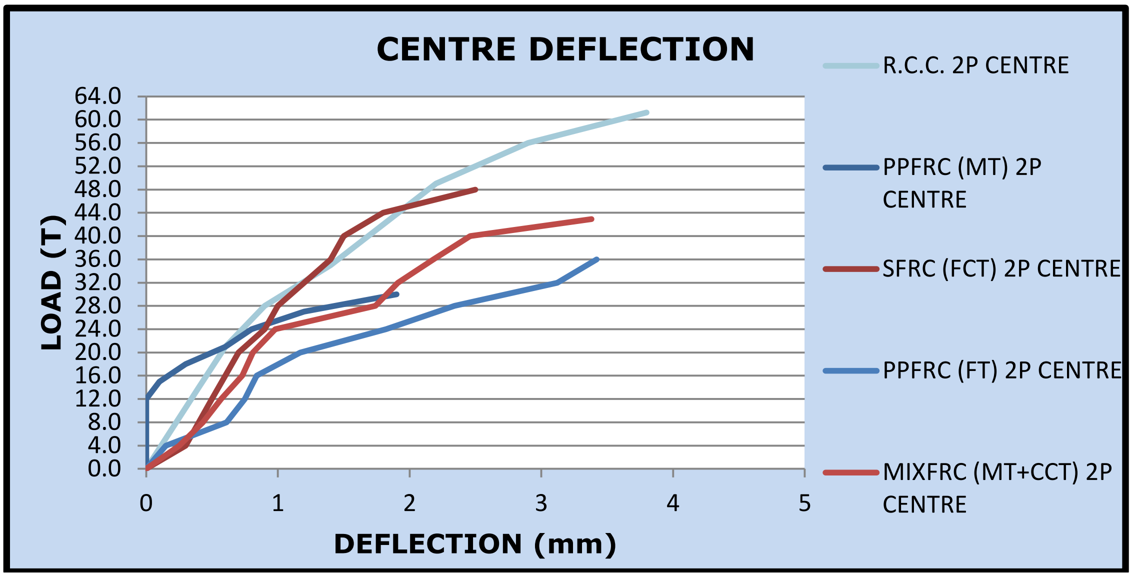
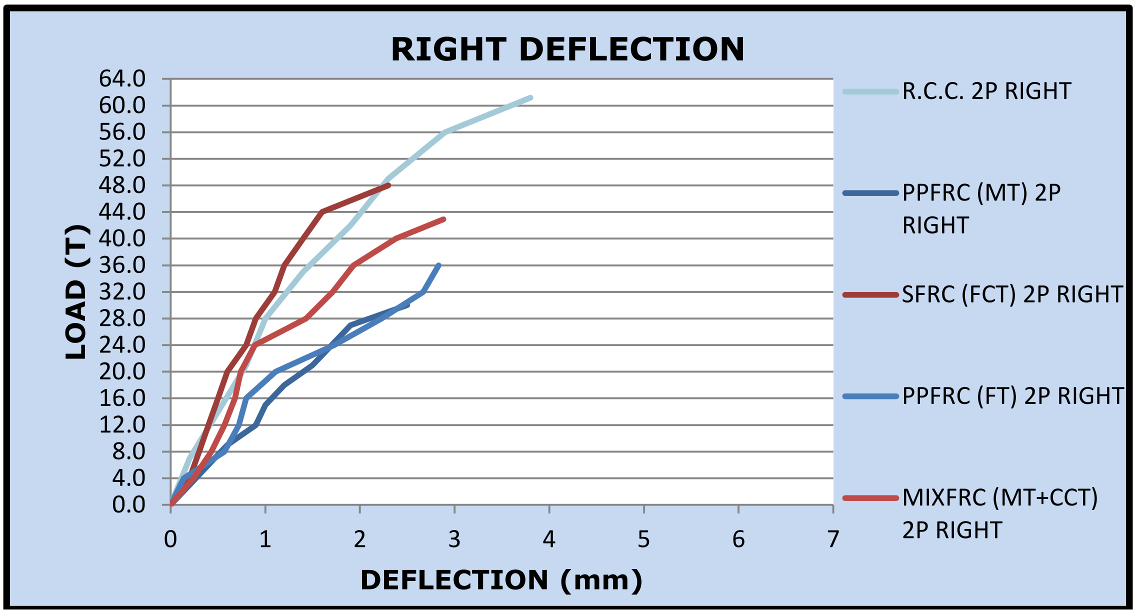


Fig.4.4a Load Vs Deflection Graphs Of D 60 S 0.0 for 1P





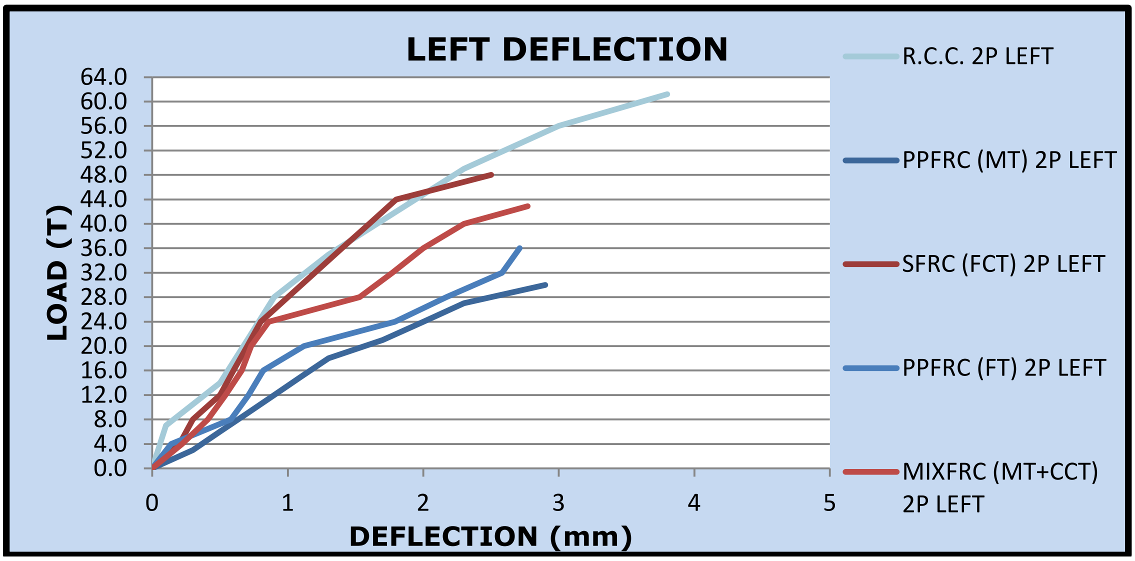


Fig.4.4b Load Vs Deflection Graphs Of D 60 S 0.0 for 2P

TABLE GROUP 4.4 SHEAR STRAIN VARIATION ALONG VERTICAL AXIS

TABLE 4.4.1 Shear Strain Variation Along Vertical Axis For PPFRC (MT) 1P D50 S 0.0

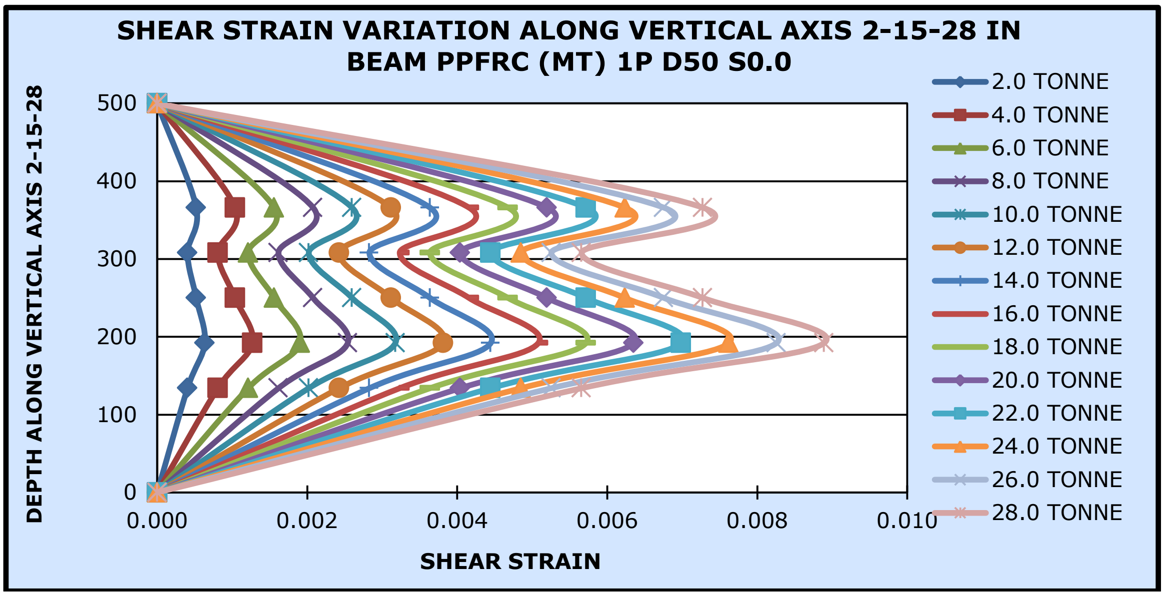
Shear Strain Variation Along VERTICAL AXIS 2-15-28 In PPFRC (MT) D50 S 0.0																
DEPTH	**SHEAR**	**0.0 T**	**2.0 T**	**4.0 T**	**6.0 T**	**8.0 T**	**10.0 T**	**12.0 T**	**14.0 T**	**16.0 T**	**18.0 T**	**20.0 T**	**22.0 T**	**24.0 T**	**26.0 T**	**28.0 T**
500		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
366	**1-3-15**	0.0000	0.0005	0.0010	0.0016	0.0021	0.0026	0.0031	0.0036	0.0042	0.0047	0.0052	0.0057	0.0062	0.0068	0.0073
308	**2-14-16**	0.0000	0.0004	0.0008	0.0012	0.0016	0.0020	0.0024	0.0028	0.0032	0.0036	0.0040	0.0044	0.0049	0.0053	0.0057
250	**15.00**	0.0000	0.0005	0.0010	0.0016	0.0021	0.0026	0.0031	0.0036	0.0042	0.0047	0.0052	0.0057	0.0062	0.0068	0.0073
192	**14-16-28**	0.0000	0.0006	0.0013	0.0019	0.0025	0.0032	0.0038	0.0044	0.0051	0.0057	0.0064	0.0070	0.0076	0.0083	0.0089
134	**15-27-29**	0.0000	0.0004	0.0008	0.0012	0.0016	0.0020	0.0024	0.0028	0.0032	0.0036	0.0040	0.0044	0.0049	0.0053	0.0057
0		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

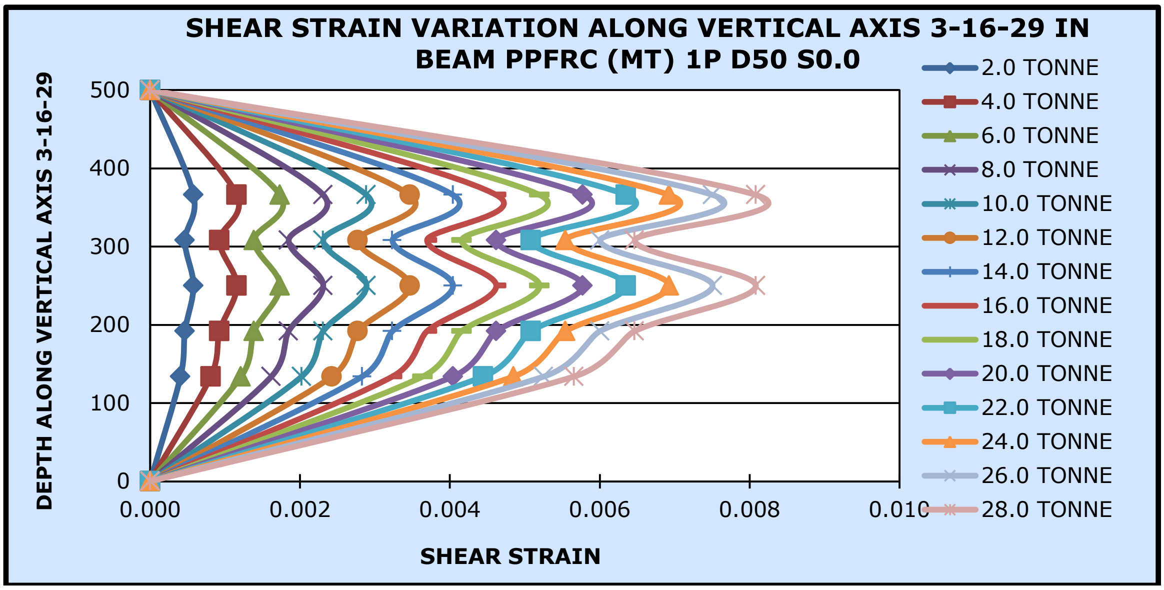
Shear Strain Variation Along VERTICAL AXIS 3-16-29 In PPFRC (MT) D50 S 0.0																
DEPTH	**SHEAR**	**0.0 T**	**2.0 T**	**4.0 T**	**6.0 T**	**8.0 T**	**10.0 T**	**12.0 T**	**14.0 T**	**16.0 T**	**18.0 T**	**20.0 T**	**22.0 T**	**24.0 T**	**26.0 T**	**28.0 T**
500		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
366	**2-4-16**	0.0000	0.0006	0.0012	0.0017	0.0023	0.0029	0.0035	0.0040	0.0046	0.0052	0.0058	0.0064	0.0069	0.0075	0.0081
308	**3-15-17**	0.0000	0.0005	0.0009	0.0014	0.0018	0.0023	0.0028	0.0032	0.0037	0.0042	0.0046	0.0051	0.0055	0.0060	0.0065
250	**16.00**	0.0000	0.0006	0.0012	0.0017	0.0023	0.0029	0.0035	0.0040	0.0046	0.0052	0.0058	0.0064	0.0069	0.0075	0.0081
192	**15-17-29**	0.0000	0.0005	0.0009	0.0014	0.0018	0.0023	0.0028	0.0032	0.0037	0.0042	0.0046	0.0051	0.0055	0.0060	0.0065
134	**16-28-30**	0.0000	0.0004	0.0008	0.0012	0.0016	0.0020	0.0024	0.0028	0.0032	0.0036	0.0040	0.0044	0.0049	0.0053	0.0057
0		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Shear Strain Variation Along VERTICAL AXIS 4-17-30 In PPFRC (MT) D50 S 0.0																
DEPTH	**SHEAR**	**0.0 T**	**2.0 T**	**4.0 T**	**6.0 T**	**8.0 T**	**10.0 T**	**12.0 T**	**14.0 T**	**16.0 T**	**18.0 T**	**20.0 T**	**22.0 T**	**24.0 T**	**26.0 T**	**28.0 T**
500		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
366	**3-5-17**	0.0000	0.0005	0.0010	0.0016	0.0021	0.0026	0.0031	0.0036	0.0042	0.0047	0.0052	0.0057	0.0062	0.0068	0.0073
308	**4-16-18**	0.0000	0.0005	0.0010	0.0016	0.0021	0.0026	0.0031	0.0036	0.0042	0.0047	0.0052	0.0057	0.0062	0.0068	0.0073
250	**17**	0.0000	0.0005	0.0010	0.0016	0.0021	0.0026	0.0031	0.0036	0.0042	0.0047	0.0052	0.0057	0.0062	0.0068	0.0073
192	**16-18-30**	0.0000	0.0003	0.0006	0.0009	0.0012	0.0014	0.0017	0.0020	0.0023	0.0026	0.0029	0.0032	0.0035	0.0038	0.0040
134	**17-29-31**	0.0000	0.0005	0.0010	0.0016	0.0021	0.0026	0.0031	0.0036	0.0042	0.0047	0.0052	0.0057	0.0062	0.0068	0.0073
0		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Shear Strain Variation Along VERTICAL AXIS 5-18-31 In PPFRC (MT) D50 S 0.0																
DEPTH	**SHEAR**	**0.0 T**	**2.0 T**	**4.0 T**	**6.0 T**	**8.0 T**	**10.0 T**	**12.0 T**	**14.0 T**	**16.0 T**	**18.0 T**	**20.0 T**	**22.0 T**	**24.0 T**	**26.0 T**	**28.0 T**
500		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
366	**4-6-18**	0.0000	0.0004	0.0008	0.0012	0.0016	0.0020	0.0024	0.0028	0.0032	0.0036	0.0040	0.0044	0.0049	0.0053	0.0057
308	**5-17-19**	0.0000	0.0004	0.0008	0.0012	0.0016	0.0020	0.0024	0.0028	0.0032	0.0036	0.0040	0.0044	0.0049	0.0053	0.0057
250	**18.00**	0.0000	0.0005	0.0010	0.0016	0.0021	0.0026	0.0031	0.0036	0.0042	0.0047	0.0052	0.0057	0.0062	0.0068	0.0073
192	**17-19-31**	0.0000	0.0005	0.0009	0.0014	0.0018	0.0023	0.0028	0.0032	0.0037	0.0042	0.0046	0.0051	0.0055	0.0060	0.0065
134	**18-30-32**	0.0000	0.0005	0.0009	0.0014	0.0018	0.0023	0.0028	0.0032	0.0037	0.0042	0.0046	0.0051	0.0055	0.0060	0.0065
0		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Shear Strain Variation Along VERTICAL AXIS 6-19-32 In PPFRC (MT) D50 S 0.0																
DEPTH	**SHEAR**	**0.0 T**	**2.0 T**	**4.0 T**	**6.0 T**	**8.0 T**	**10.0 T**	**12.0 T**	**14.0 T**	**16.0 T**	**18.0 T**	**20.0 T**	**22.0 T**	**24.0 T**	**26.0 T**	**28.0 T**
500		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
366	**5-7-19**	0.0000	0.0003	0.0006	0.0009	0.0012	0.0014	0.0017	0.0020	0.0023	0.0026	0.0029	0.0032	0.0035	0.0038	0.0040
308	**6-18-20**	0.0000	0.0005	0.0009	0.0014	0.0018	0.0023	0.0028	0.0032	0.0037	0.0042	0.0046	0.0051	0.0055	0.0060	0.0065
250	**19.00**	0.0000	0.0006	0.0012	0.0017	0.0023	0.0029	0.0035	0.0040	0.0046	0.0052	0.0058	0.0064	0.0069	0.0075	0.0081
192	**18-20-32**	0.0000	0.0006	0.0012	0.0017	0.0023	0.0029	0.0035	0.0040	0.0046	0.0052	0.0058	0.0064	0.0069	0.0075	0.0081
134	**19-31-33**	0.0000	0.0004	0.0008	0.0012	0.0016	0.0020	0.0024	0.0028	0.0032	0.0036	0.0040	0.0044	0.0049	0.0053	0.0057
0		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000


SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 2-15-28 IN BEAM PPFRC (MT) 1P D50 S0.0
DEPTH ALONG VERTICAL AXIS 2-15-28
SHEAR STRAIN
0
100
200
300
400
500
0.000
0.002
0.004
0.006
0.008
0.010
2.0 TONNE
4.0 TONNE
6.0 TONNE
8.0 TONNE
10.0 TONNE
12.0 TONNE
14.0 TONNE
16.0 TONNE
18.0 TONNE
20.0 TONNE
22.0 TONNE
24.0 TONNE
26.0 TONNE
28.0 TONNE


SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 3-16-29 IN BEAM PPFRC (MT) 1P D50 S0.0
DEPTH ALONG VERTICAL AXIS 3-16-29
SHEAR STRAIN
0
100
200
300
400
500
0.000
0.002
0.004
0.006
0.008
0.010
2.0 TONNE
4.0 TONNE
6.0 TONNE
8.0 TONNE
10.0 TONNE
12.0 TONNE
14.0 TONNE
16.0 TONNE
18.0 TONNE
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22.0 TONNE
24.0 TONNE
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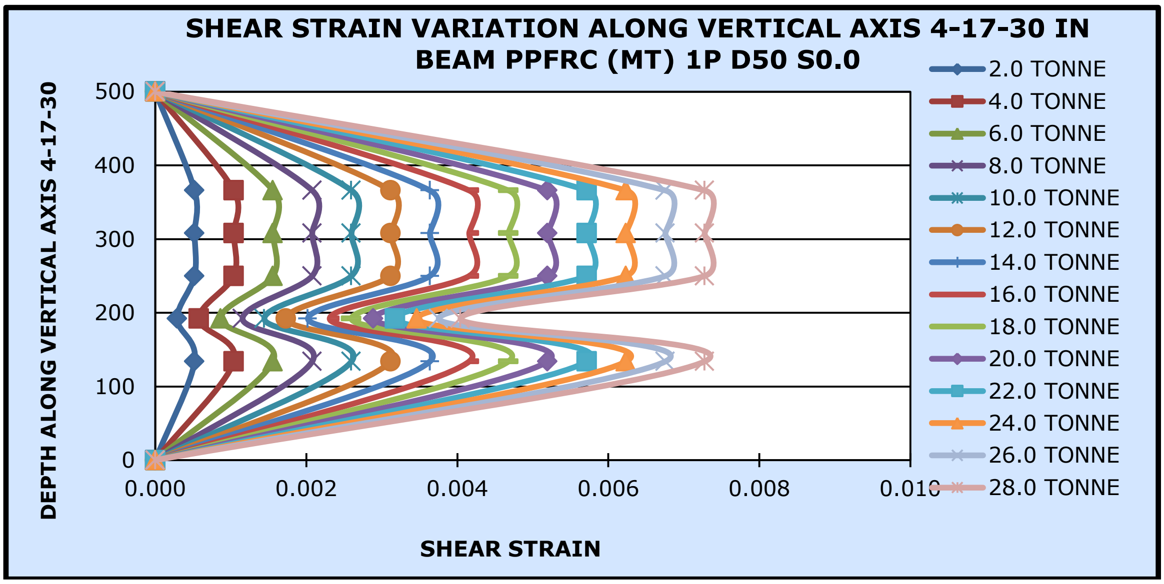
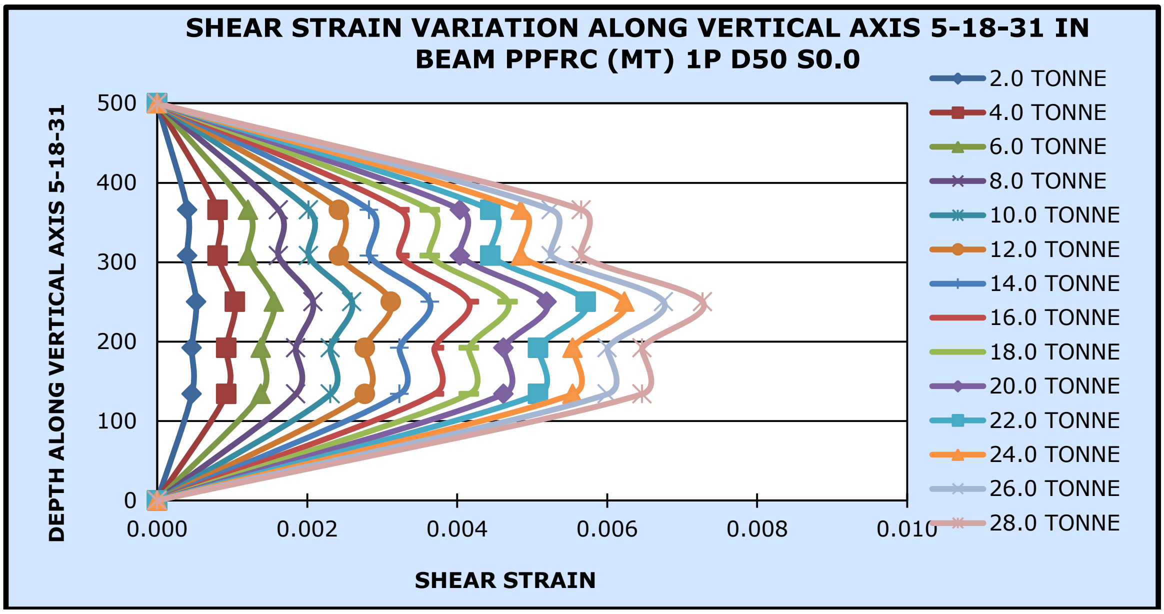
28.0 TONNE


SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 4-17-30 IN BEAM PPFRC (MT) 1P D50 S0.0
DEPTH ALONG VERTICAL AXIS 4-17-30
SHEAR STRAIN
0
100
200
300
400
500
0.000
0.002
0.004
0.006
0.008
0.010
2.0 TONNE
4.0 TONNE
6.0 TONNE
8.0 TONNE
10.0 TONNE
12.0 TONNE
14.0 TONNE
16.0 TONNE
18.0 TONNE
20.0 TONNE
22.0 TONNE
24.0 TONNE
26.0 TONNE
28.0 TONNE



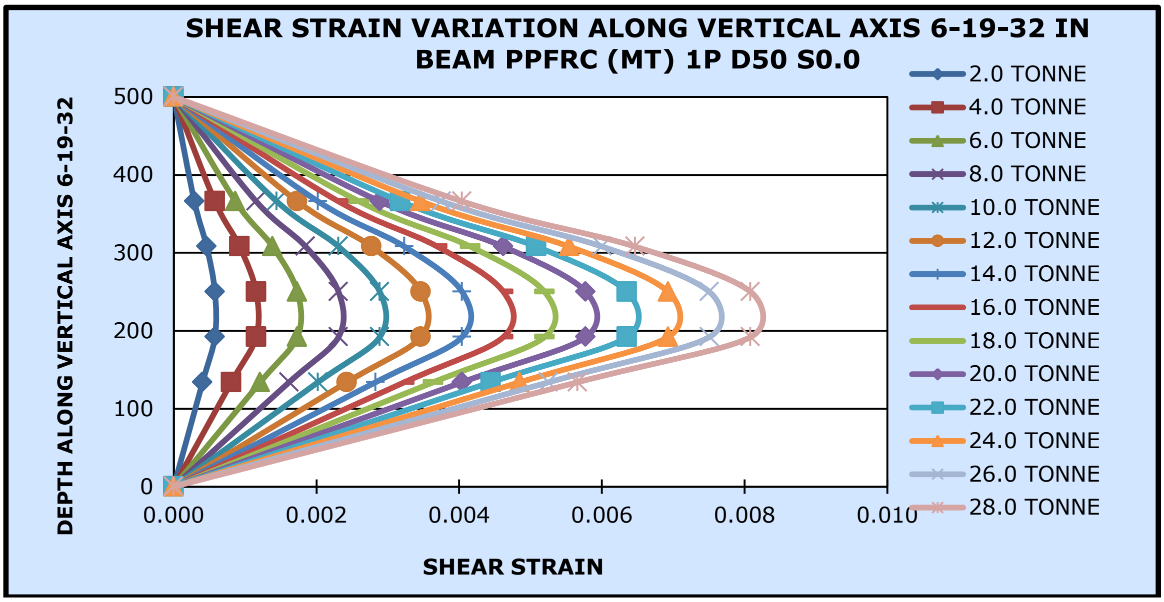
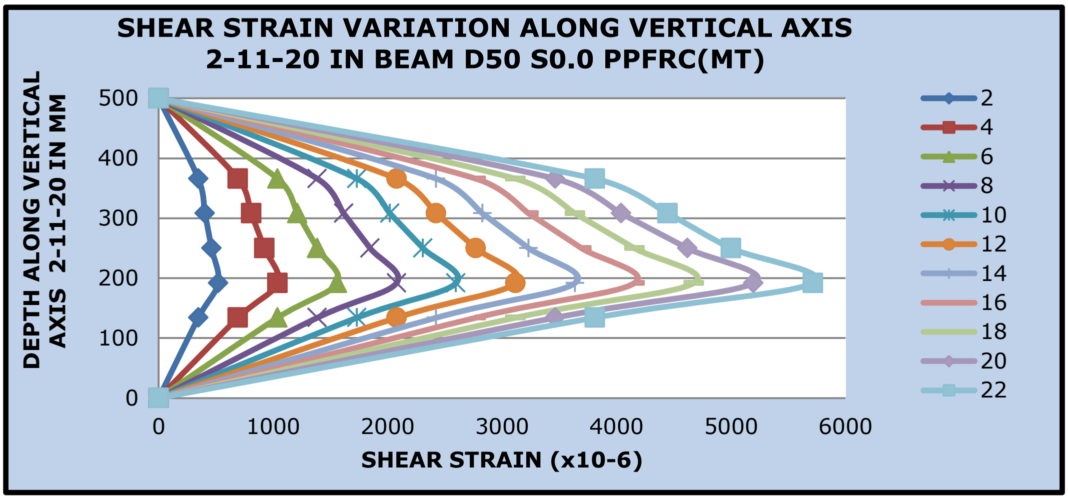
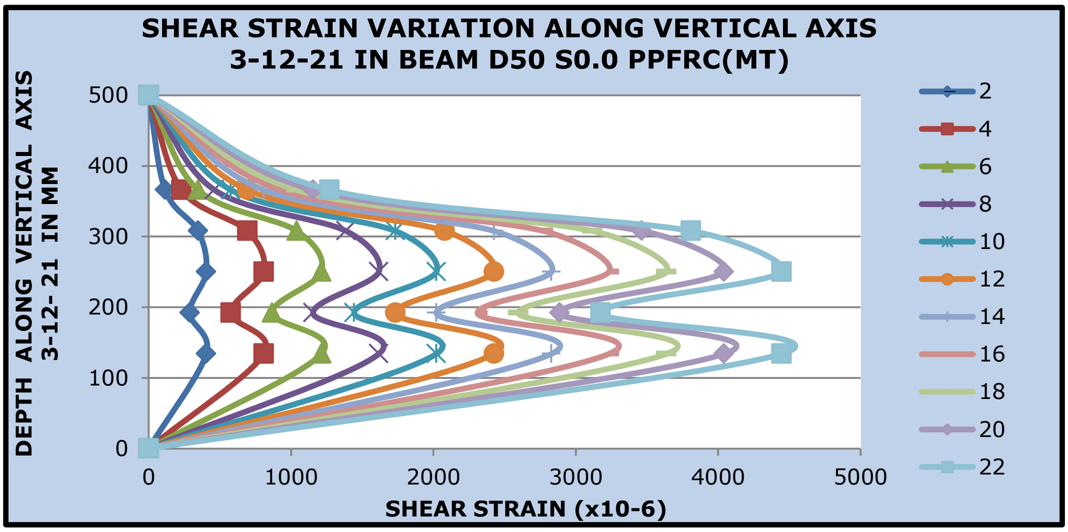


Fig. 4.5 Vertical Shear Strain Graphs Of PPFRC (MT) 1P D50 S 0.0





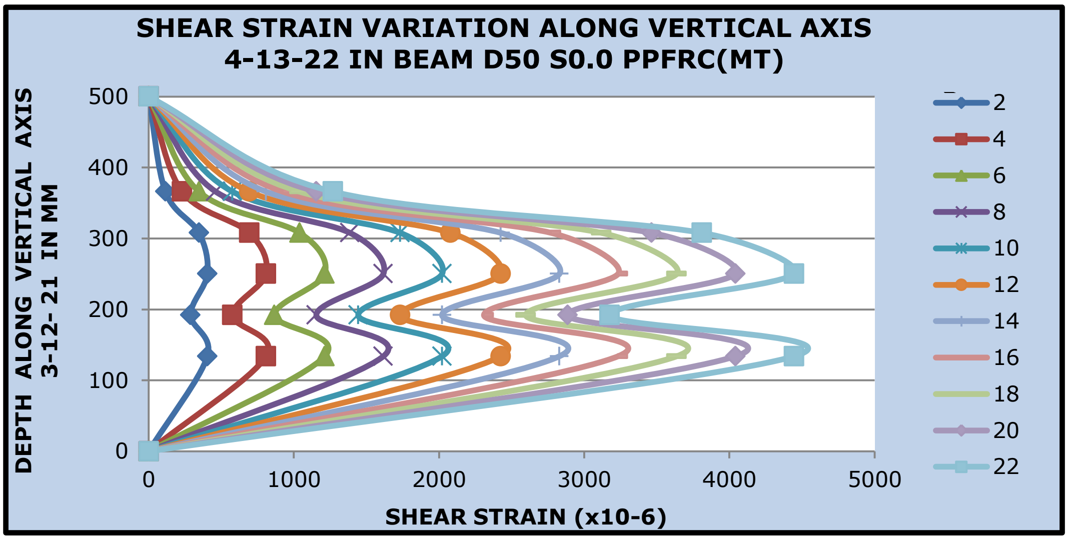
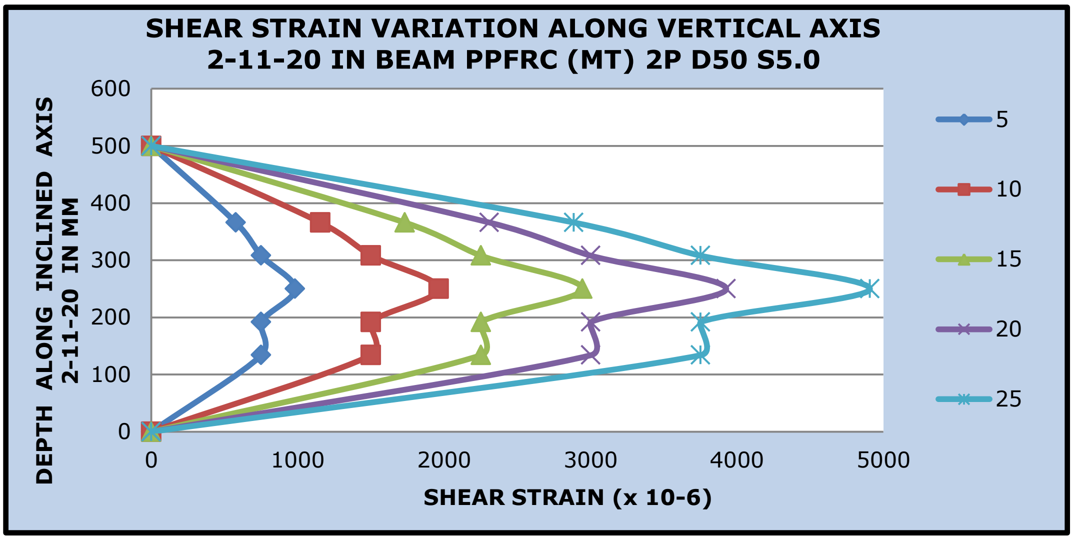
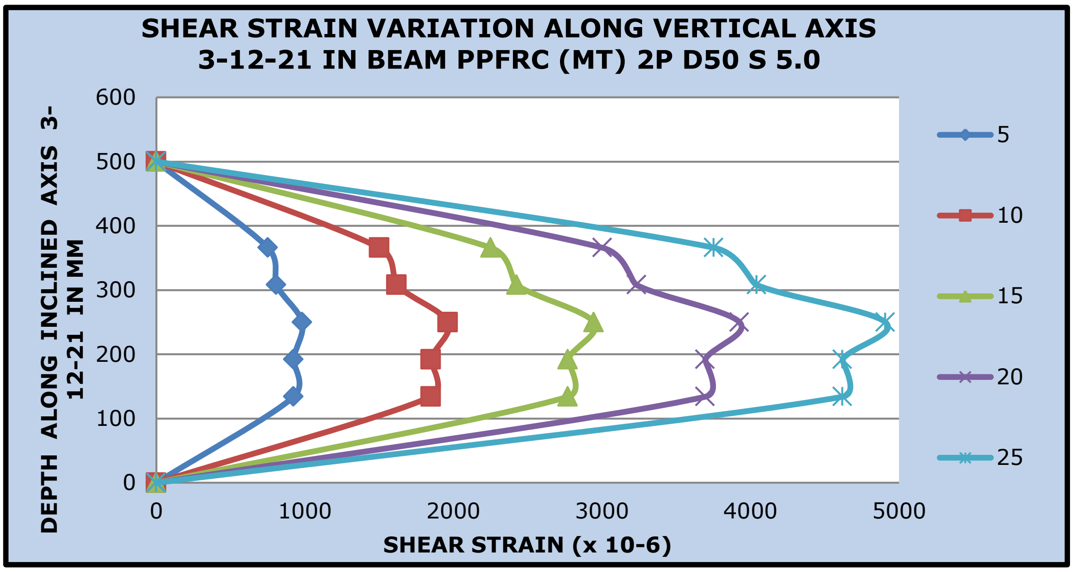


Fig. 4.6 Vertical Shear Strain Graphs Of PPFRC (MT) 2P D50 S 0.0





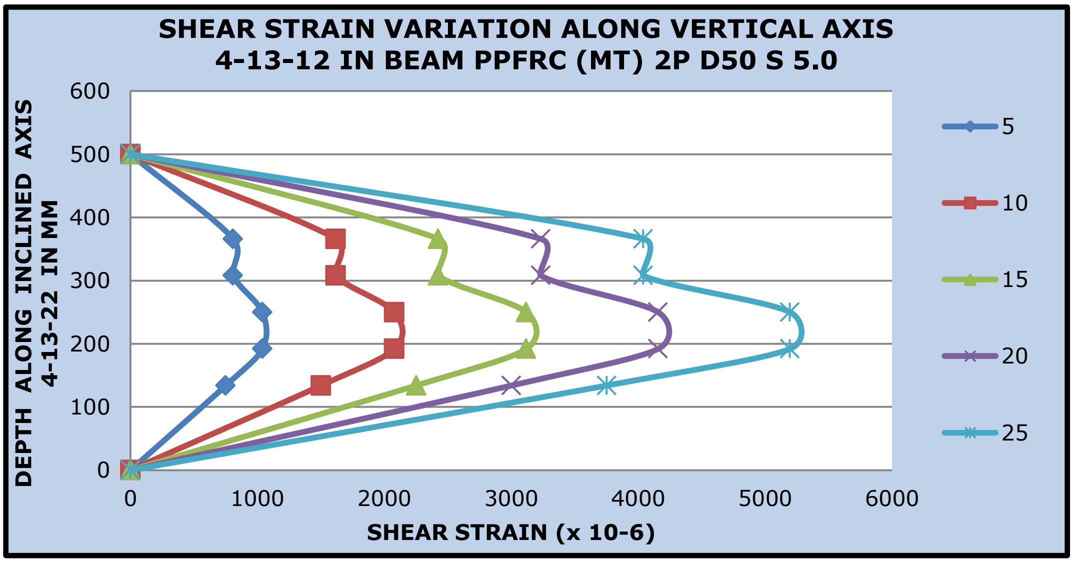
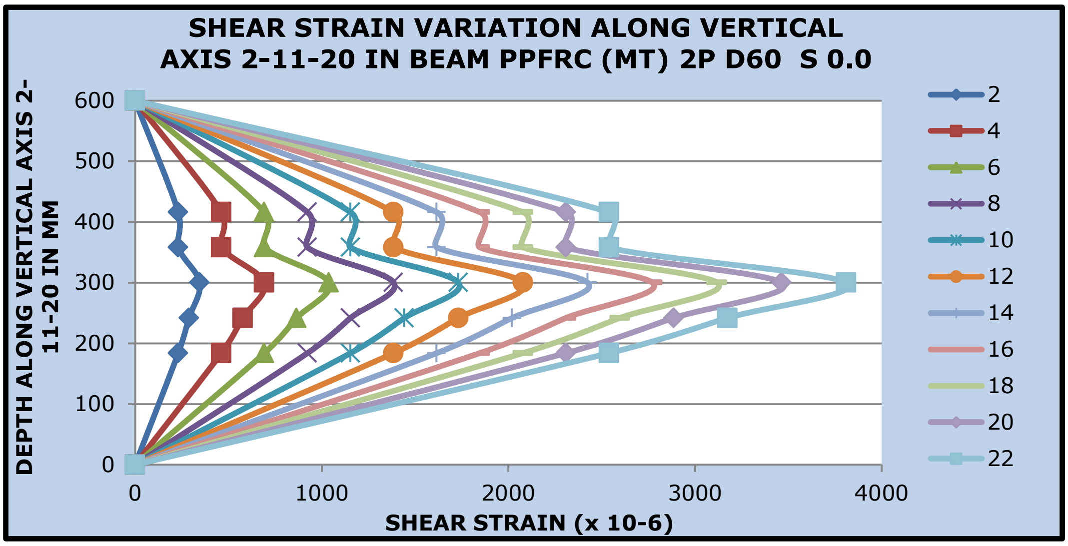
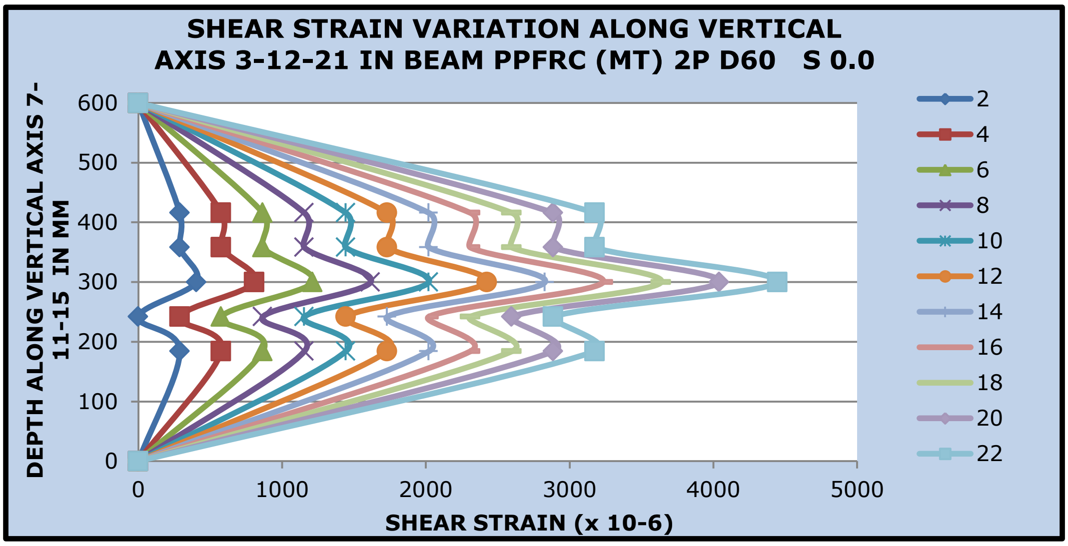


Fig. 4.7 Vertical Shear Strain Graphs Of PPFRC (MT) 2P D50 S 5.0





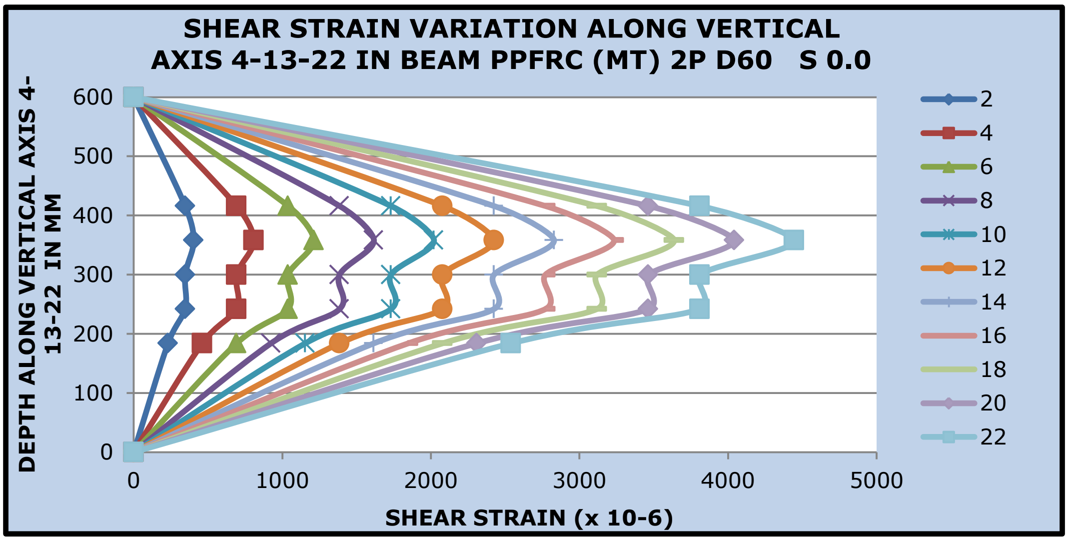


Fig. 4.8 Vertical Shear Strain Graphs Of PPFRC (MT) 2P D60 S 0.0

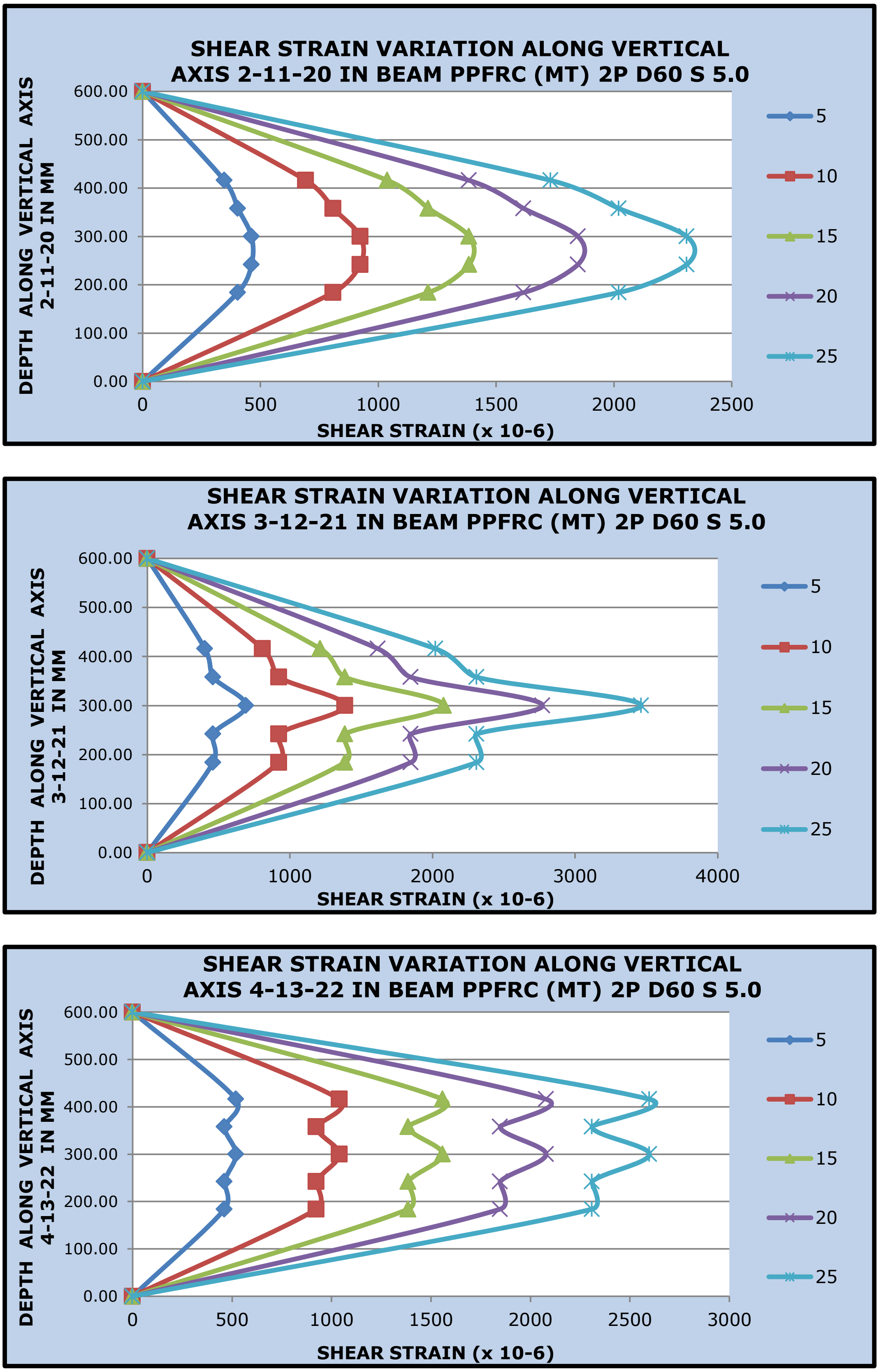
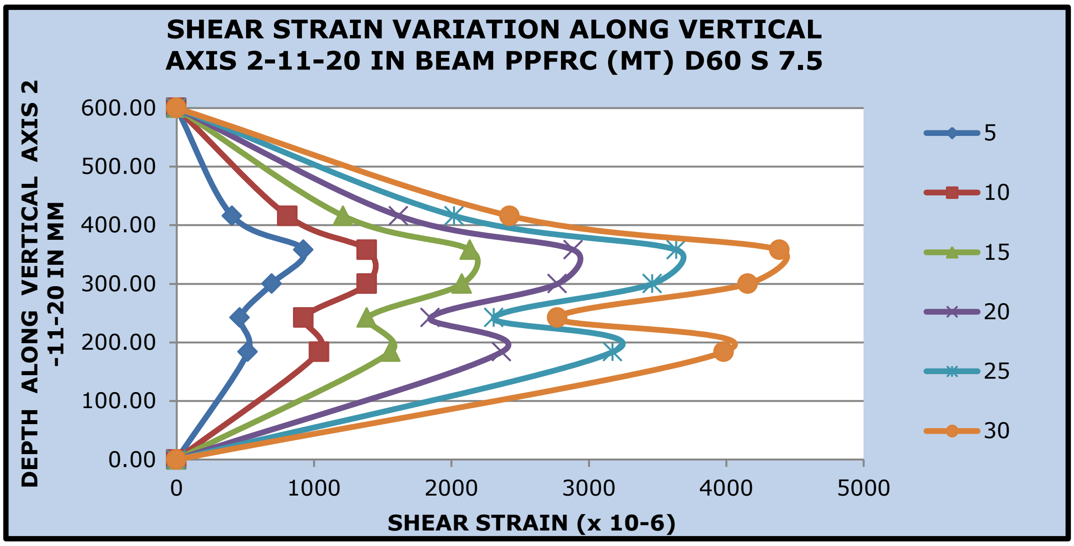
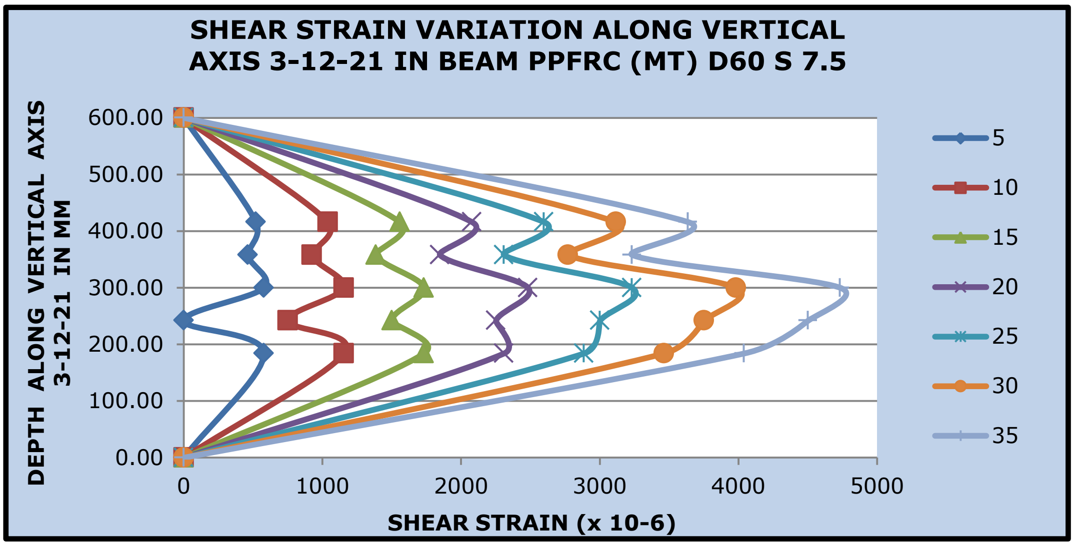


Fig. 4.9 Vertical Shear Strain Graphs Of PPFRC (MT) 2P D60 S 5.0





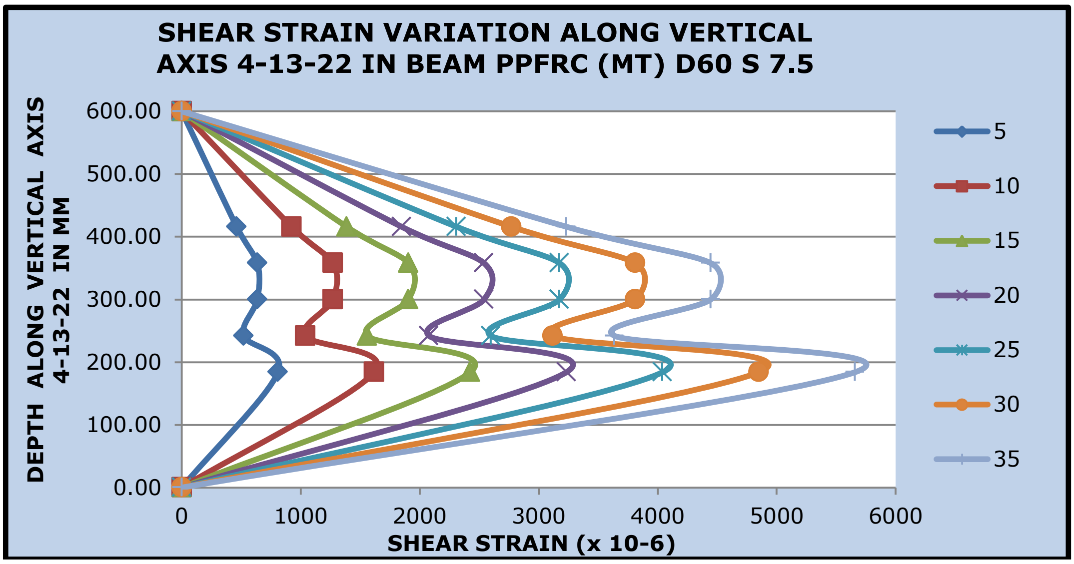


Fig. 4.10 Vertical Shear Strain Graphs Of PPFRC (MT) 2P D60 S 7.5

TABLE 4.4.2 Shear Strain Variation Along Vertical Axis For PPFRC (FT) 1P D50 S 0.0

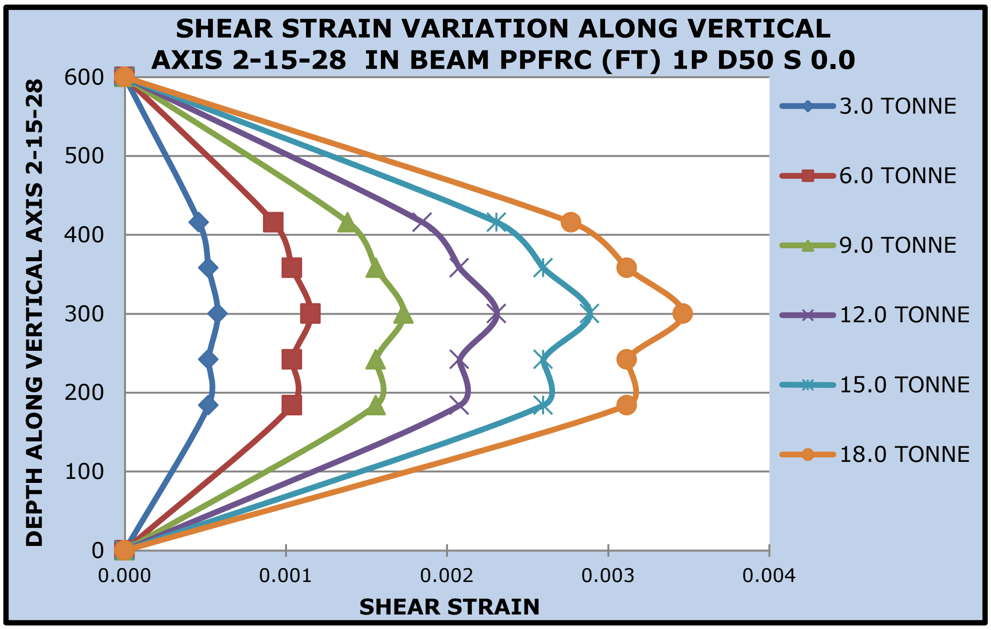
SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 2-15-28 IN D 50 S 0.0								
DEPTH	**LOAD**	**0.0 T**	**3.0 T**	**6.0 T**	**9.0 T**	**12.0 T**	**14.0 T**	**15.2 T**
600		0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
416	**1-3-15**	0.00000	0.00046	0.00092	0.00139	0.00185	0.00231	0.00277
358	**2-14-16**	0.00000	0.00052	0.00104	0.00156	0.00208	0.00260	0.00312
300	**15**	0.00000	0.00058	0.00115	0.00173	0.00231	0.00289	0.00346
242	**14-16-28**	0.00000	0.00052	0.00104	0.00156	0.00208	0.00260	0.00312
184	**15-27-29**	0.00000	0.00052	0.00104	0.00156	0.00208	0.00260	0.00312
0		0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

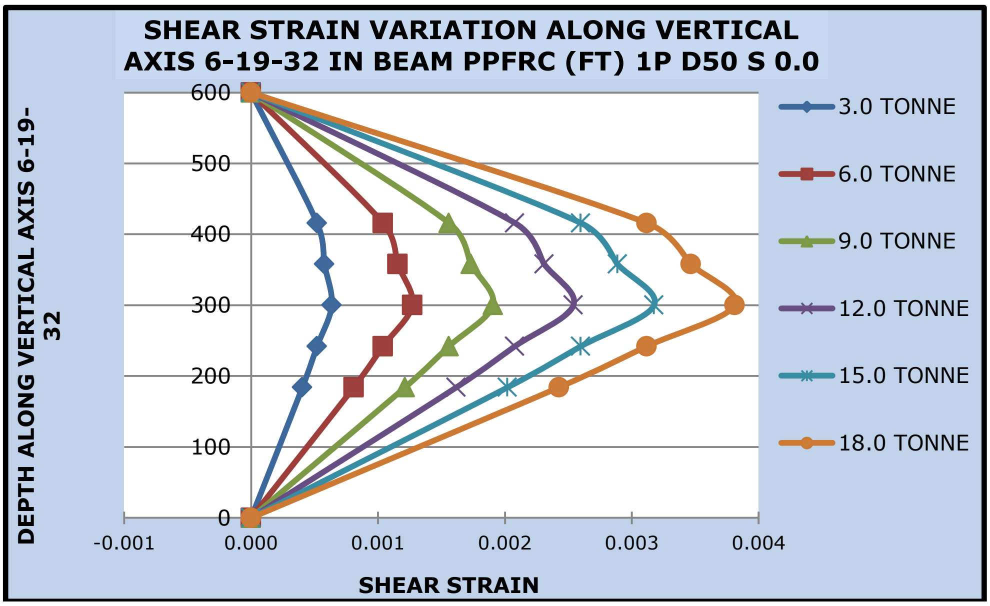
SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 3-16-29 IN D 50 S 0.0								
DEPTH	**LOAD**	**0.0 T**	**3.0 T**	**6.0 T**	**9.0 T**	**12.0 T**	**14.0 T**	**15.2 T**
600		0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
416	**2-4-16**	0.00000	0.00058	0.00115	0.00173	0.00231	0.00289	0.00346
358	**3-15-17**	0.00000	0.00052	0.00104	0.00156	0.00208	0.00260	0.00312
300	**16**	0.00000	0.00064	0.00127	0.00191	0.00254	0.00318	0.00381
242	**15-17-29**	0.00000	0.00046	0.00092	0.00139	0.00185	0.00231	0.00277
184	**16-28-30**	0.00000	0.00052	0.00104	0.00156	0.00208	0.00260	0.00312
0		0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

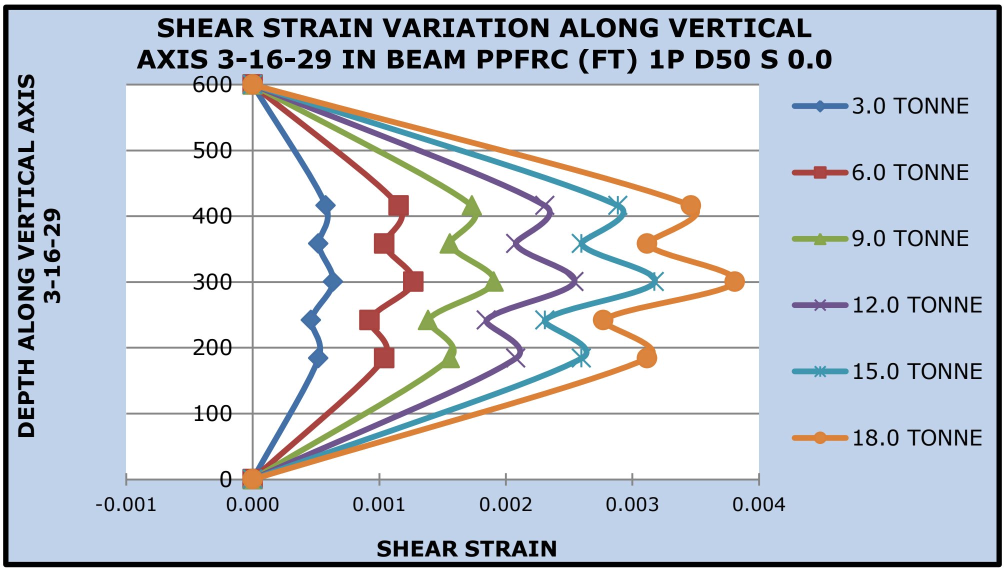
SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 4-17-30 IN D 50 S 0.0								
DEPTH	**LOAD**	**0.0 T**	**3.0 T**	**6.0 T**	**9.0 T**	**12.0 T**	**14.0 T**	**15.2 T**
600		0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
416	**3-5-17**	0.00000	0.00058	0.00115	0.00173	0.00231	0.00289	0.00346
358	**4-16-18**	0.00000	0.00046	0.00092	0.00139	0.00185	0.00231	0.00277
300	**17**	0.00000	0.00069	0.00139	0.00208	0.00277	0.00346	0.00416
242	**16-18-30**	0.00000	0.00052	0.00104	0.00156	0.00208	0.00260	0.00312
184	**17-29-31**	0.00000	0.00052	0.00104	0.00156	0.00208	0.00260	0.00312
0		0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

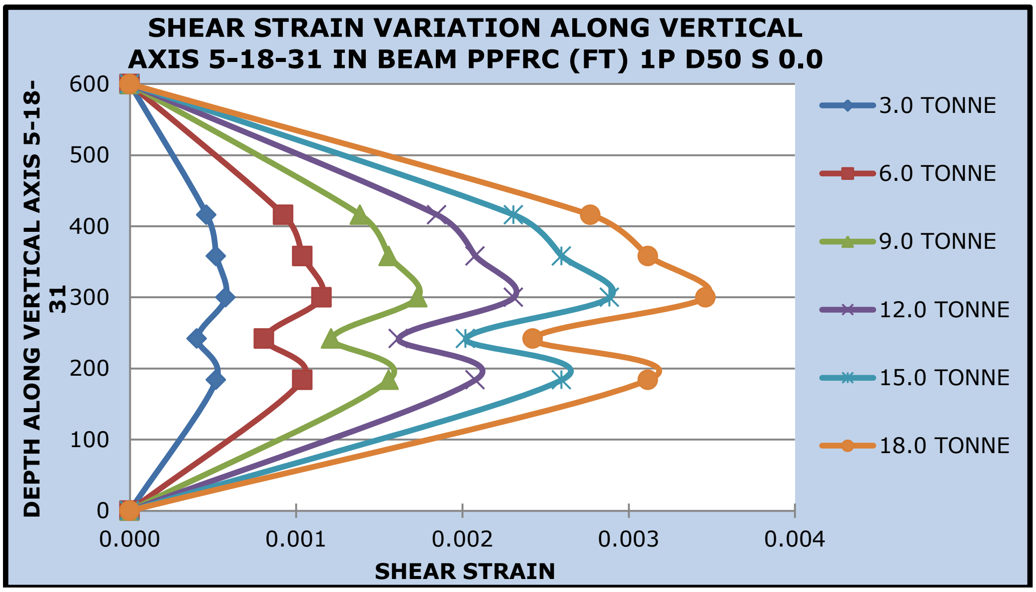
SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 5-18-31 IN D 50 S 0.0								
DEPTH	**LOAD**	**0.0 T**	**3.0 T**	**6.0 T**	**9.0 T**	**12.0 T**	**14.0 T**	**15.2 T**
600		0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
416	**4-6-18**	0.00000	0.00046	0.00092	0.00139	0.00185	0.00231	0.00277
358	**5-17-19**	0.00000	0.00052	0.00104	0.00156	0.00208	0.00260	0.00312
300	**18**	0.00000	0.00058	0.00115	0.00173	0.00231	0.00289	0.00346
242	**17-19-31**	0.00000	0.00040	0.00081	0.00121	0.00162	0.00202	0.00242
184	**18-30-32**	0.00000	0.00052	0.00104	0.00156	0.00208	0.00260	0.00312
0		0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 6-19-32 IN D 50 S 0.0								
DEPTH	**LOAD**	**0.0 T**	**3.0 T**	**6.0 T**	**9.0 T**	**12.0 T**	**14.0 T**	**15.2 T**
600		0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
416	**5-7-19**	0.00000	0.00052	0.00104	0.00156	0.00208	0.00260	0.00312
358	**6-18-20**	0.00000	0.00058	0.00115	0.00173	0.00231	0.00289	0.00346
300	**19**	0.00000	0.00064	0.00127	0.00191	0.00254	0.00318	0.00381
242	**18-20-32**	0.00000	0.00052	0.00104	0.00156	0.00208	0.00260	0.00312
184	**19-31-33**	0.00000	0.00040	0.00081	0.00121	0.00162	0.00202	0.00242
0		0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000


SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 2-15-28 IN BEAM PPFRC (FT) 1P D50 S 0.0
DEPTH ALONG VERTICAL AXIS 2-15-28
600
500
400
300
200
100
0
0.000
0.001
0.002
0.003
0.004
SHEAR STRAIN
3.0 TONNE
6.0 TONNE
9.0 TONNE
12.0 TONNE
15.0 TONNE
18.0 TONNE


SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 6-19-32 IN BEAM PPFRC (FT) 1P D50 S 0.0
DEPTH ALONG VERTICAL AXIS 6-19-32
600
500
400
300
200
100
0
-0.001
0.000
0.001
0.002
0.003
0.004
SHEAR STRAIN
3.0 TONNE
6.0 TONNE
9.0 TONNE
12.0 TONNE
15.0 TONNE
18.0 TONNE


SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 3-16-29 IN BEAM PPFRC (FT) 1P D50 S 0.0
DEPTH ALONG VERTICAL AXIS 3-16-29
600
500
400
300
200
100
0
-0.001
0.000
0.001
0.002
0.003
0.004
SHEAR STRAIN
3.0 TONNE
6.0 TONNE
9.0 TONNE
12.0 TONNE
15.0 TONNE
18.0 TONNE



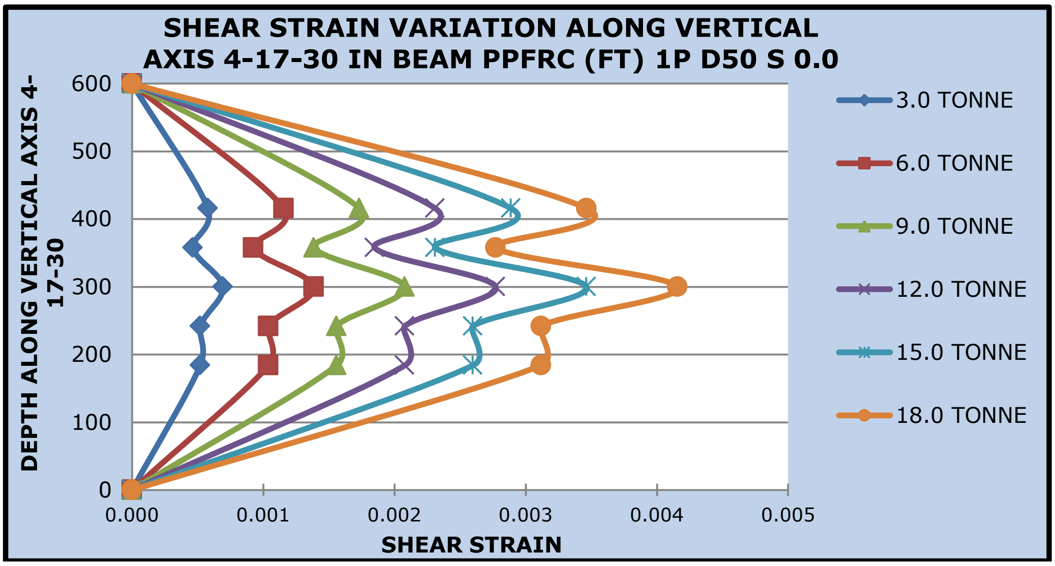
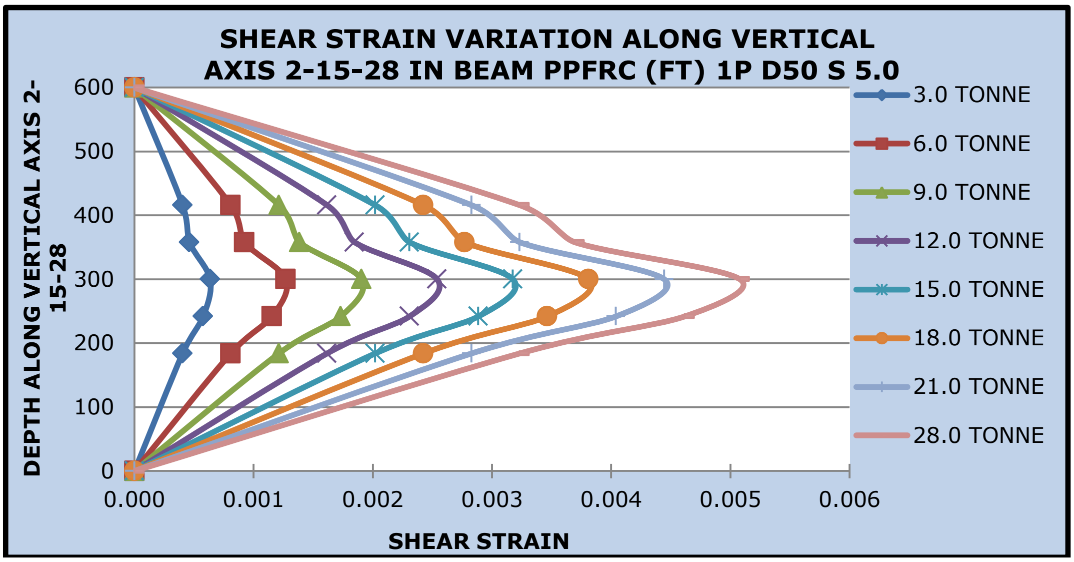
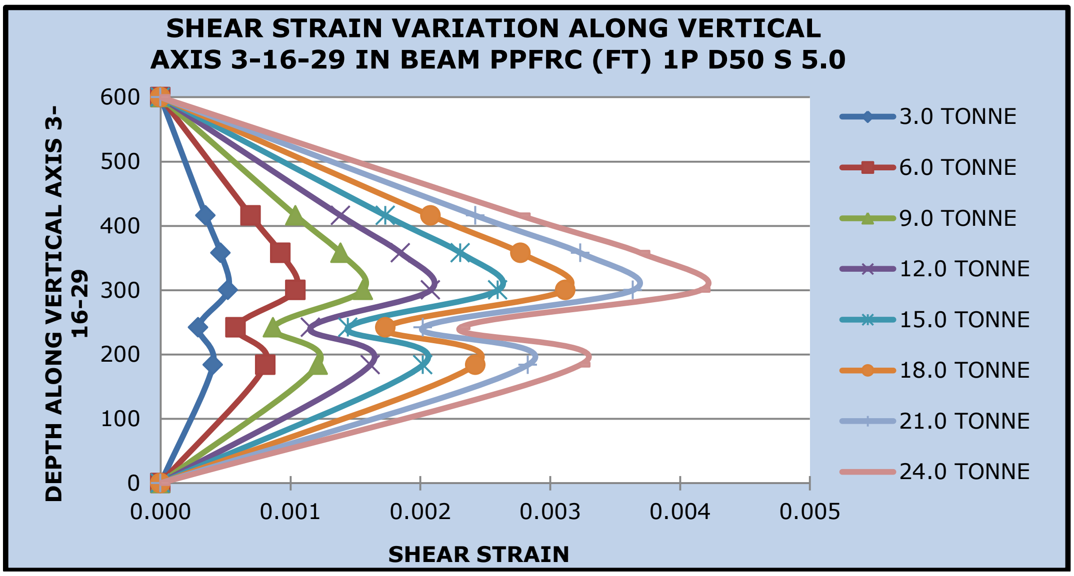
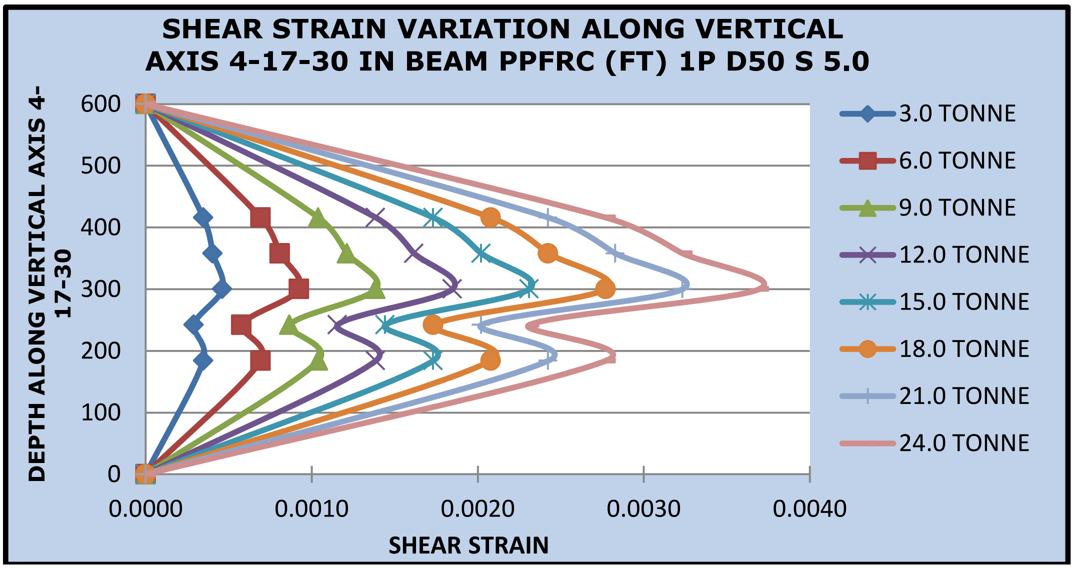
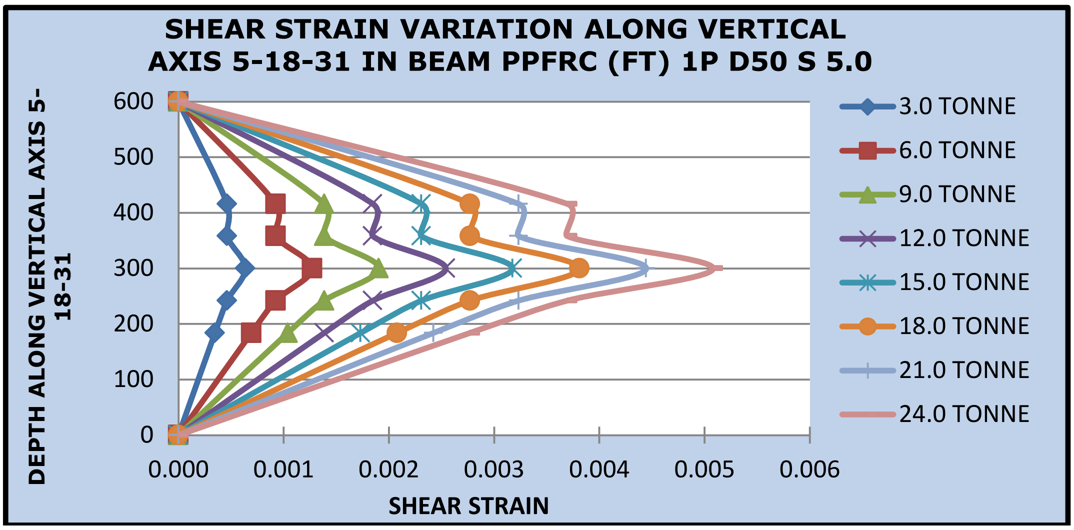


Fig. 4.11 Vertical Shear Strain Graphs Of PPFRC (FT) 1P D50 S 0.0


SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 2-15-28 IN BEAM PPFRC (FT) 1P D50 S 5.0
DEPTH ALONG VERTICAL AXIS 2-15-28
SHEAR STRAIN
0
100
200
300
400
500
600
0.000
0.001
0.002
0.003
0.004
0.005
0.006
3.0 TONNE
6.0 TONNE
9.0 TONNE
12.0 TONNE
15.0 TONNE
18.0 TONNE
21.0 TONNE
28.0 TONNE


SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 3-16-29 IN BEAM PPFRC (FT) 1P D50 S 5.0
DEPTH ALONG VERTICAL AXIS 3-16-29
SHEAR STRAIN
0
100
200
300
400
500
600
0.000
0.001
0.002
0.003
0.004
0.005
3.0 TONNE
6.0 TONNE
9.0 TONNE
12.0 TONNE
15.0 TONNE
18.0 TONNE
21.0 TONNE
24.0 TONNE


SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 4-17-30 IN BEAM PPFRC (FT) 1P D50 S 5.0
DEPTH ALONG VERTICAL AXIS 4-17-30
SHEAR STRAIN
0
100
200
300
400
500
600
0.0000
0.0010
0.0020
0.0030
0.0040
3.0 TONNE
6.0 TONNE
9.0 TONNE
12.0 TONNE
15.0 TONNE
18.0 TONNE
21.0 TONNE
24.0 TONNE



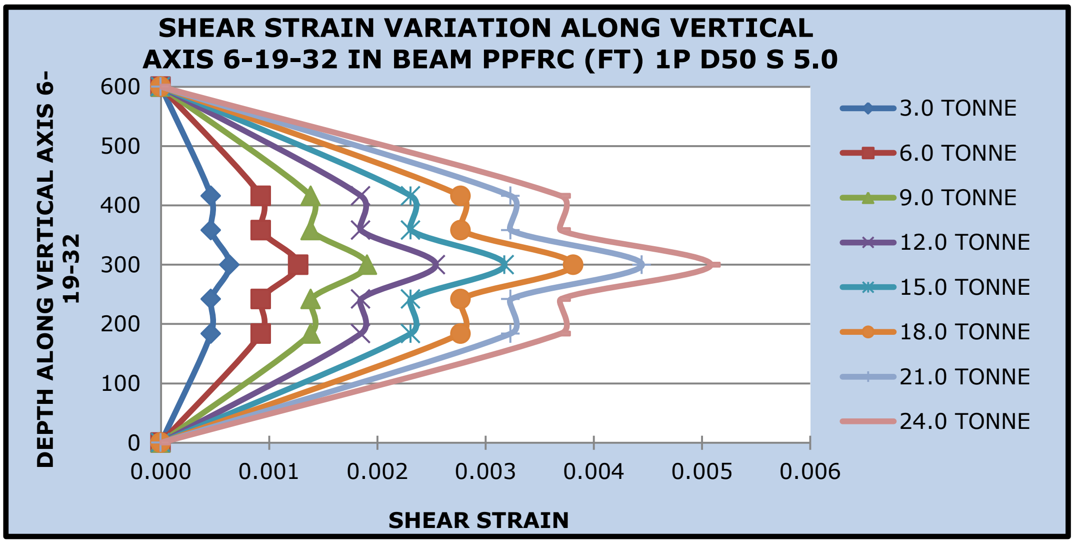
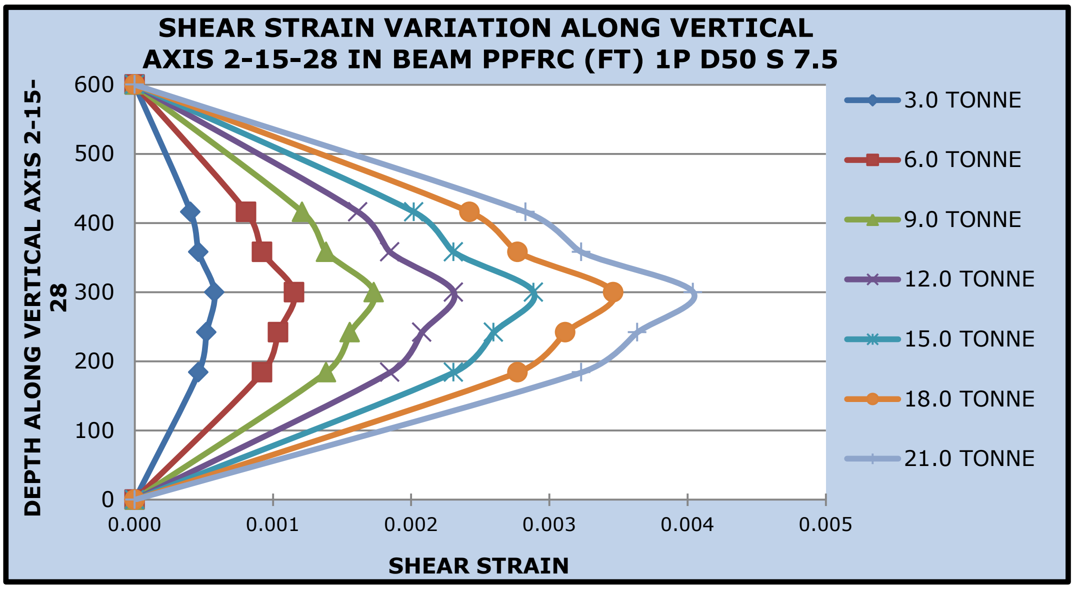
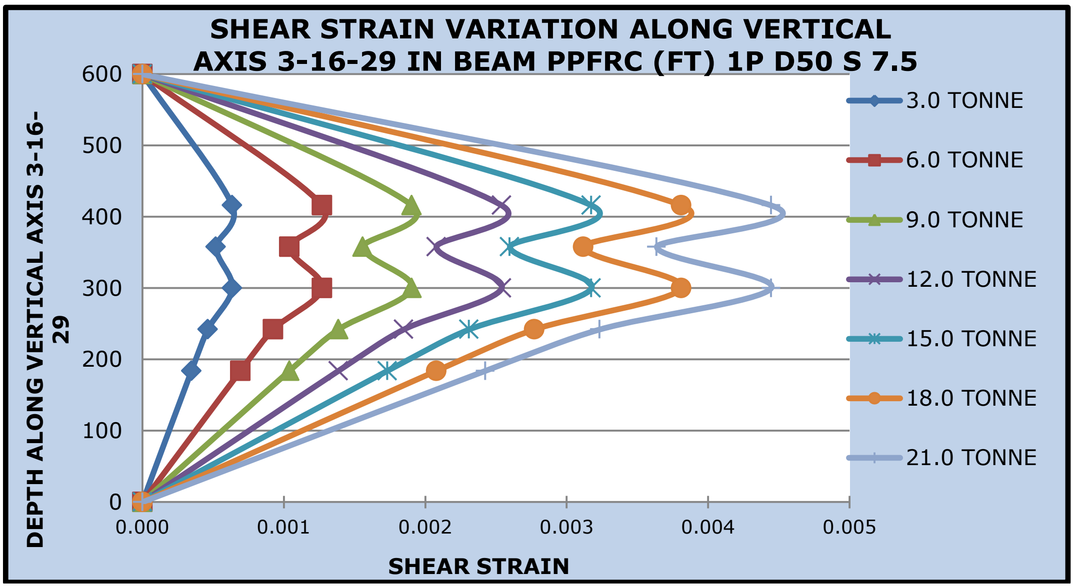
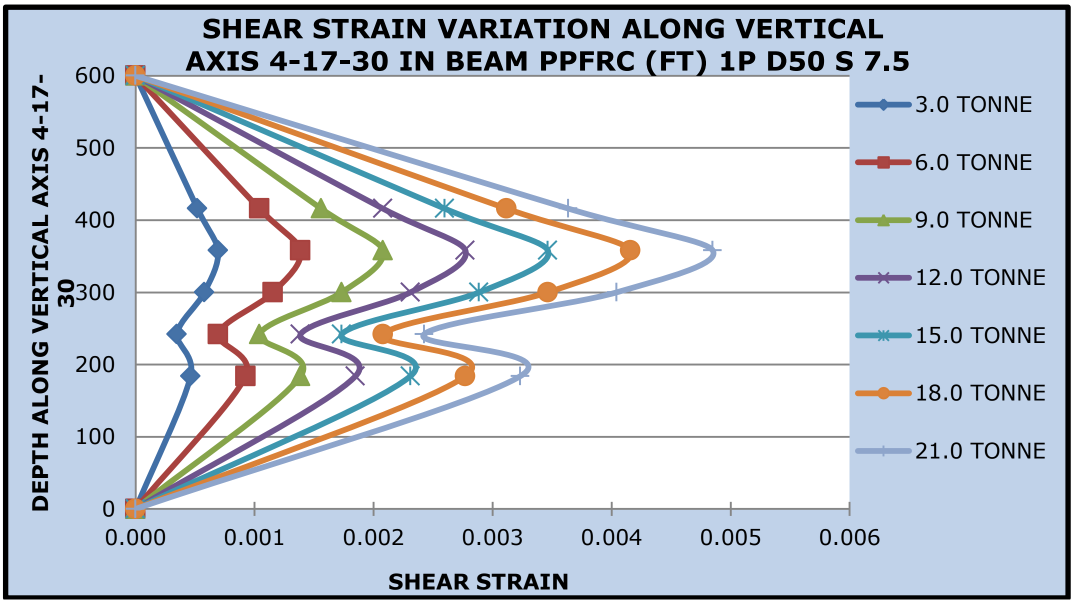
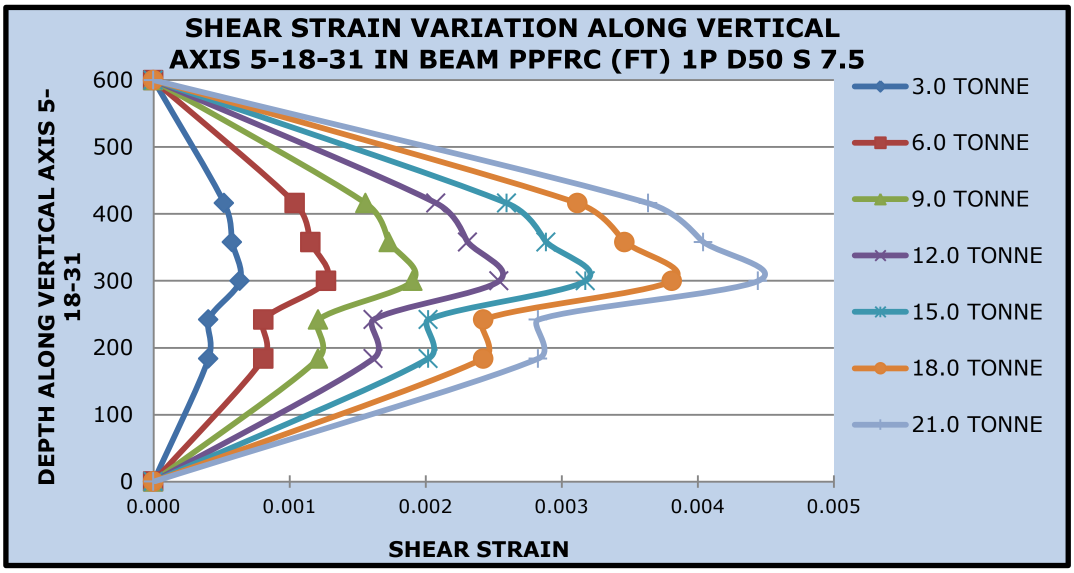


Fig. 4.12 Vertical Shear Strain Graphs Of PPFRC (FT) 1P D50 S 5.0


SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 2-15-28 IN BEAM PPFRC (FT) 1P D50 S 7.5
DEPTH ALONG VERTICAL AXIS 2-15-28
SHEAR STRAIN
600
500
400
300
200
100
0
0.000
0.001
0.002
0.003
0.004
0.005
3.0 TONNE
6.0 TONNE
9.0 TONNE
12.0 TONNE
15.0 TONNE
18.0 TONNE
21.0 TONNE


SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 3-16-29 IN BEAM PPFRC (FT) 1P D50 S 7.5
DEPTH ALONG VERTICAL AXIS 3-16-29
SHEAR STRAIN
600
500
400
300
200
100
0
0.000
0.001
0.002
0.003
0.004
0.005
3.0 TONNE
6.0 TONNE
9.0 TONNE
12.0 TONNE
15.0 TONNE
18.0 TONNE
21.0 TONNE


SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 4-17-30 IN BEAM PPFRC (FT) 1P D50 S 7.5
DEPTH ALONG VERTICAL AXIS 4-17-30
SHEAR STRAIN
600
500
400
300
200
100
0
0.000
0.001
0.002
0.003
0.004
0.005
0.006
3.0 TONNE
6.0 TONNE
9.0 TONNE
12.0 TONNE
15.0 TONNE
18.0 TONNE
21.0 TONNE



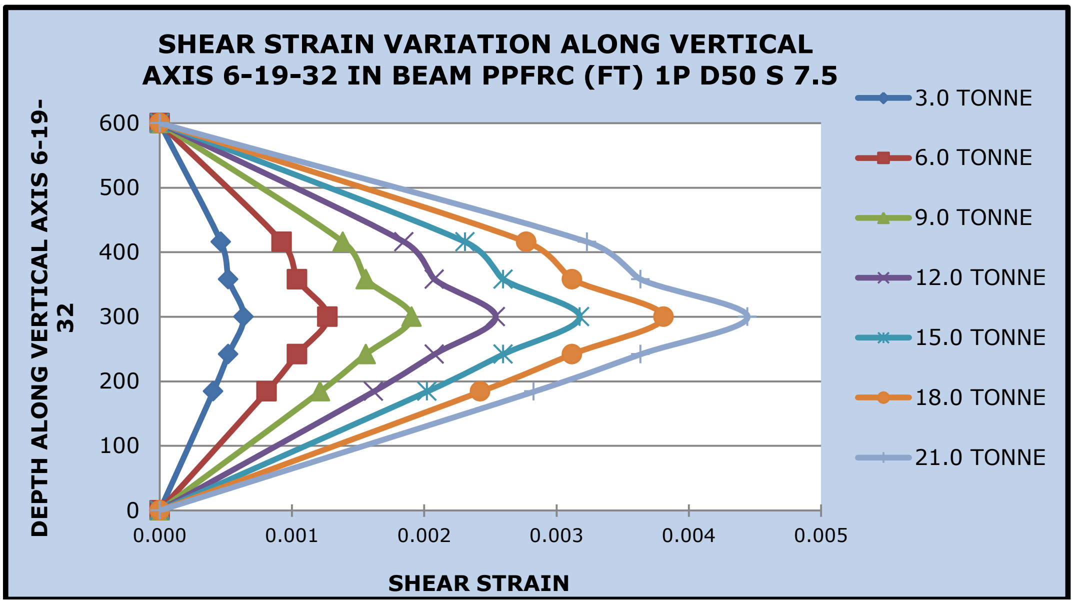
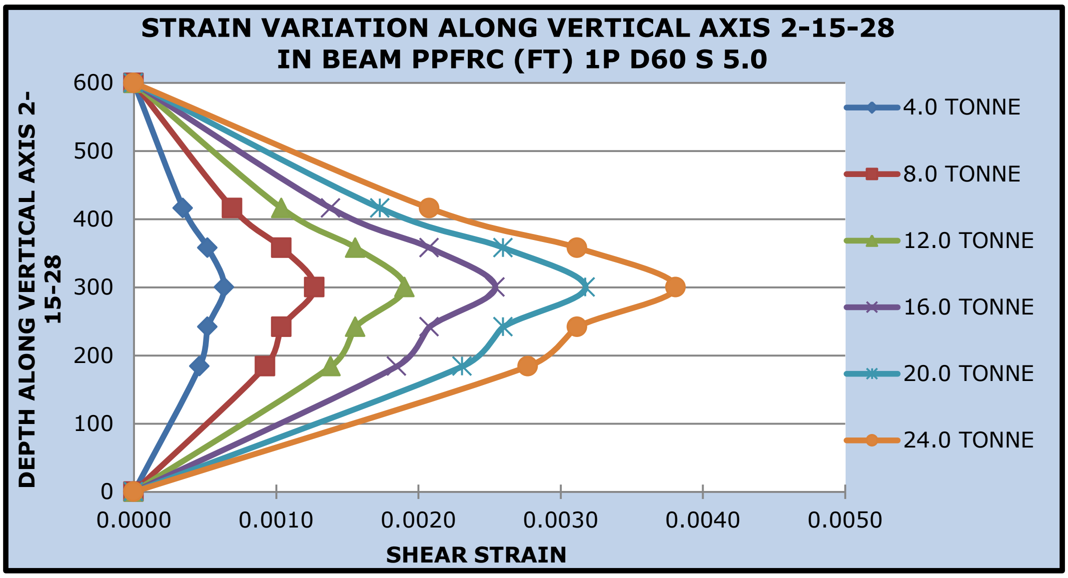
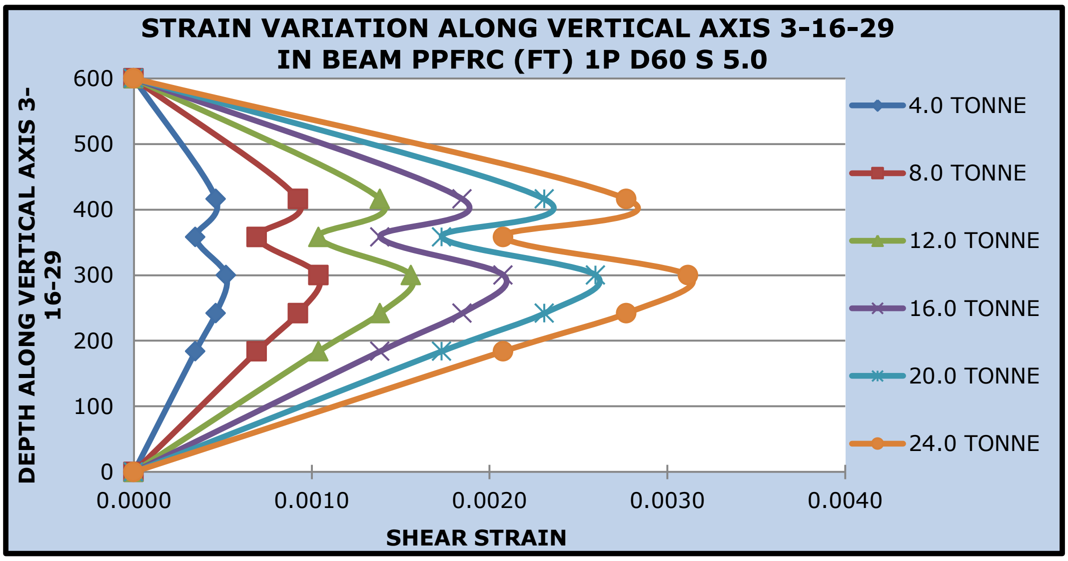
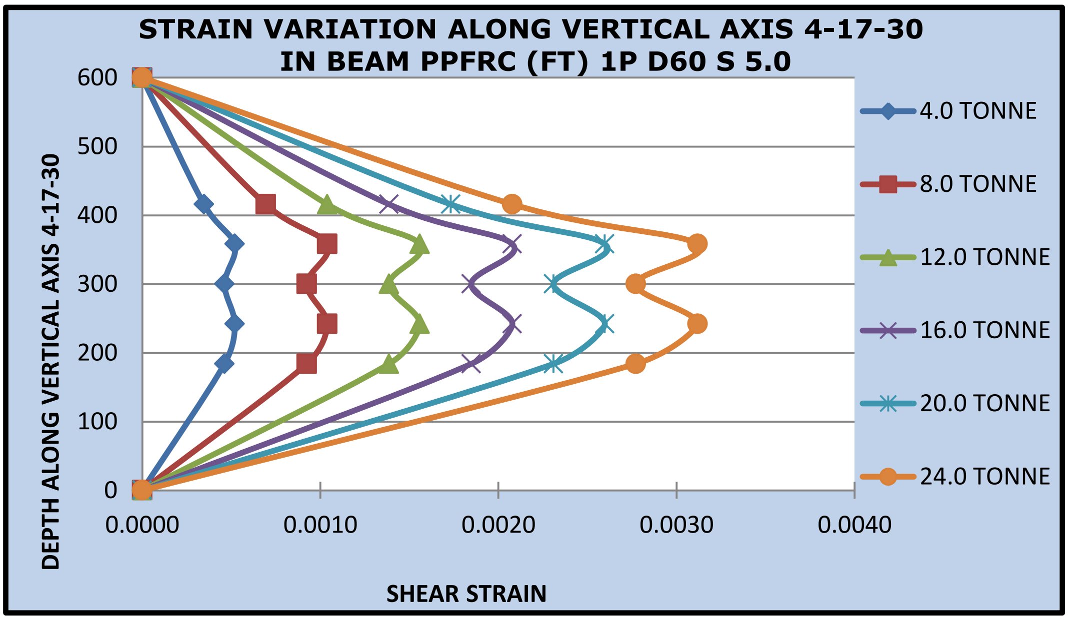
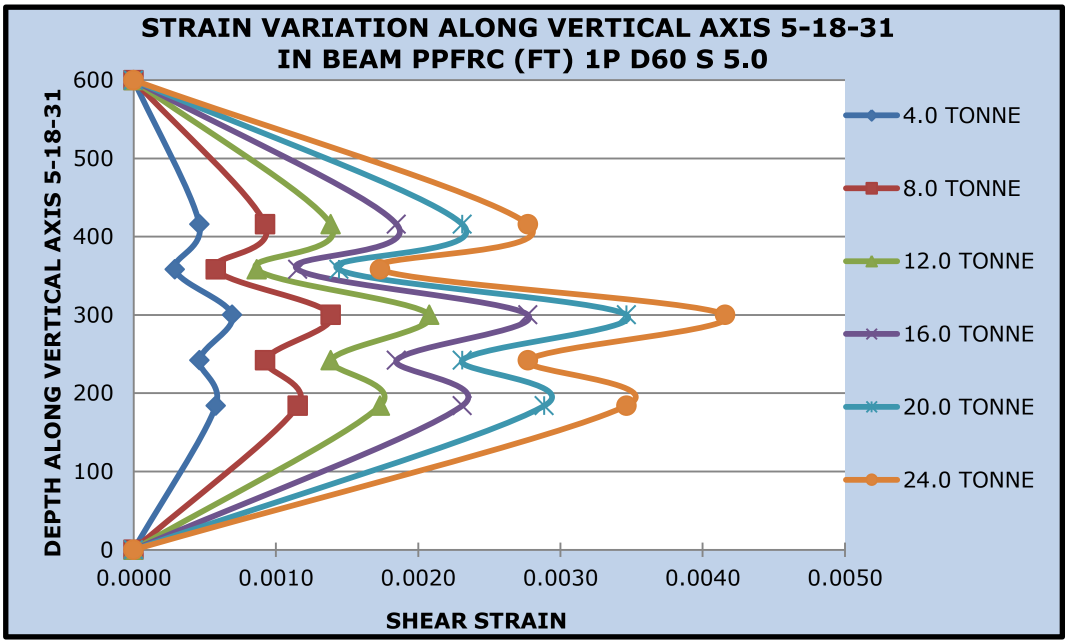


Fig. 4.13 Vertical Shear Strain Graphs Of PPFRC (FT) 1P D50 S 7.5


STRAIN VARIATION ALONG VERTICAL AXIS 2-15-28
IN BEAM PPFRC (FT) 1P D60 S 5.0
DEPTH ALONG VERTICAL AXIS 2-15-28
SHEAR STRAIN
0
100
200
300
400
500
600
0.0000
0.0010
0.0020
0.0030
0.0040
0.0050
4.0 TONNE
8.0 TONNE
12.0 TONNE
16.0 TONNE
20.0 TONNE
24.0 TONNE


STRAIN VARIATION ALONG VERTICAL AXIS 3-16-29
IN BEAM PPFRC (FT) 1P D60 S 5.0
DEPTH ALONG VERTICAL AXIS 3-16-29
SHEAR STRAIN
0
100
200
300
400
500
600
0.0000
0.0010
0.0020
0.0030
0.0040
4.0 TONNE
8.0 TONNE
12.0 TONNE
16.0 TONNE
20.0 TONNE
24.0 TONNE


STRAIN VARIATION ALONG VERTICAL AXIS 4-17-30
IN BEAM PPFRC (FT) 1P D60 S 5.0
DEPTH ALONG VERTICAL AXIS 4-17-30
SHEAR STRAIN
0
100
200
300
400
500
600
0.0000
0.0010
0.0020
0.0030
0.0040
4.0 TONNE
8.0 TONNE
12.0 TONNE
16.0 TONNE
20.0 TONNE
24.0 TONNE



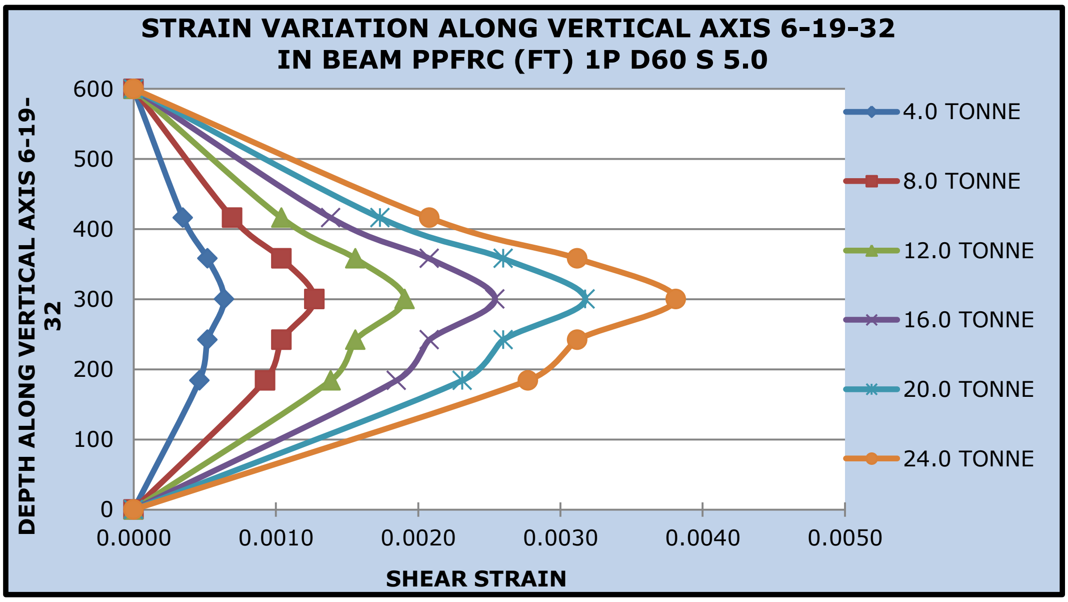
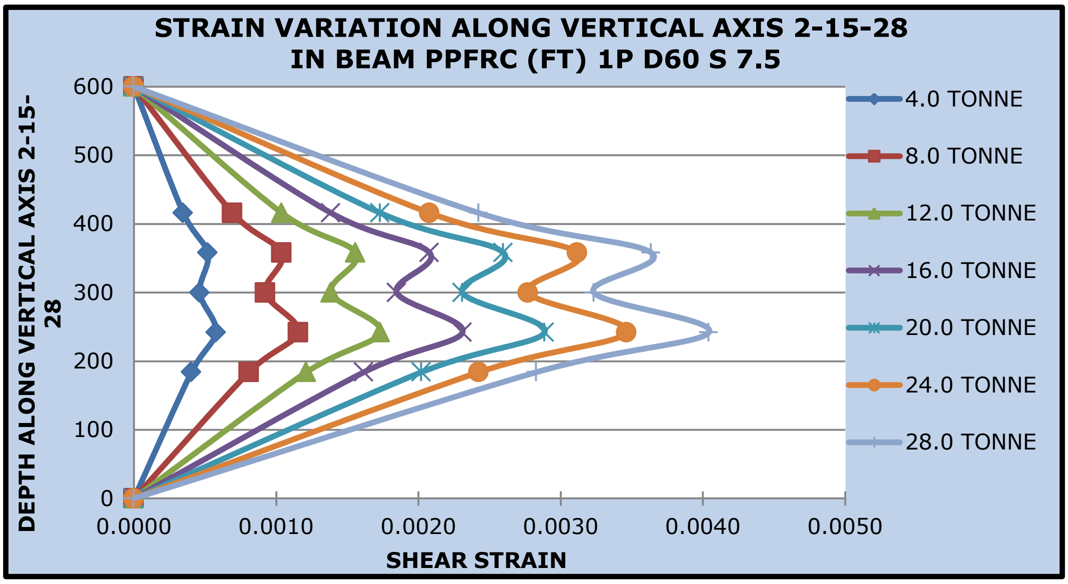
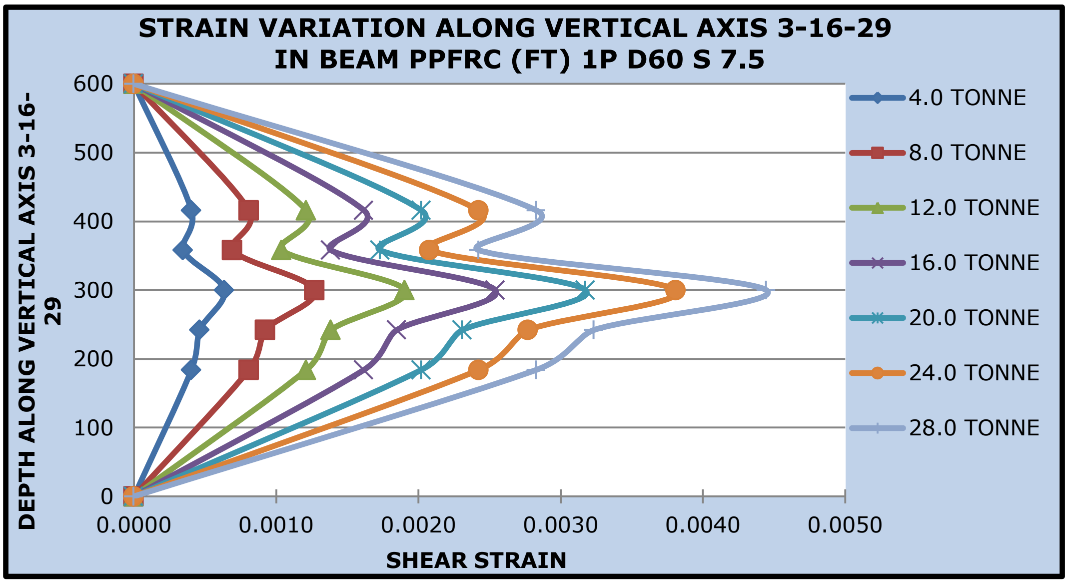
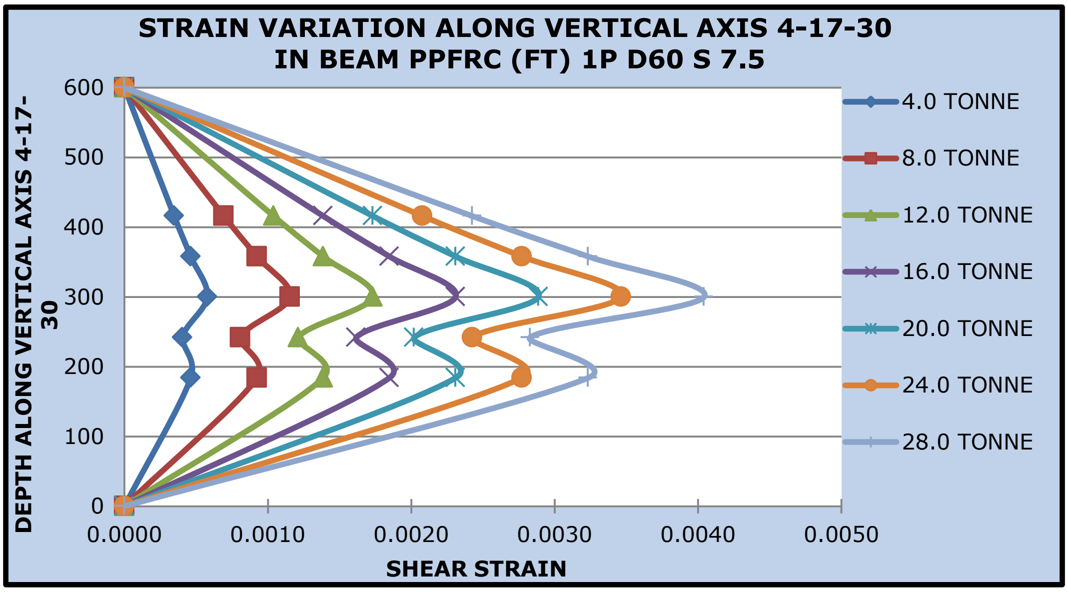
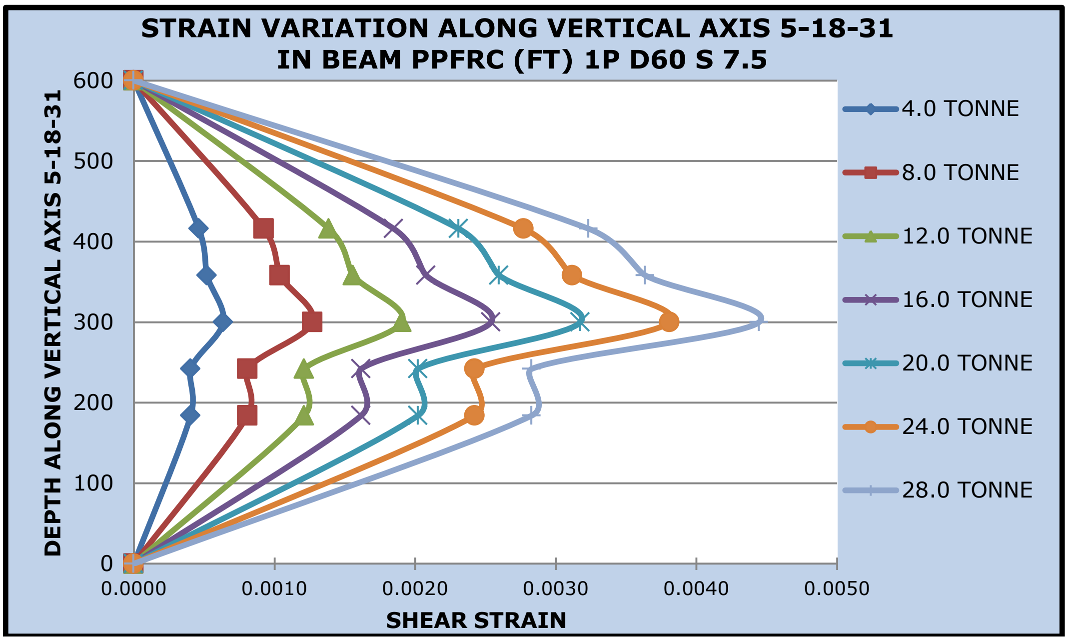


Fig. 4.14 Vertical Shear Strain Graphs Of PPFRC (FT) 1P D60 S 5.0


STRAIN VARIATION ALONG VERTICAL AXIS 2-15-28
IN BEAM PPFRC (FT) 1P D60 S 7.5
DEPTH ALONG VERTICAL AXIS 2-15-28
SHEAR STRAIN
0
100
200
300
400
500
600
0.0000
0.0010
0.0020
0.0030
0.0040
0.0050
4.0 TONNE
8.0 TONNE
12.0 TONNE
16.0 TONNE
20.0 TONNE
24.0 TONNE
28.0 TONNE


STRAIN VARIATION ALONG VERTICAL AXIS 3-16-29
IN BEAM PPFRC (FT) 1P D60 S 7.5
DEPTH ALONG VERTICAL AXIS 3-16-29
SHEAR STRAIN
0
100
200
300
400
500
600
0.0000
0.0010
0.0020
0.0030
0.0040
0.0050
4.0 TONNE
8.0 TONNE
12.0 TONNE
16.0 TONNE
20.0 TONNE
24.0 TONNE
28.0 TONNE


STRAIN VARIATION ALONG VERTICAL AXIS 4-17-30
IN BEAM PPFRC (FT) 1P D60 S 7.5
DEPTH ALONG VERTICAL AXIS 4-17-30
SHEAR STRAIN
0
100
200
300
400
500
600
0.0000
0.0010
0.0020
0.0030
0.0040
0.0050
4.0 TONNE
8.0 TONNE
12.0 TONNE
16.0 TONNE
20.0 TONNE
24.0 TONNE
28.0 TONNE



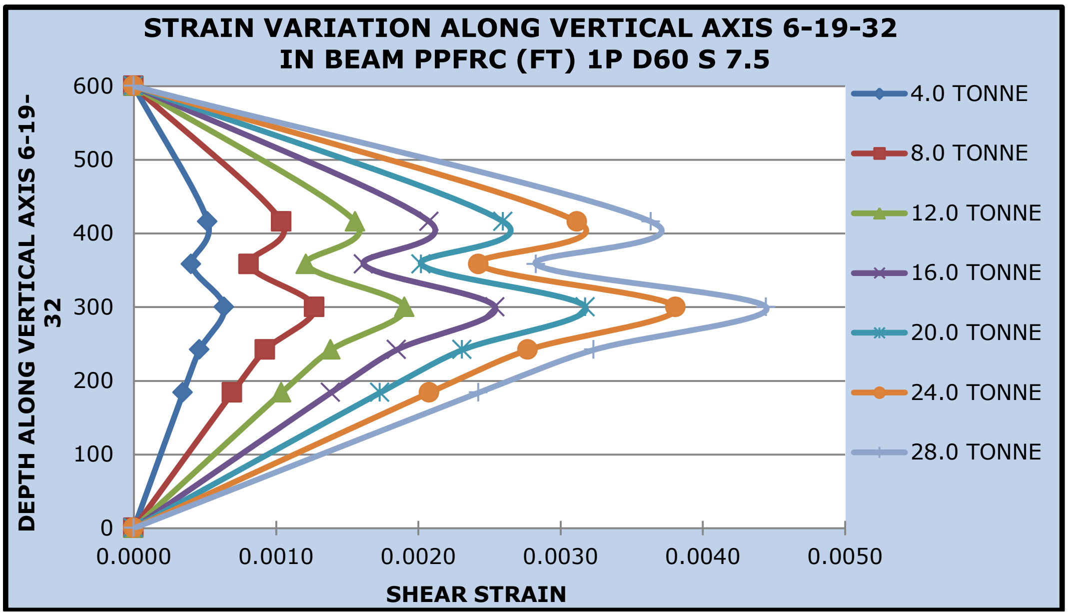
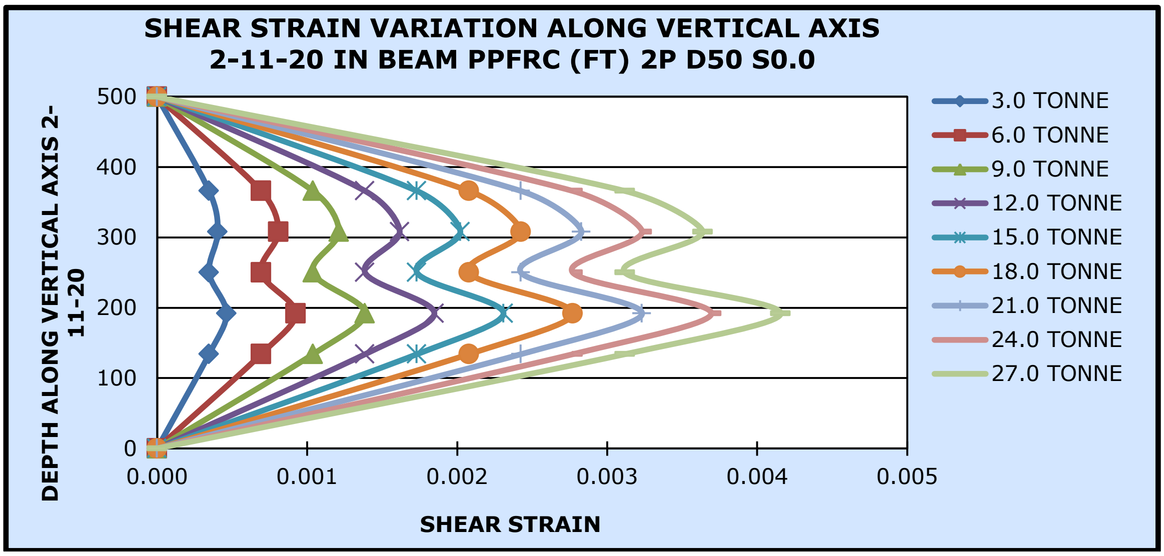
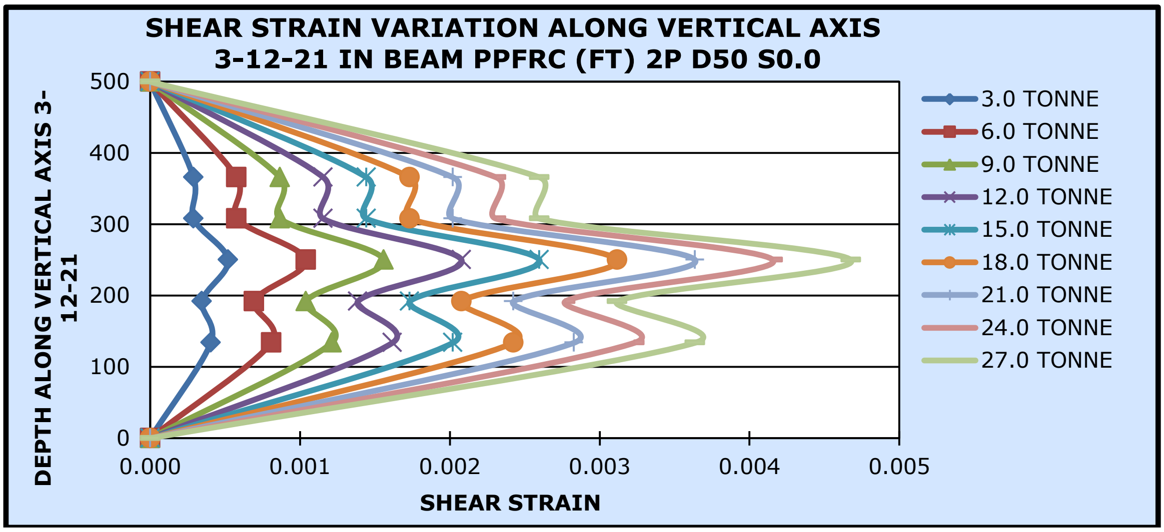


Fig. 4.15 Vertical Shear Strain Graphs Of PPFRC (FT) 1P D60 S 7.5





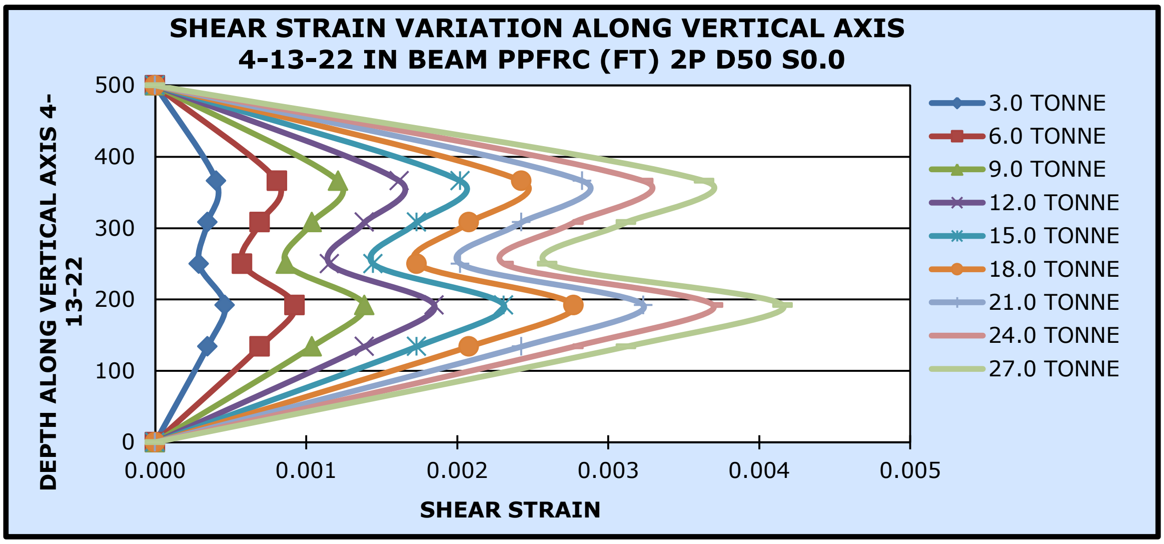
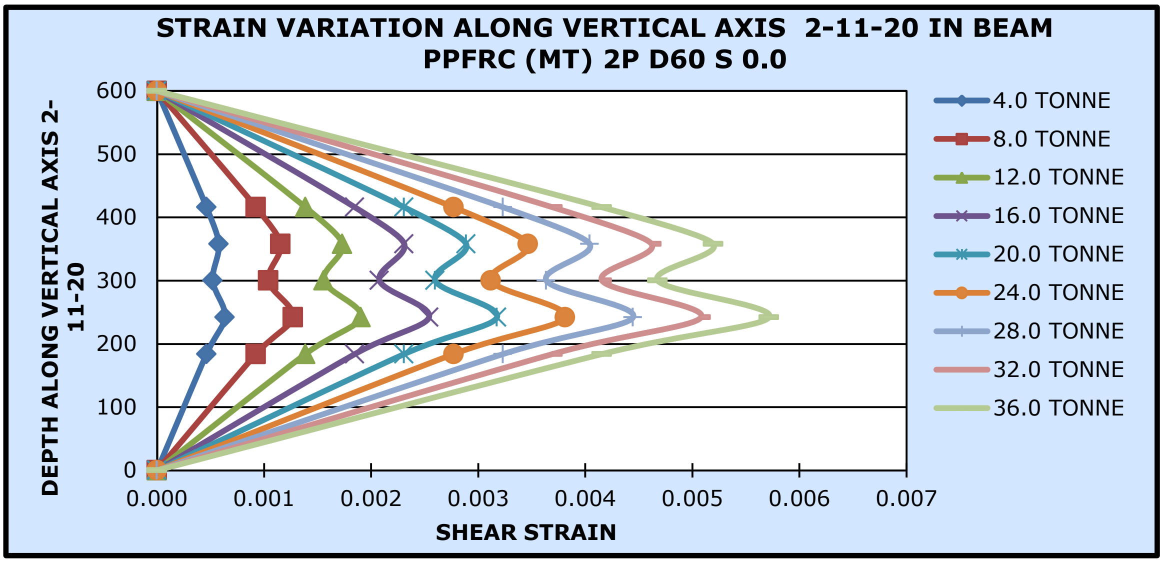
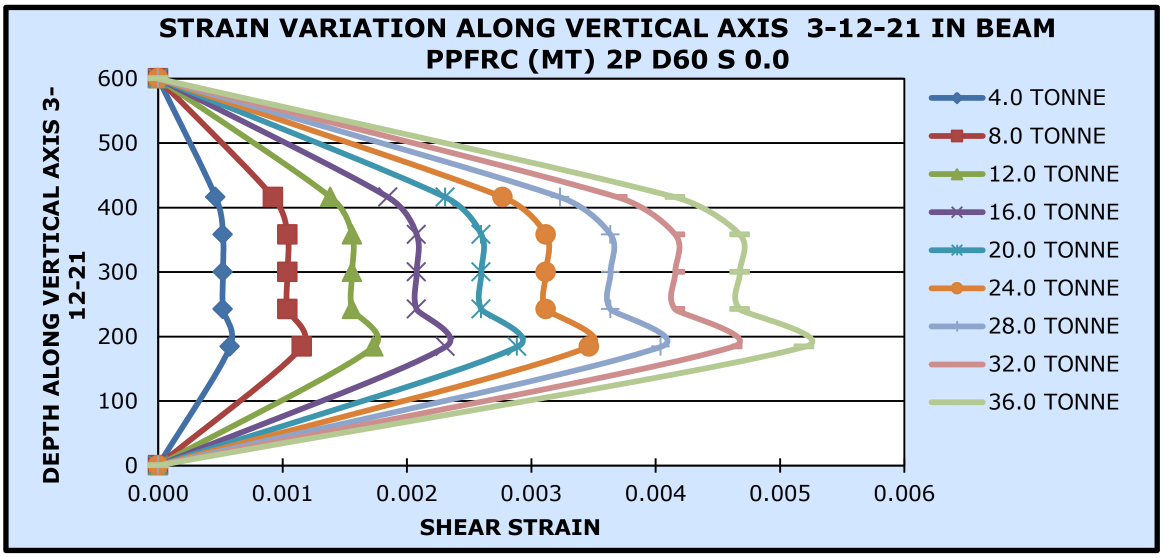


Fig. 4.16 Vertical Shear Strain Graphs Of PPFRC (FT) 2P D50 S 0.0





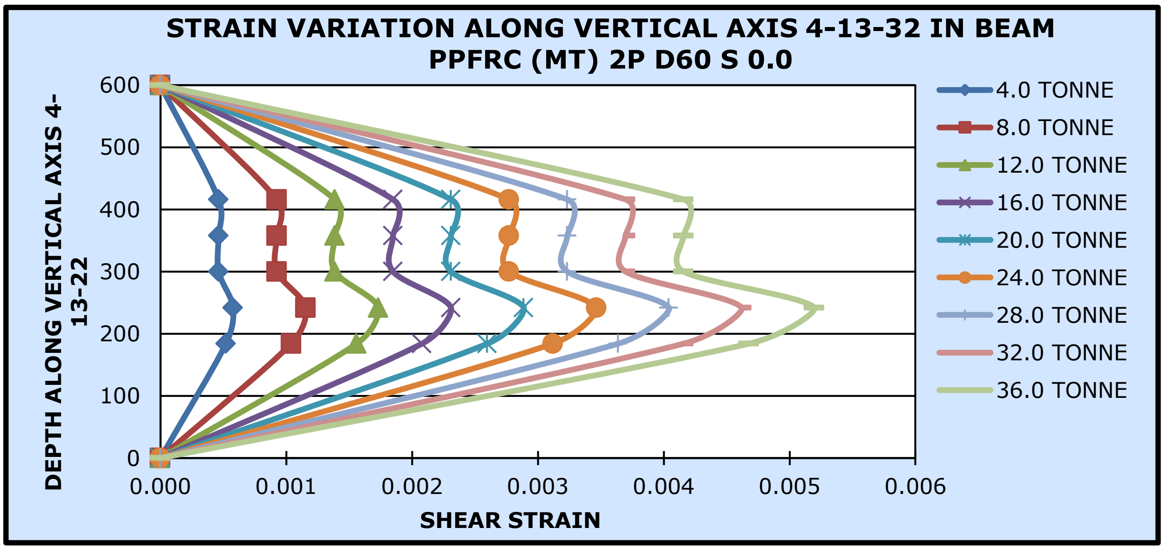
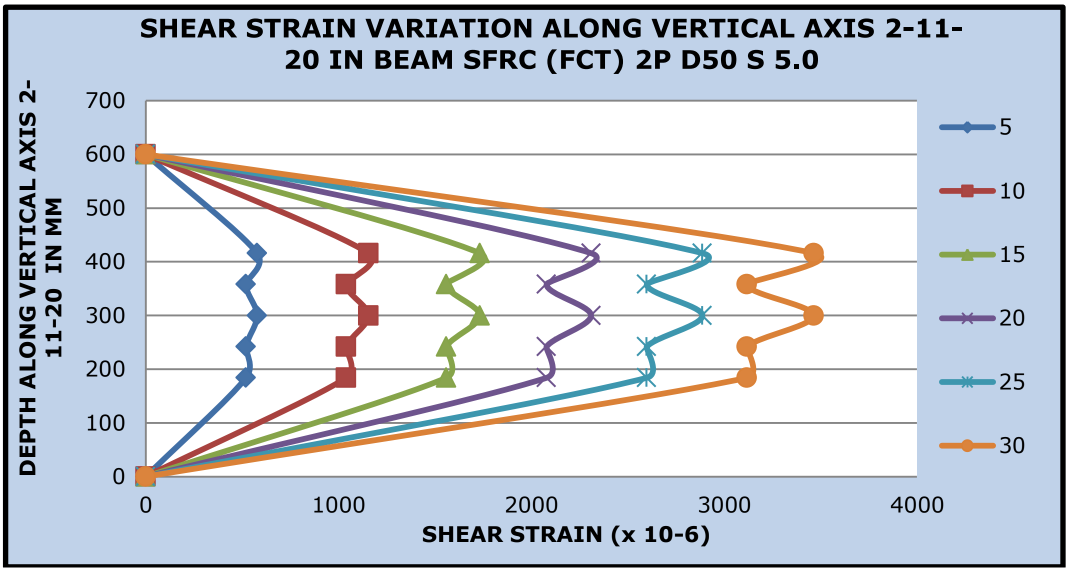
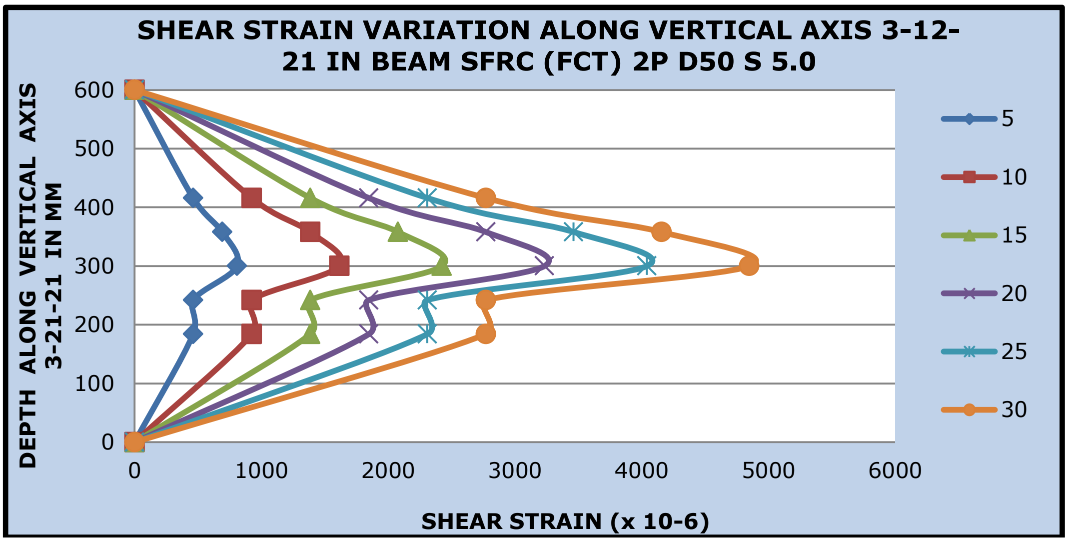


Fig. 4.17 Vertical Shear Strain Graphs Of PPFRC (FT) 2P D60 S 0.0





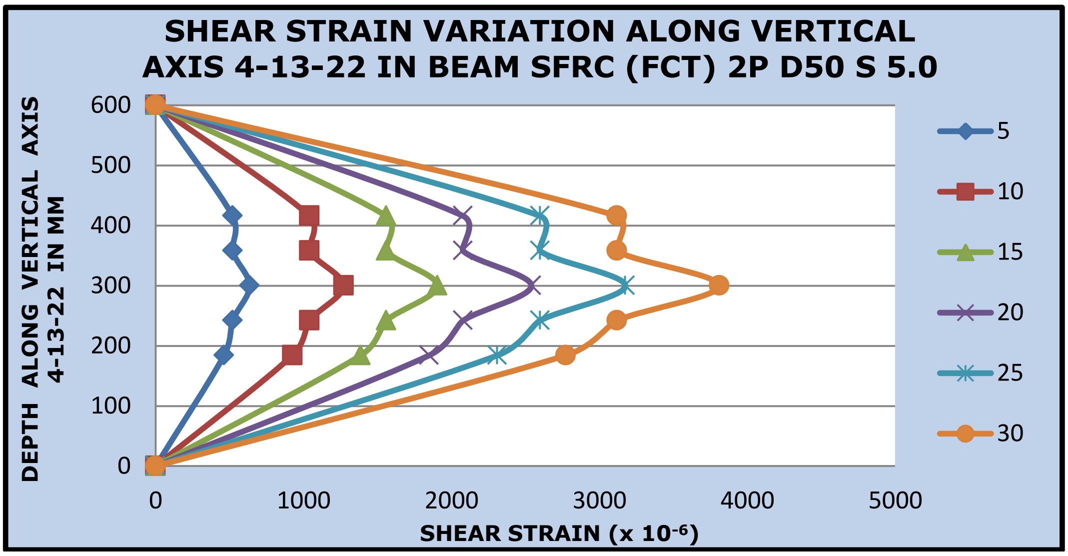
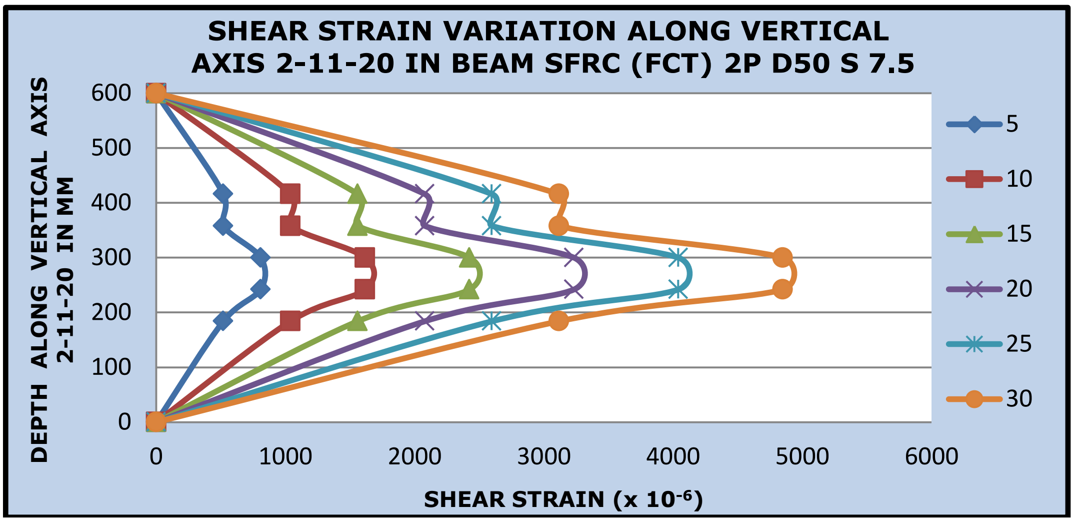
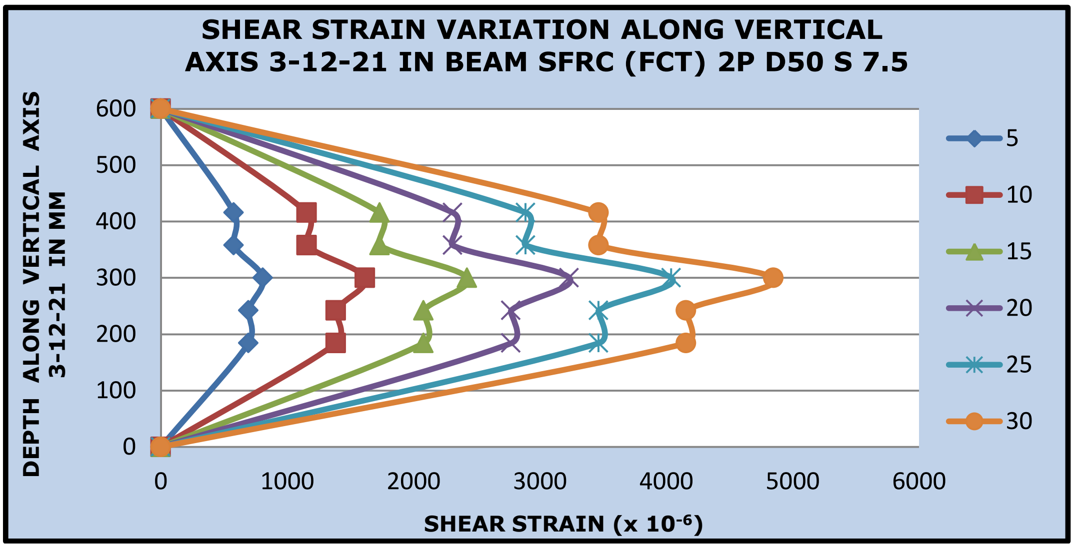


Fig. 4.18 Vertical Shear Strain Graphs Of SFRC (FCT) 2P D50 S 5.0





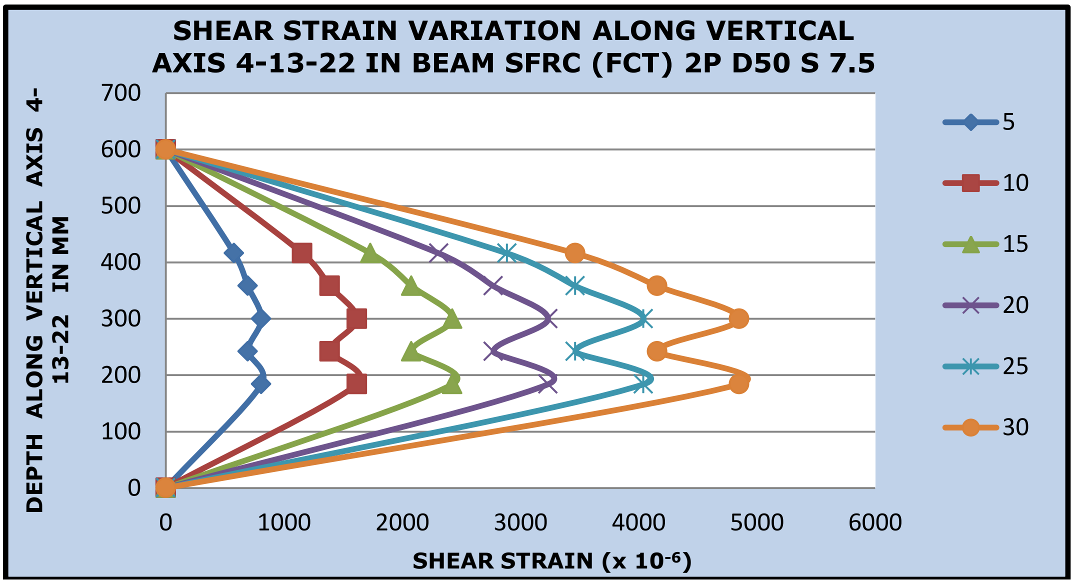
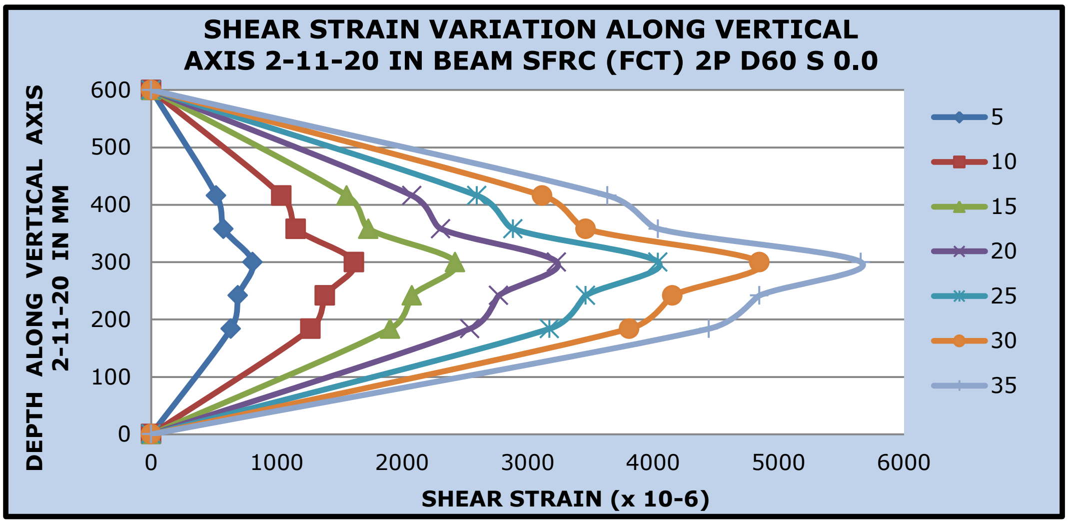
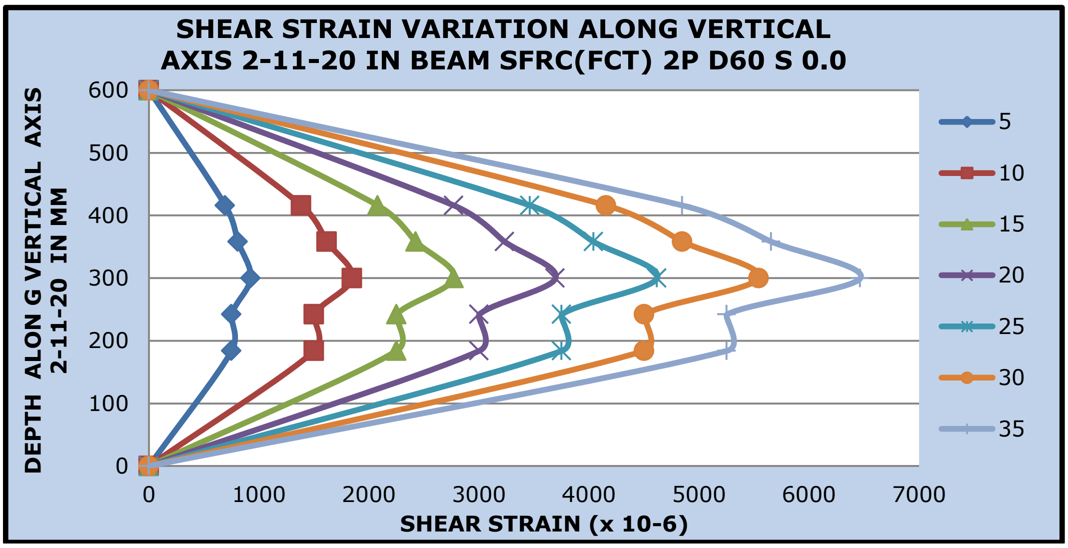


Fig. 4.19 Vertical Shear Strain Graphs Of SFRC (FCT) 2P D50 S 7.5





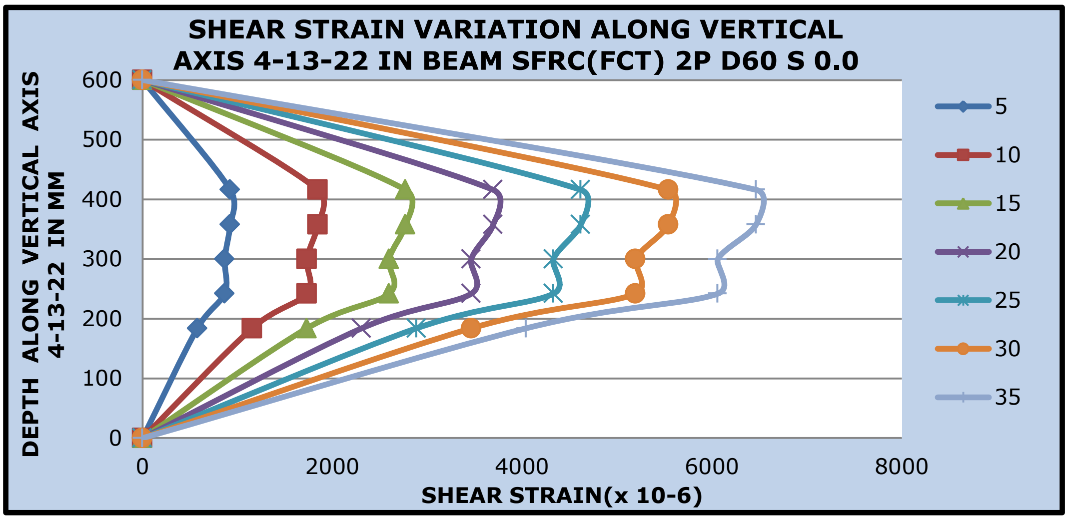
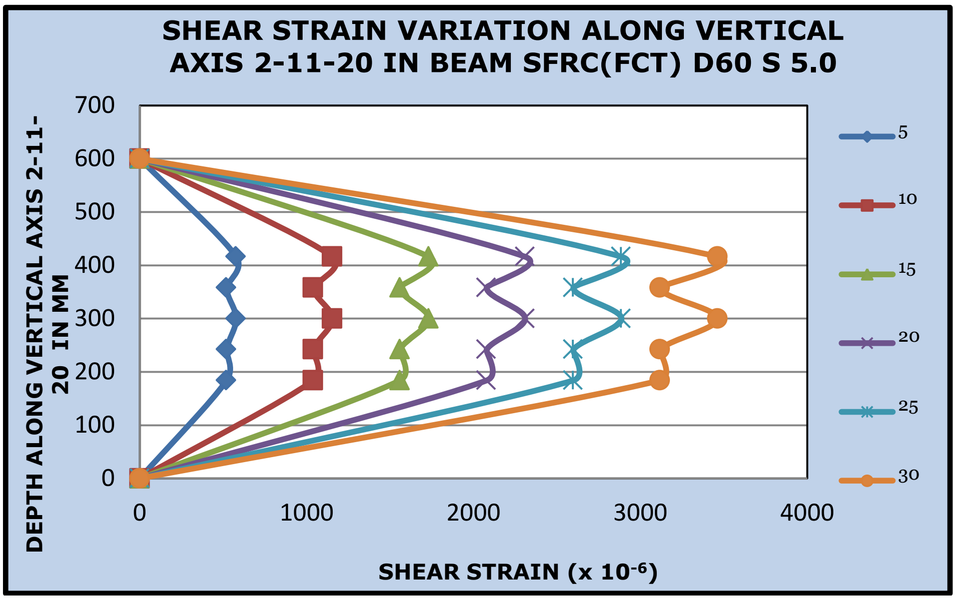
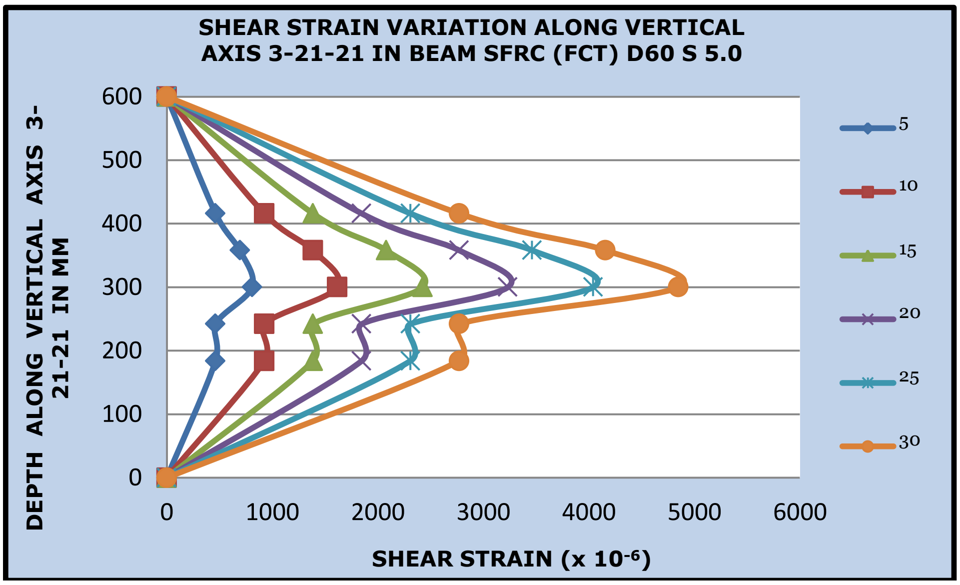


Fig. 4.20 Vertical Shear Strain Graphs Of SFRC (FCT) 2P D60 S 0.0





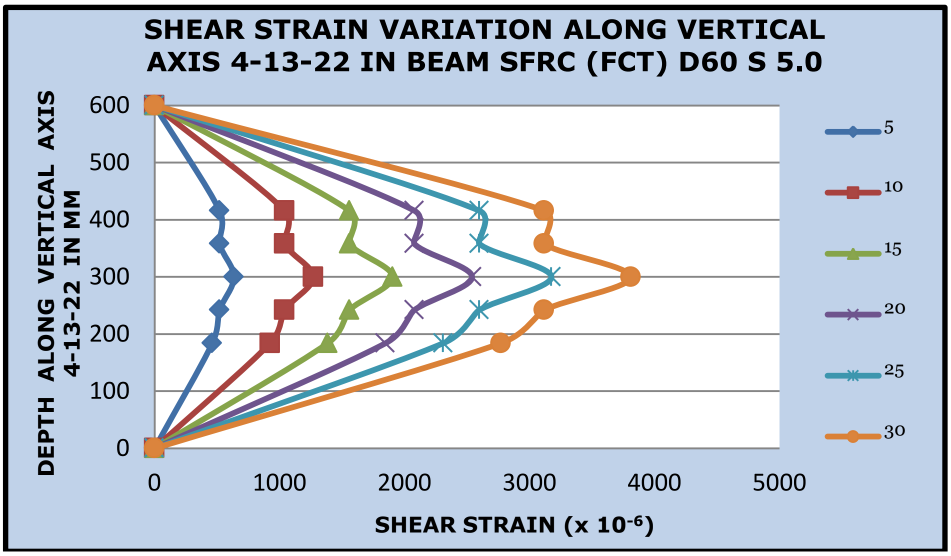
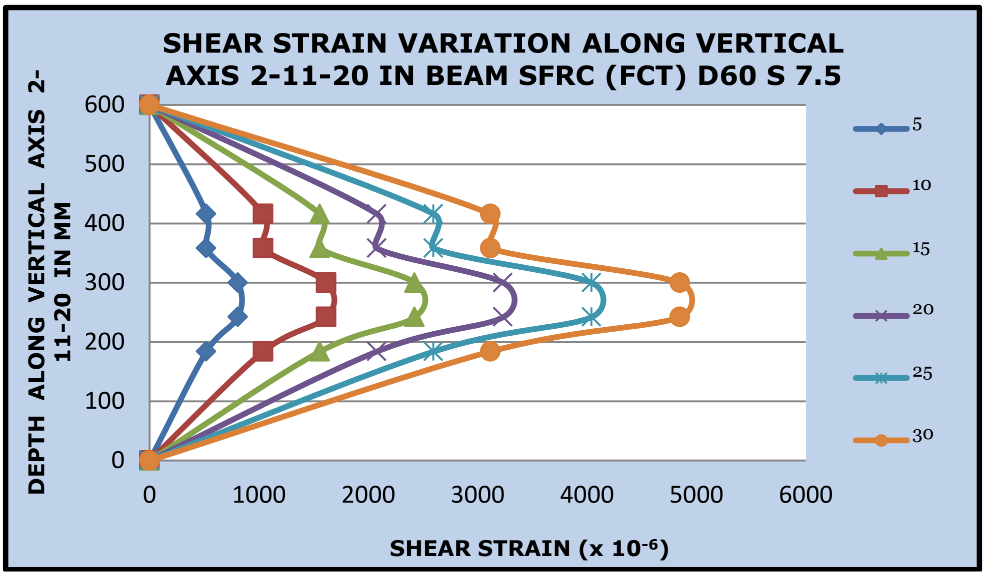
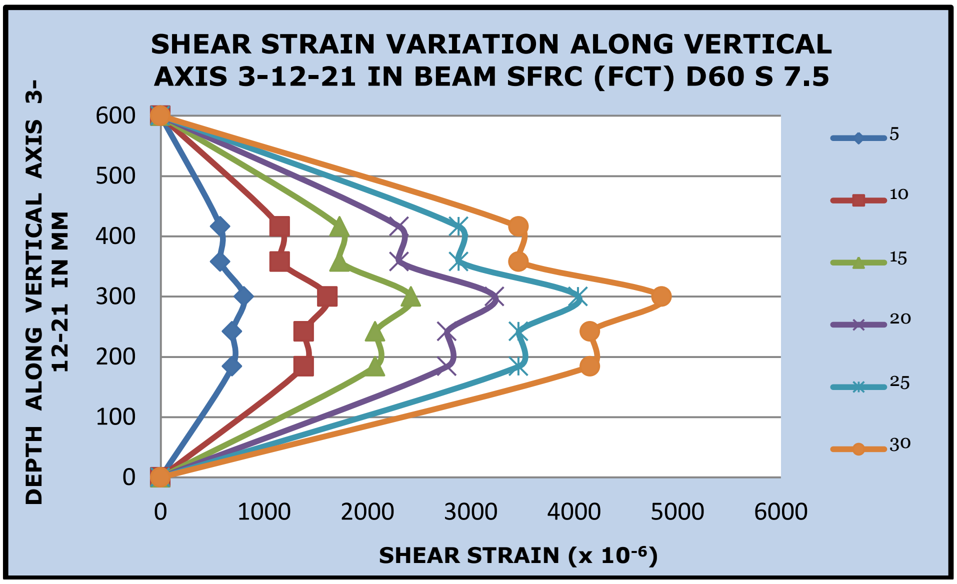


Fig. 4.21 Vertical Shear Strain Graphs Of SFRC (FCT) 2P D60 S 5.0





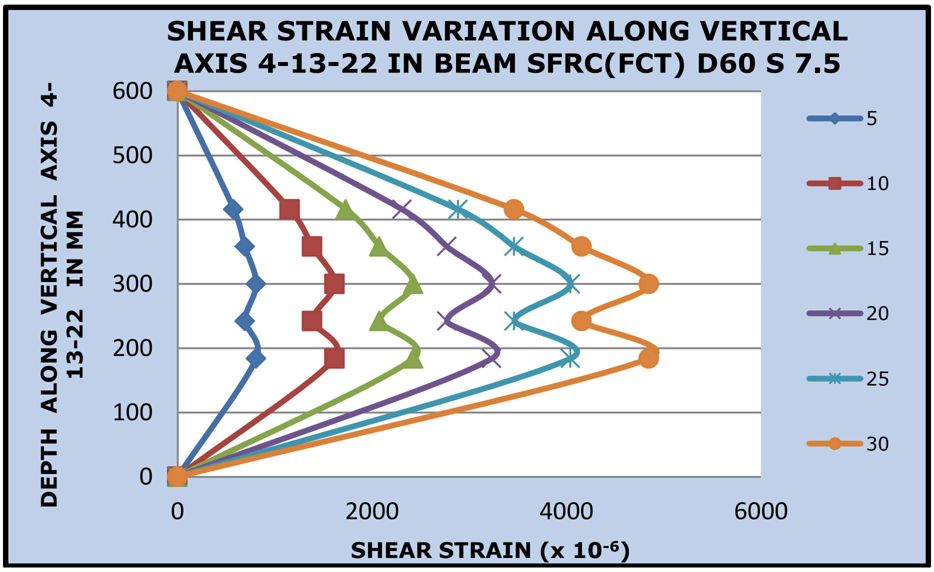


Fig. 4.22 Vertical Shear Strain Graphs Of SFRC (FCT) 2P D60 S 7.5

TABLE 4.4.3 Shear Strain Variation Along Vertical Axis For SFRC (CCT) 1P D50 S 0.0

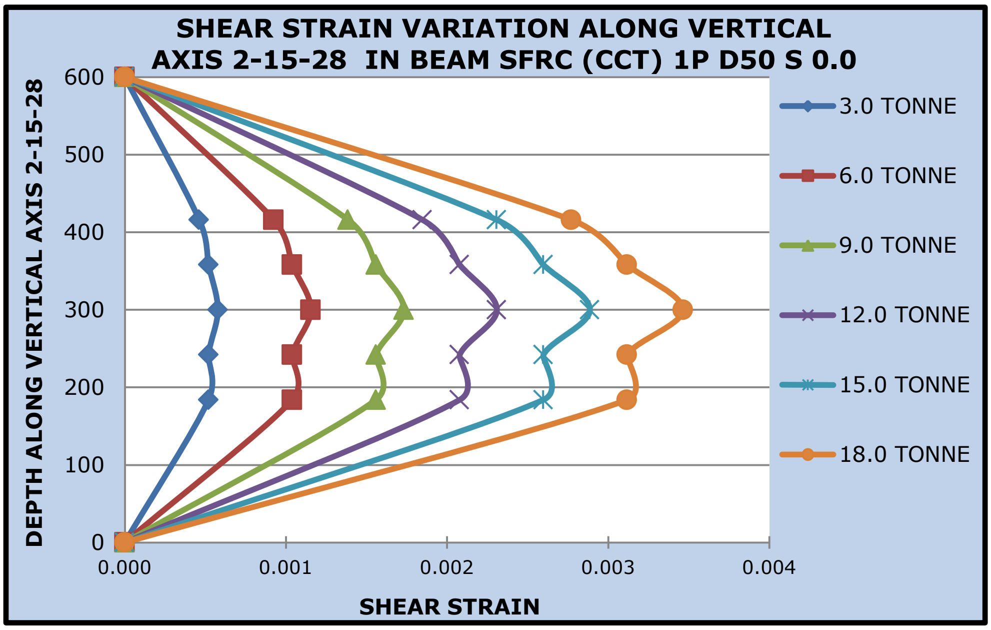
SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 2-15-28 IN D 50 S 0.0								
DEPTH	**LOAD**	**0.0 T**	**3.0 T**	**6.0 T**	**9.0 T**	**12.0 T**	**14.0 T**	**15.2 T**
600		0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
416	**1-3-15**	0.00000	0.00046	0.00092	0.00139	0.00185	0.00231	0.00277
358	**2-14-16**	0.00000	0.00052	0.00104	0.00156	0.00208	0.00260	0.00312
300	**15**	0.00000	0.00058	0.00115	0.00173	0.00231	0.00289	0.00346
242	**14-16-28**	0.00000	0.00052	0.00104	0.00156	0.00208	0.00260	0.00312
184	**15-27-29**	0.00000	0.00052	0.00104	0.00156	0.00208	0.00260	0.00312
0		0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

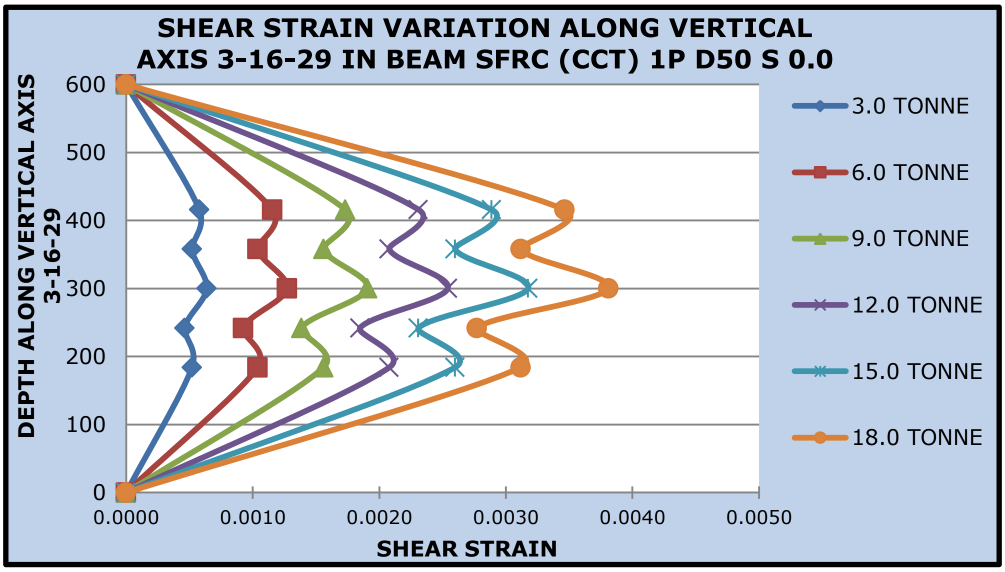
SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 3-16-29 IN D 50 S 0.0								
DEPTH	**LOAD**	**0.0 T**	**3.0 T**	**6.0 T**	**9.0 T**	**12.0 T**	**14.0 T**	**15.2 T**
600		0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
416	**2-4-16**	0.00000	0.00058	0.00115	0.00173	0.00231	0.00289	0.00346
358	**3-15-17**	0.00000	0.00052	0.00104	0.00156	0.00208	0.00260	0.00312
300	**16**	0.00000	0.00064	0.00127	0.00191	0.00254	0.00318	0.00381
242	**15-17-29**	0.00000	0.00046	0.00092	0.00139	0.00185	0.00231	0.00277
184	**16-28-30**	0.00000	0.00052	0.00104	0.00156	0.00208	0.00260	0.00312
0		0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

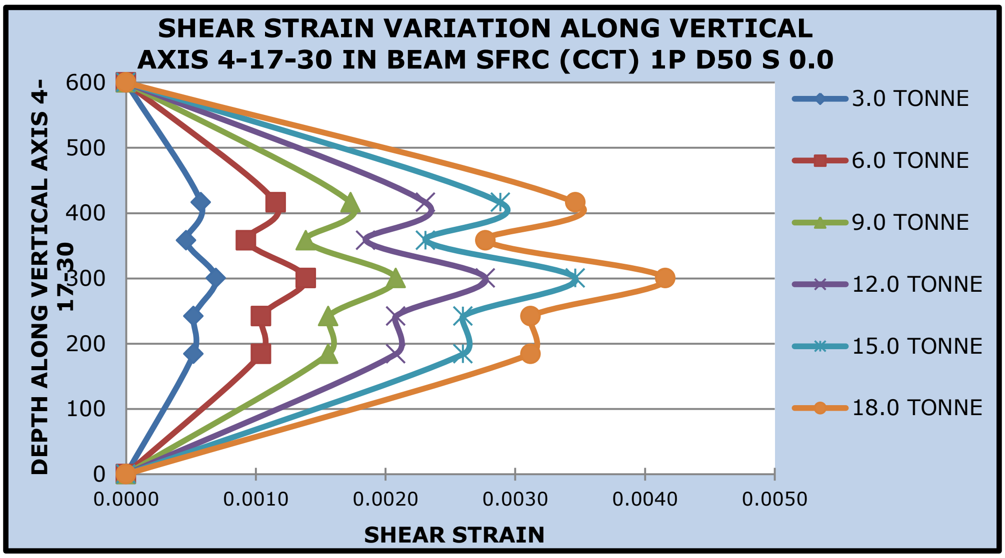
SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 4-17-30 IN D 50 S 0.0								
DEPTH	**LOAD**	**0.0 T**	**3.0 T**	**6.0 T**	**9.0 T**	**12.0 T**	**14.0 T**	**15.2 T**
600		0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
416	**3-5-17**	0.00000	0.00058	0.00115	0.00173	0.00231	0.00289	0.00346
358	**4-16-18**	0.00000	0.00046	0.00092	0.00139	0.00185	0.00231	0.00277
300	**17**	0.00000	0.00069	0.00139	0.00208	0.00277	0.00346	0.00416
242	**16-18-30**	0.00000	0.00052	0.00104	0.00156	0.00208	0.00260	0.00312
184	**17-29-31**	0.00000	0.00052	0.00104	0.00156	0.00208	0.00260	0.00312
0		0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

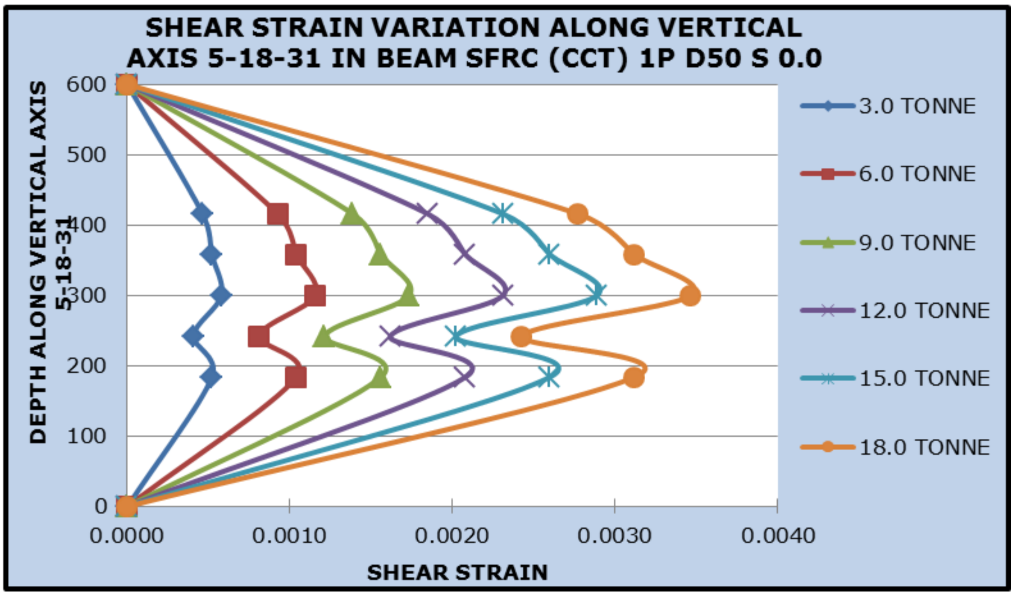
SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 5-18-31 IN D 50 S 0.0								
DEPTH	**LOAD**	**0.0 T**	**3.0 T**	**6.0 T**	**9.0 T**	**12.0 T**	**14.0 T**	**15.2 T**
600		0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
416	**4-6-18**	0.00000	0.00046	0.00092	0.00139	0.00185	0.00231	0.00277
358	**5-17-19**	0.00000	0.00052	0.00104	0.00156	0.00208	0.00260	0.00312
300	**18**	0.00000	0.00058	0.00115	0.00173	0.00231	0.00289	0.00346
242	**17-19-31**	0.00000	0.00040	0.00081	0.00121	0.00162	0.00202	0.00242
184	**18-30-32**	0.00000	0.00052	0.00104	0.00156	0.00208	0.00260	0.00312
0		0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 6-19-32 IN D 50 S 0.0								
DEPTH	**LOAD**	**0.0 T**	**3.0 T**	**6.0 T**	**9.0 T**	**12.0 T**	**14.0 T**	**15.2 T**
600		0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
416	**5-7-19**	0.00000	0.00052	0.00104	0.00156	0.00208	0.00260	0.00312
358	**6-18-20**	0.00000	0.00058	0.00115	0.00173	0.00231	0.00289	0.00346
300	**19**	0.00000	0.00064	0.00127	0.00191	0.00254	0.00318	0.00381
242	**18-20-32**	0.00000	0.00052	0.00104	0.00156	0.00208	0.00260	0.00312
184	**19-31-33**	0.00000	0.00040	0.00081	0.00121	0.00162	0.00202	0.00242
0		0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000


SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 2-15-28 IN BEAM SFRC (CCT) 1P D50 S 0.0
DEPTH ALONG VERTICAL AXIS 2-15-28
SHEAR STRAIN
0
100
200
300
400
500
600
0.000
0.001
0.002
0.003
0.004
3.0 TONNE
6.0 TONNE
9.0 TONNE
12.0 TONNE
15.0 TONNE
18.0 TONNE


SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 3-16-29 IN BEAM SFRC (CCT) 1P D50 S 0.0
DEPTH ALONG VERTICAL AXIS 3-16-29
SHEAR STRAIN
0
100
200
300
400
500
600
0.0000
0.0010
0.0020
0.0030
0.0040
0.0050
3.0 TONNE
6.0 TONNE
9.0 TONNE
12.0 TONNE
15.0 TONNE
18.0 TONNE


SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 4-17-30 IN BEAM SFRC (CCT) 1P D50 S 0.0
DEPTH ALONG VERTICAL AXIS 4-17-30
SHEAR STRAIN
0
100
200
300
400
500
600
0.0000
0.0010
0.0020
0.0030
0.0040
0.0050
3.0 TONNE
6.0 TONNE
9.0 TONNE
12.0 TONNE
15.0 TONNE
18.0 TONNE



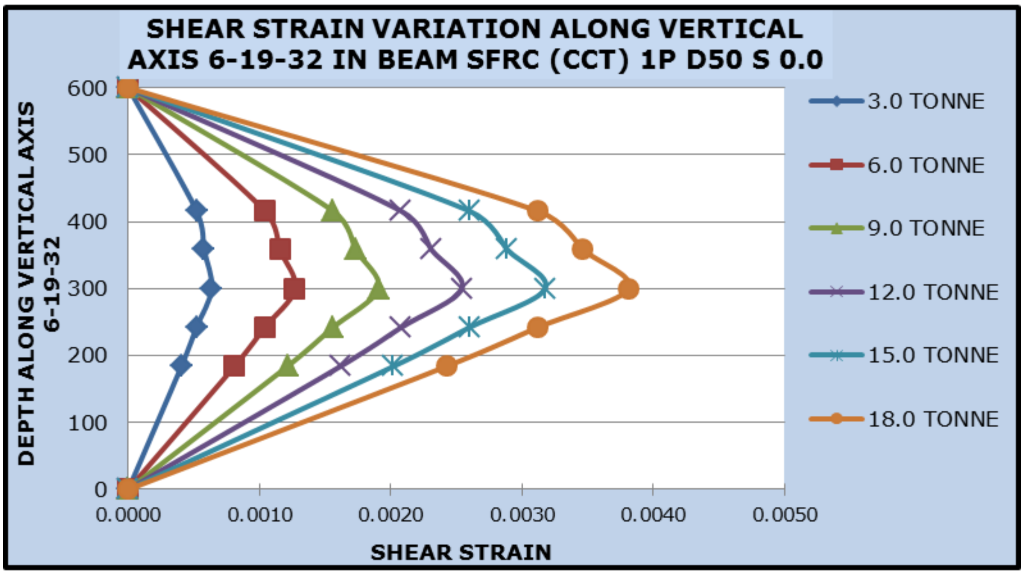
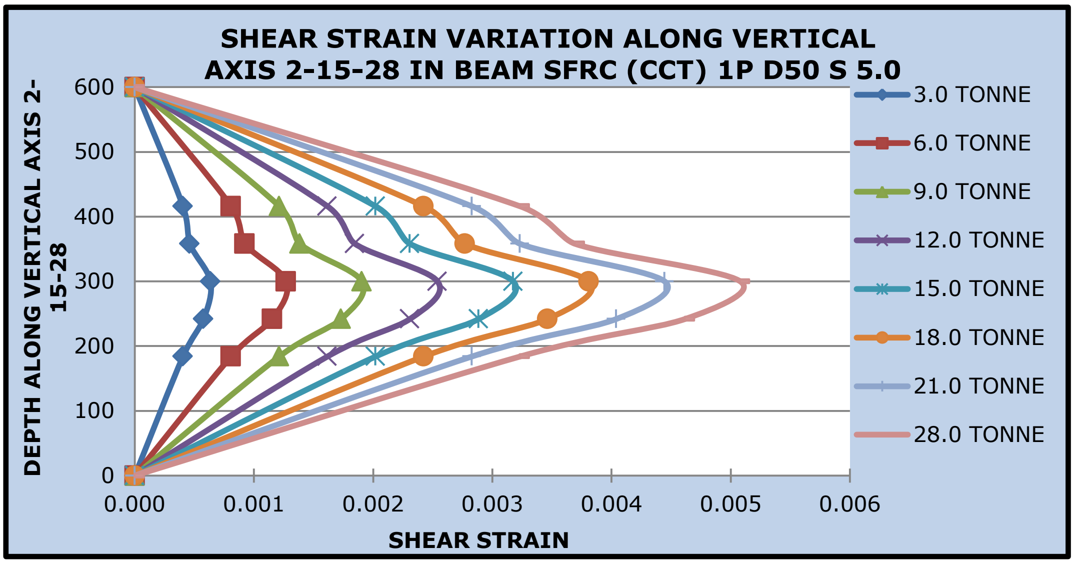
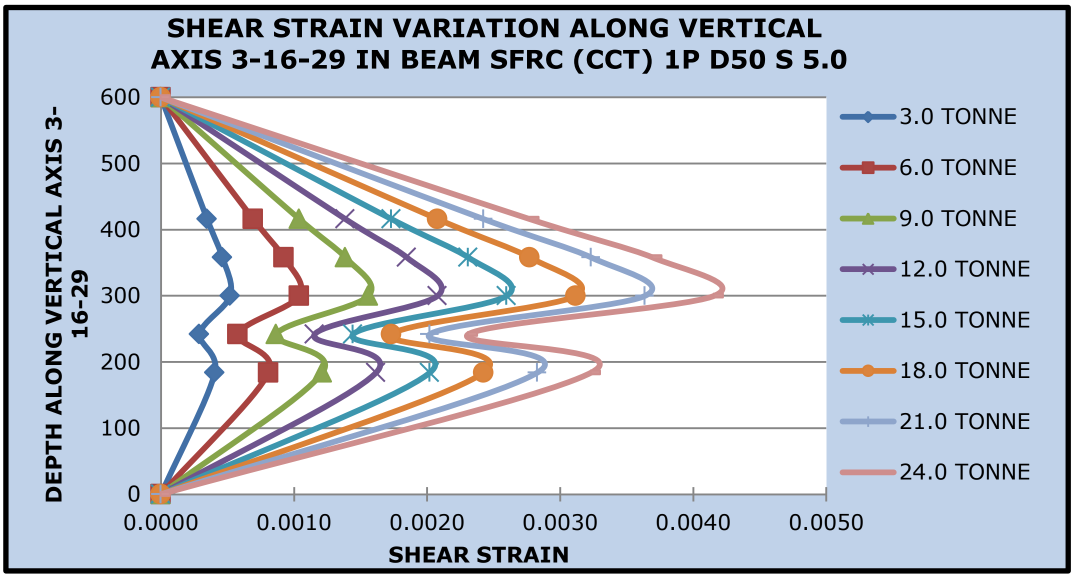
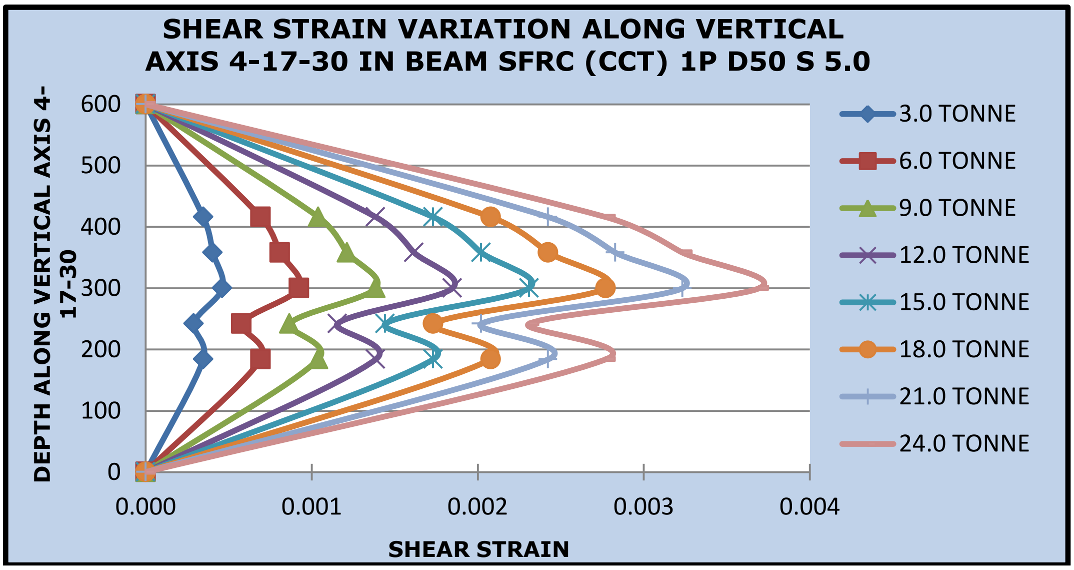
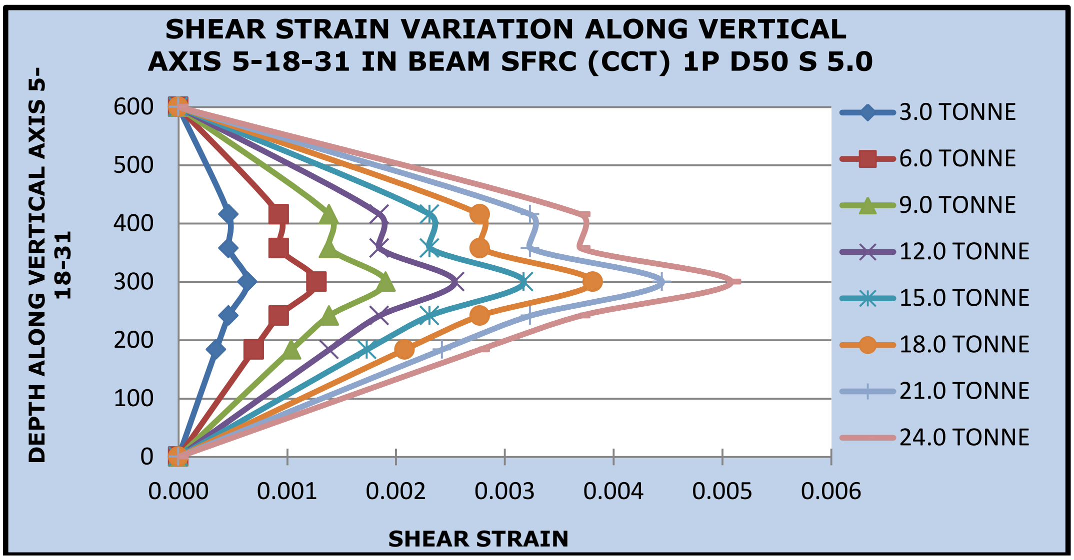


Fig. 4.23 Vertical Shear Strain Graphs Of SFRC (CCT) 1P D50 S 0.0


SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 2-15-28 IN BEAM SFRC (CCT) 1P D50 S 5.0
DEPTH ALONG VERTICAL AXIS 2-15-28
SHEAR STRAIN
0
100
200
300
400
500
600
0.000
0.001
0.002
0.003
0.004
0.005
0.006
3.0 TONNE
6.0 TONNE
9.0 TONNE
12.0 TONNE
15.0 TONNE
18.0 TONNE
21.0 TONNE
28.0 TONNE


SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 3-16-29 IN BEAM SFRC (CCT) 1P D50 S 5.0
DEPTH ALONG VERTICAL AXIS 3-16-29
SHEAR STRAIN
0
100
200
300
400
500
600
0.0000
0.0010
0.0020
0.0030
0.0040
0.0050
3.0 TONNE
6.0 TONNE
9.0 TONNE
12.0 TONNE
15.0 TONNE
18.0 TONNE
21.0 TONNE
24.0 TONNE


SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 4-17-30 IN BEAM SFRC (CCT) 1P D50 S 5.0
DEPTH ALONG VERTICAL AXIS 4-17-30
SHEAR STRAIN
0
100
200
300
400
500
600
0.000
0.001
0.002
0.003
0.004
3.0 TONNE
6.0 TONNE
9.0 TONNE
12.0 TONNE
15.0 TONNE
18.0 TONNE
21.0 TONNE
24.0 TONNE



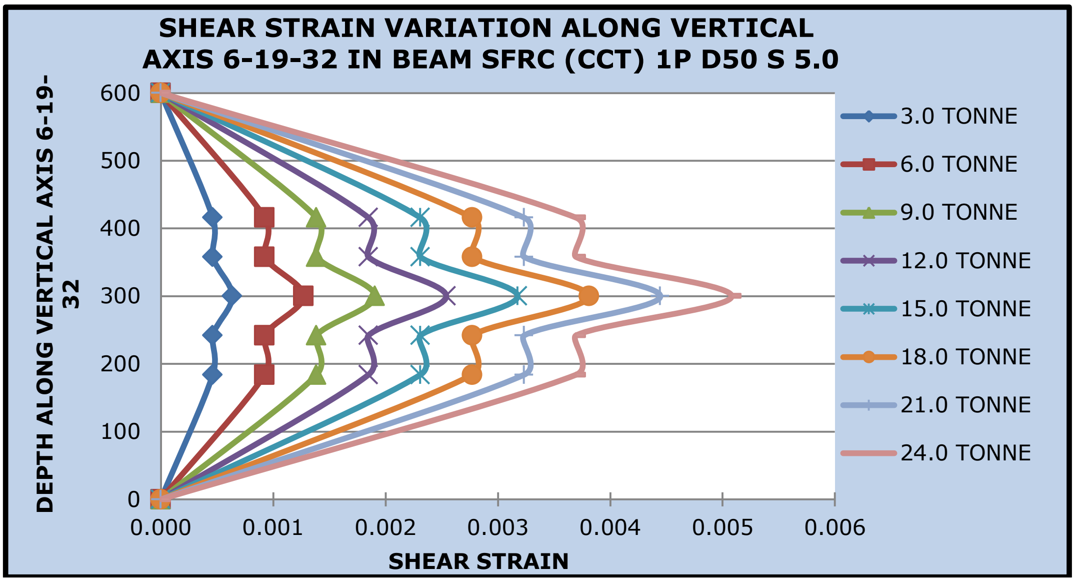
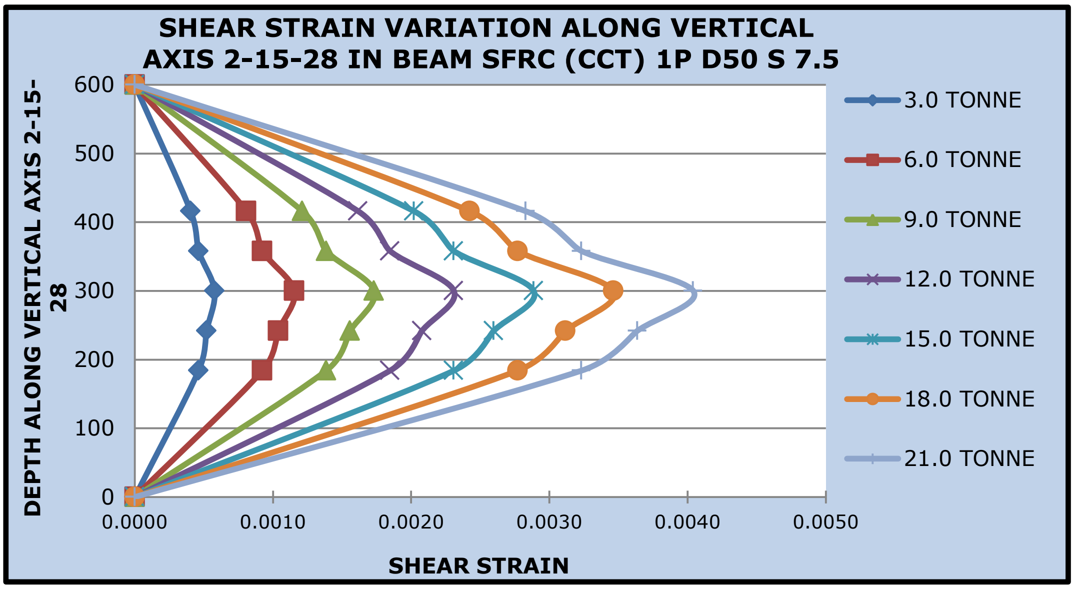
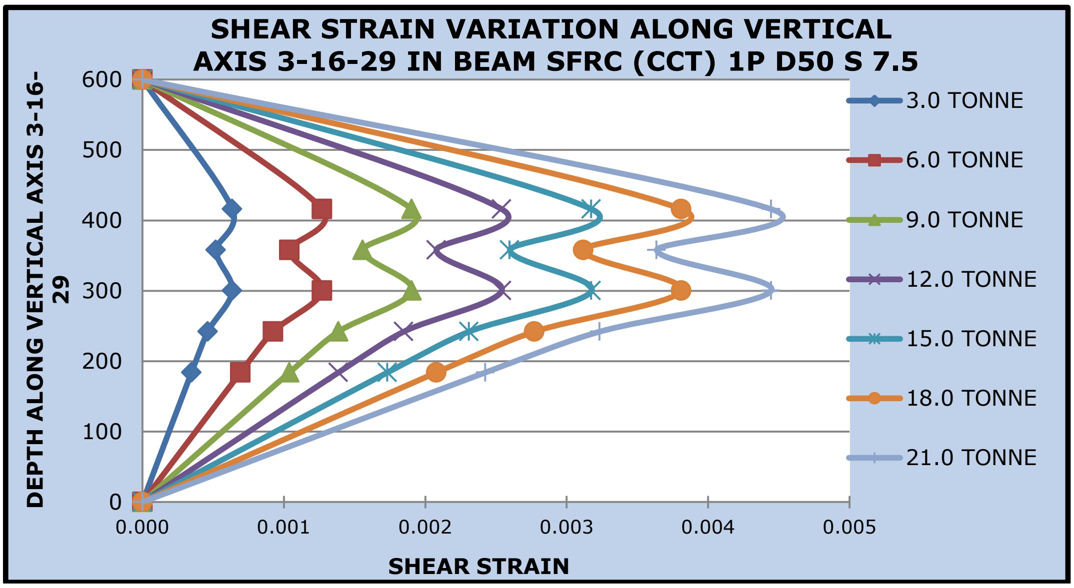
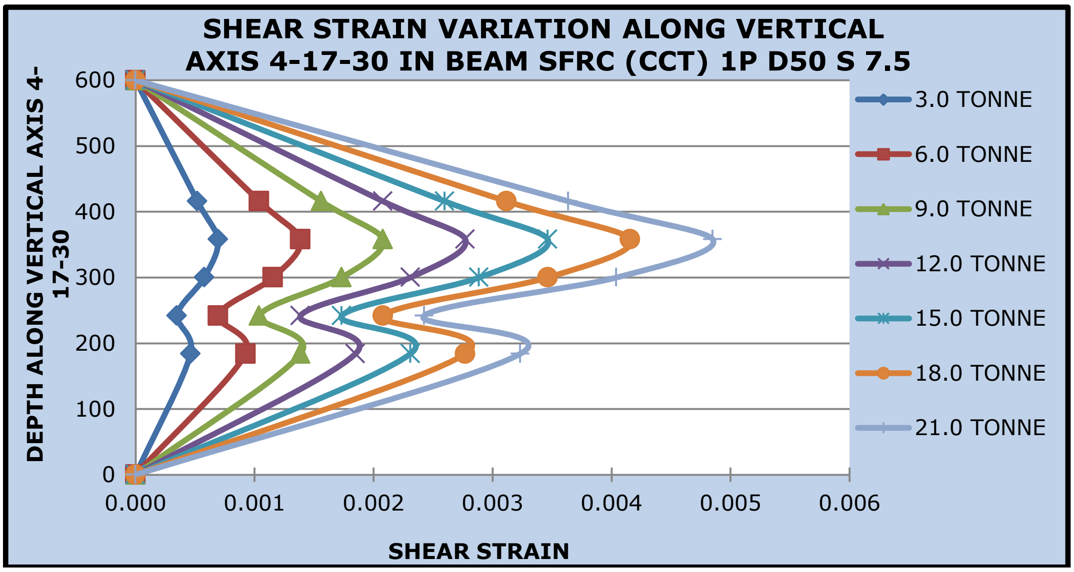
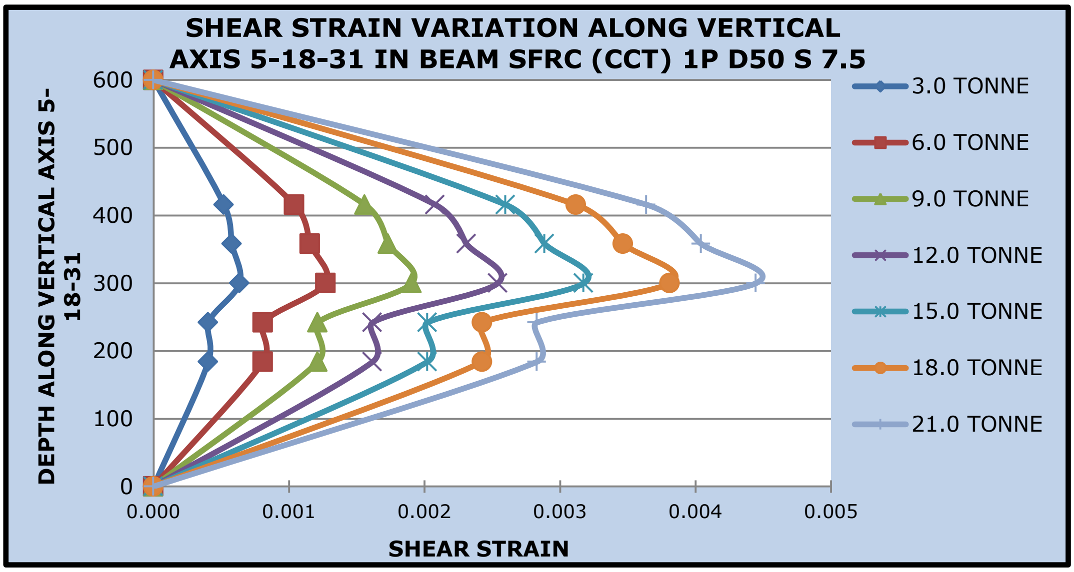


Fig. 4.24 Vertical Shear Strain Graphs Of SFRC (CCT) 1P D50 S 5.0


SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 2-15-28 IN BEAM SFRC (CCT) 1P D50 S 7.5
DEPTH ALONG VERTICAL AXIS 2-15-28
600
500
400
300
200
100
0
0.0000
0.0010
0.0020
0.0030
0.0040
0.0050
SHEAR STRAIN
3.0 TONNE
6.0 TONNE
9.0 TONNE
12.0 TONNE
15.0 TONNE
18.0 TONNE
21.0 TONNE


SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 3-16-29 IN BEAM SFRC (CCT) 1P D50 S 7.5
DEPTH ALONG VERTICAL AXIS 3-16-29
600
500
400
300
200
100
0
0.000
0.001
0.002
0.003
0.004
0.005
SHEAR STRAIN
3.0 TONNE
6.0 TONNE
9.0 TONNE
12.0 TONNE
15.0 TONNE
18.0 TONNE
21.0 TONNE


SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 4-17-30 IN BEAM SFRC (CCT) 1P D50 S 7.5
DEPTH ALONG VERTICAL AXIS 4-17-30
600
500
400
300
200
100
0
0.000
0.001
0.002
0.003
0.004
0.005
0.006
SHEAR STRAIN
3.0 TONNE
6.0 TONNE
9.0 TONNE
12.0 TONNE
15.0 TONNE
18.0 TONNE
21.0 TONNE



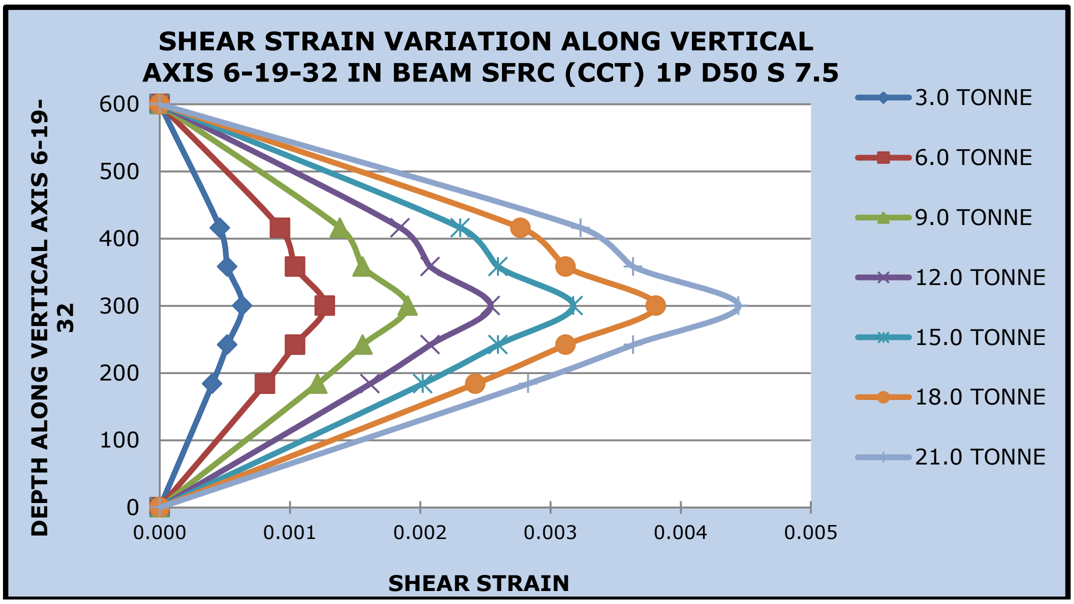
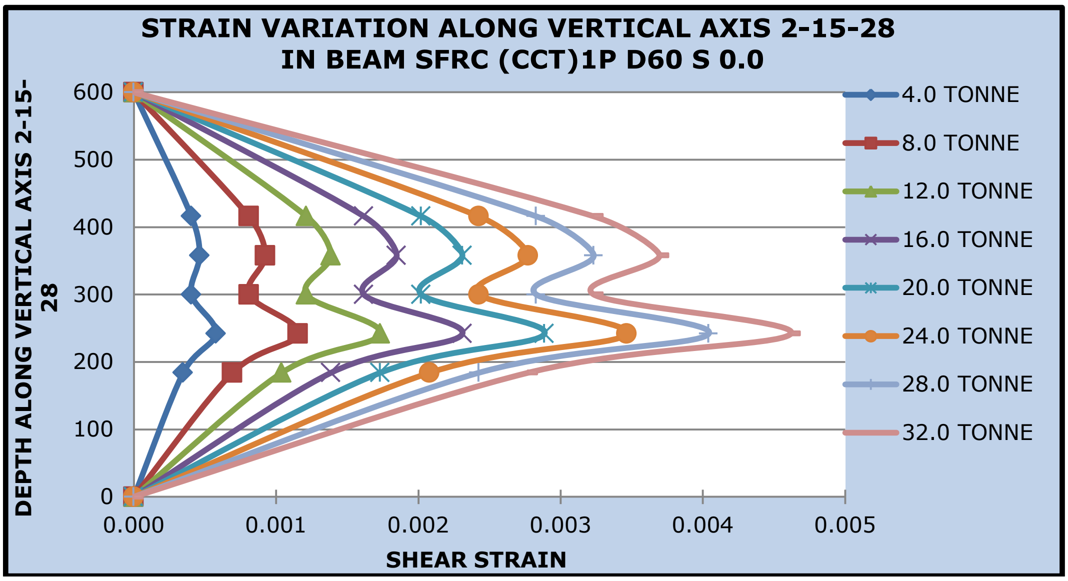
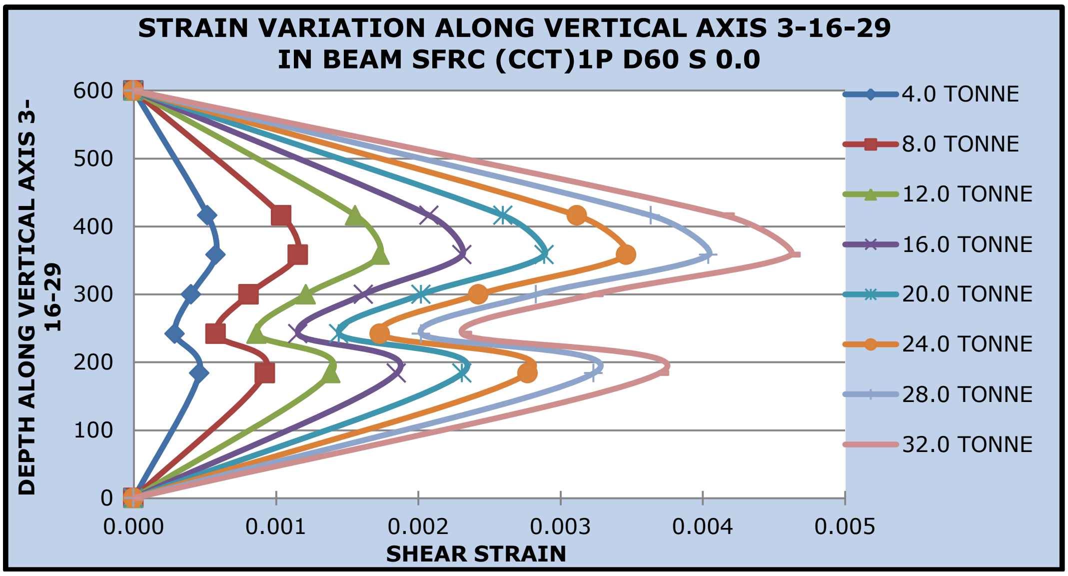


Fig. 4.25 Vertical Shear Strain Graphs Of SFRC (CCT) 1P D50 S 7.5





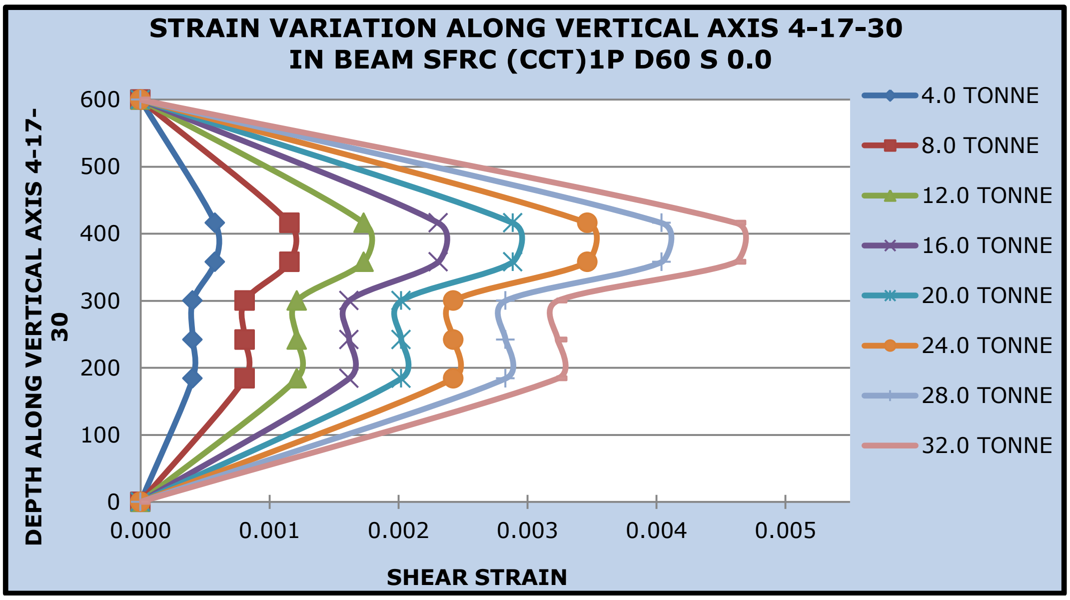
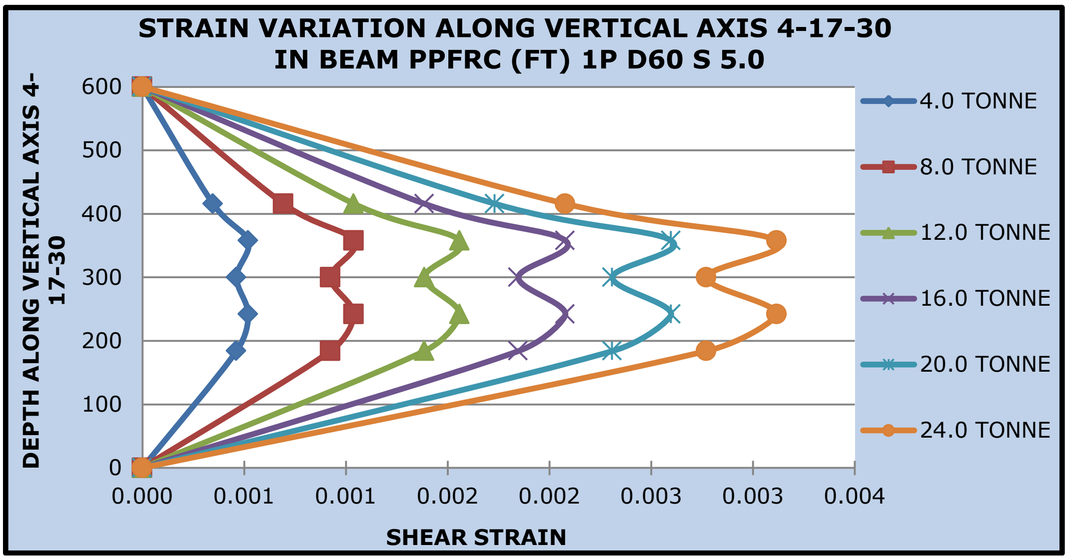
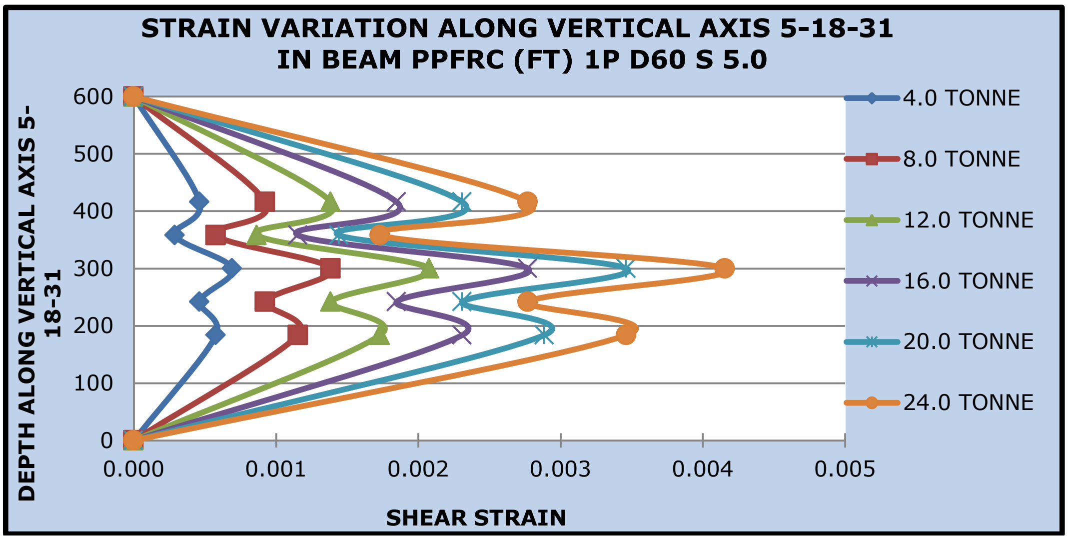


Fig. 4.26 Vertical Shear Strain Graphs Of SFRC (CCT) 1P D60 S 0.0





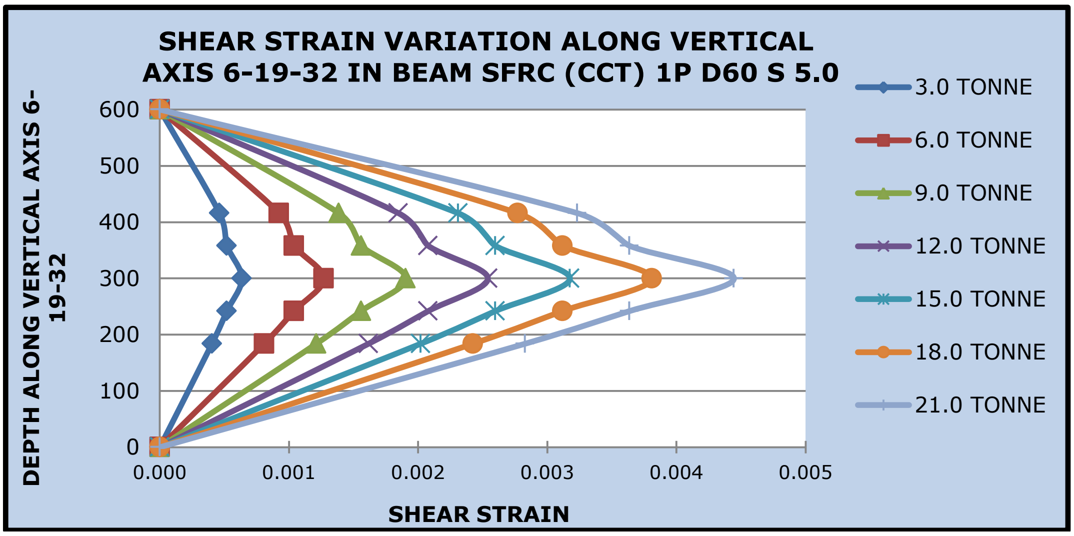
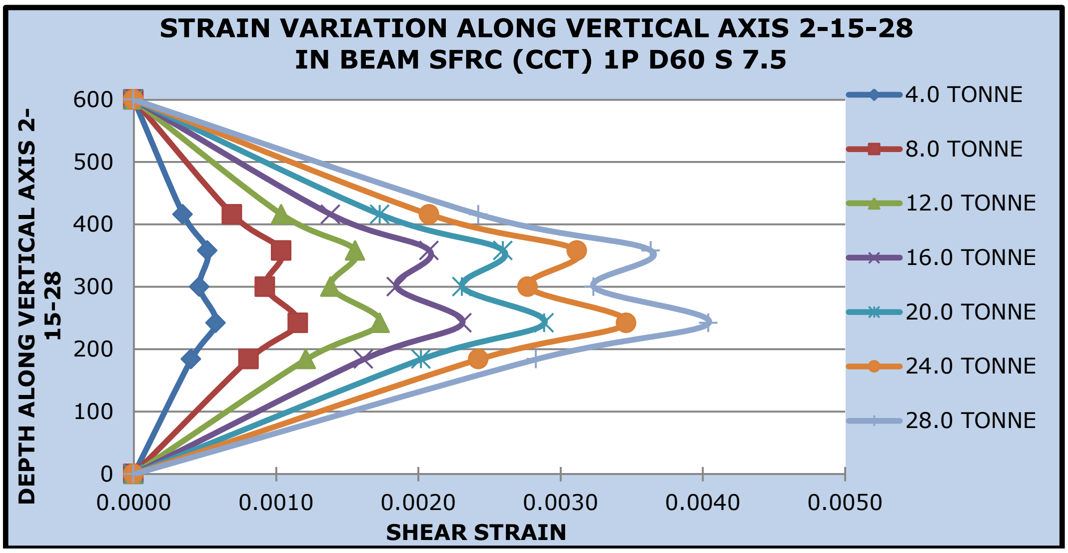
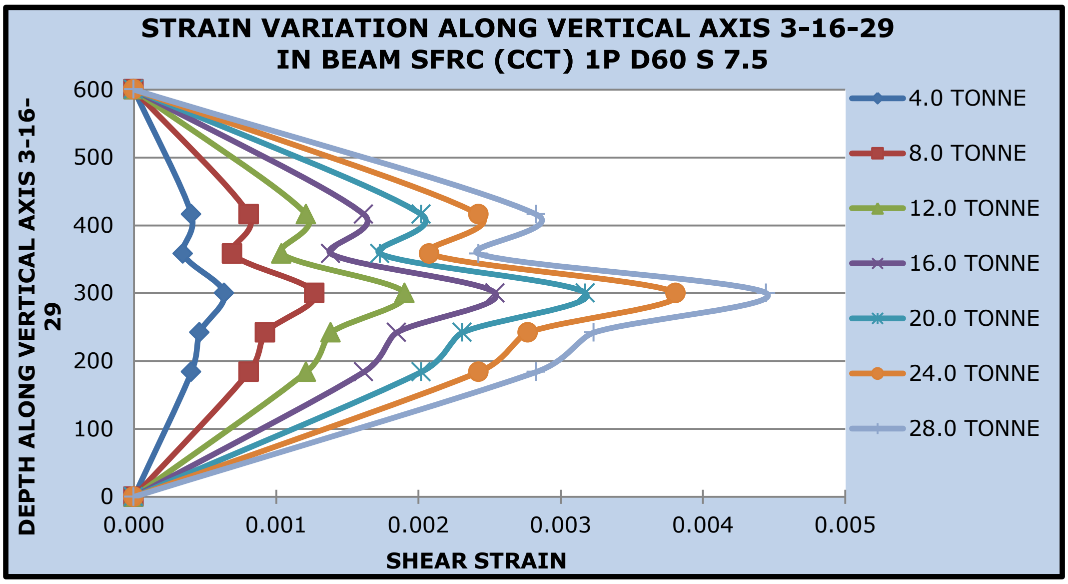
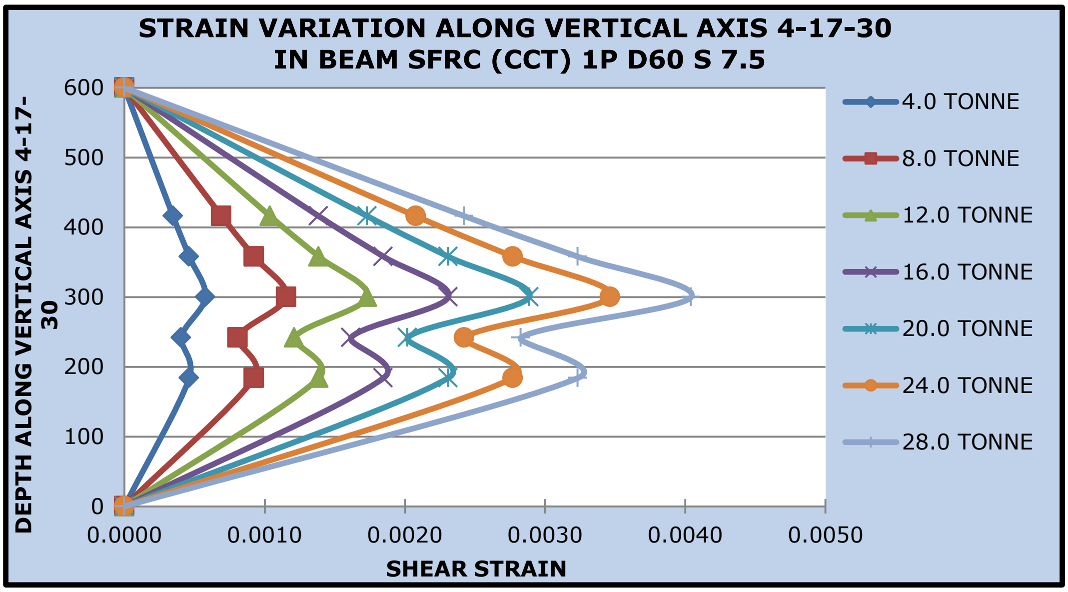
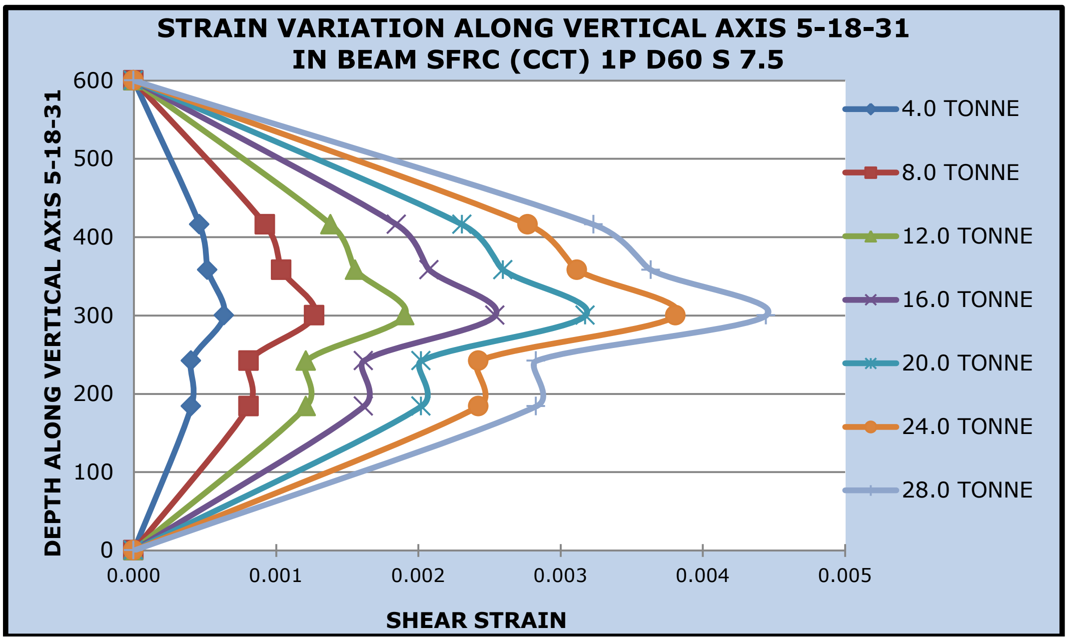


Fig. 4.27 Vertical Shear Strain Graphs Of SFRC (CCT) 1P D60 S 5.0


STRAIN VARIATION ALONG VERTICAL AXIS 2-15-28
IN BEAM SFRC (CCT) 1P D60 S 7.5
DEPTH ALONG VERTICAL AXIS 2-15-28
SHEAR STRAIN
0
100
200
300
400
500
600
0.0000
0.0010
0.0020
0.0030
0.0040
0.0050
4.0 TONNE
8.0 TONNE
12.0 TONNE
16.0 TONNE
20.0 TONNE
24.0 TONNE
28.0 TONNE


STRAIN VARIATION ALONG VERTICAL AXIS 3-16-29
IN BEAM SFRC (CCT) 1P D60 S 7.5
DEPTH ALONG VERTICAL AXIS 3-16-29
SHEAR STRAIN
0
100
200
300
400
500
600
0.000
0.001
0.002
0.003
0.004
0.005
4.0 TONNE
8.0 TONNE
12.0 TONNE
16.0 TONNE
20.0 TONNE
24.0 TONNE
28.0 TONNE


STRAIN VARIATION ALONG VERTICAL AXIS 4-17-30
IN BEAM SFRC (CCT) 1P D60 S 7.5
DEPTH ALONG VERTICAL AXIS 4-17-30
SHEAR STRAIN
0
100
200
300
400
500
600
0.0000
0.0010
0.0020
0.0030
0.0040
0.0050
4.0 TONNE
8.0 TONNE
12.0 TONNE
16.0 TONNE
20.0 TONNE
24.0 TONNE
28.0 TONNE



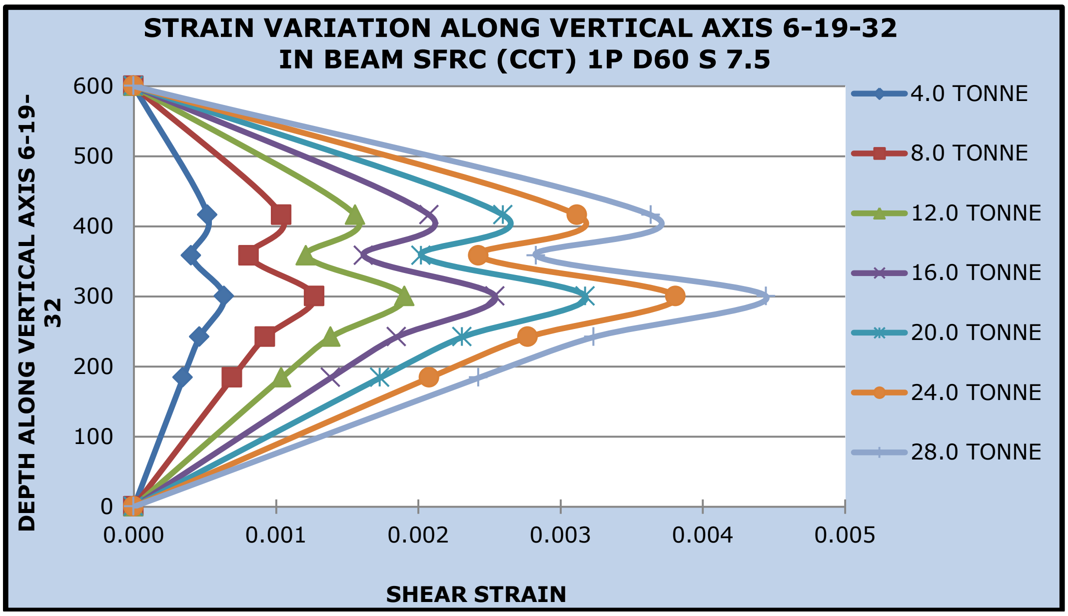


Fig. 4.28 Vertical Shear Strain Graphs Of SFRC (CCT) 1P D60 S 7.5

TABLE 4.4.4 Shear Strain Variation Along Vertical Axis For HFRC (MT+CCT) 1P D50 S 0.0

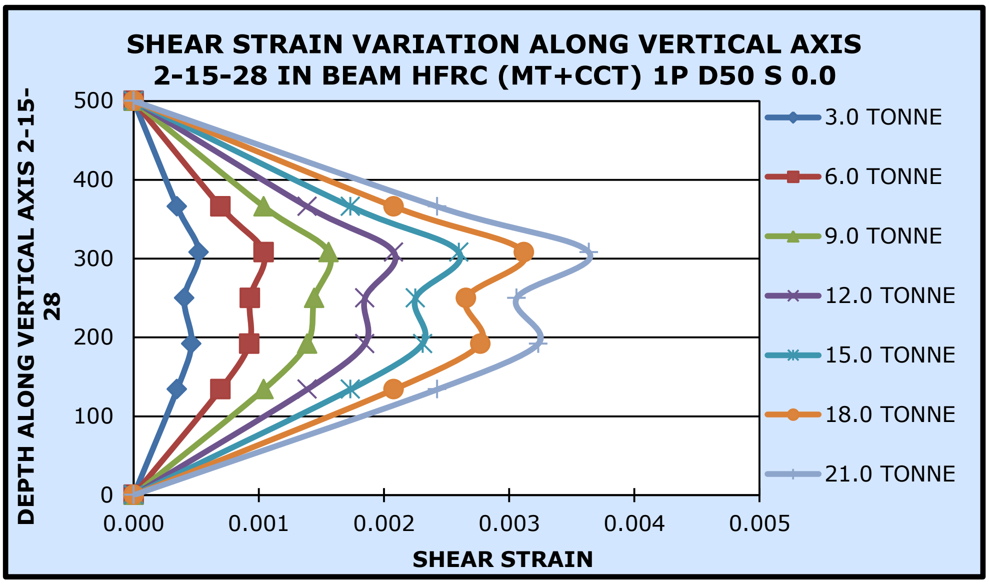
SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 2-15-28 IN HFRC (MT+CCT) 1P D50 S 0.0									
DEPTH	**LOAD**	**0.0 T**	**3.0 T**	**6.0 T**	**9.0 T**	**12.0 T**	**15.0 T**	**18.0 T**	**21.0 T**
500		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
366	**1-3-15**	0.0000	0.0003	0.0007	0.0010	0.0014	0.0017	0.0021	0.0024
308	**2-14-16**	0.0000	0.0005	0.0010	0.0016	0.0021	0.0026	0.0031	0.0036
250	**15.00**	0.0000	0.0004	0.0009	0.0014	0.0018	0.0023	0.0027	0.0031
192	**14-16-28**	0.0000	0.0005	0.0009	0.0014	0.0018	0.0023	0.0028	0.0032
134	**15-27-29**	0.0000	0.0003	0.0007	0.0010	0.0014	0.0017	0.0021	0.0024
0		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

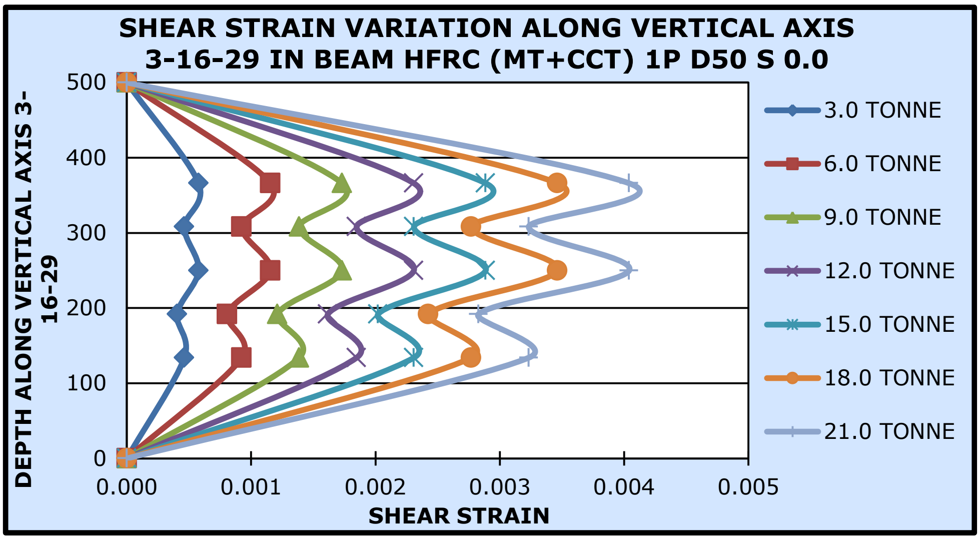
SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 3-16-29 IN HFRC (MT+CCT) 1P D50 S 0.0									
DEPTH	**LOAD**	**0.0 T**	**3.0 T**	**6.0 T**	**9.0 T**	**12.0 T**	**15.0 T**	**18.0 T**	**21.0 T**
500		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
366	**2-4-16**	0.0000	0.0006	0.0012	0.0017	0.0023	0.0029	0.0035	0.0040
308	**3-15-17**	0.0000	0.0005	0.0009	0.0014	0.0018	0.0023	0.0028	0.0032
250	**16.00**	0.0000	0.0006	0.0012	0.0017	0.0023	0.0029	0.0035	0.0040
192	**15-17-29**	0.0000	0.0004	0.0008	0.0012	0.0016	0.0020	0.0024	0.0028
134	**16-28-30**	0.0000	0.0005	0.0009	0.0014	0.0018	0.0023	0.0028	0.0032
0		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

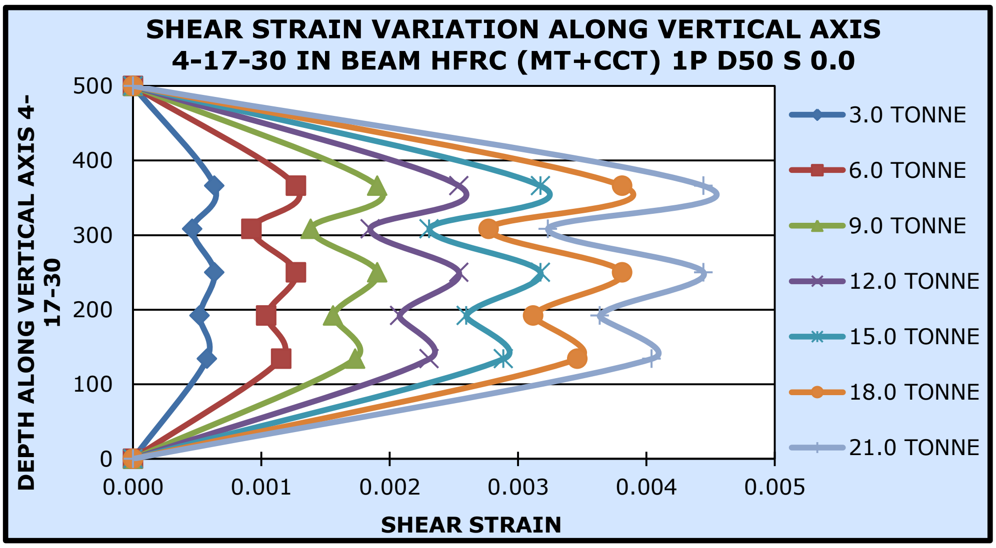
SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 3-16-29 IN HFRC (MT+CCT) 1P D50 S 0.0									
DEPTH	**LOAD**	**0.0 T**	**3.0 T**	**6.0 T**	**9.0 T**	**12.0 T**	**15.0 T**	**18.0 T**	**21.0 T**
500		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
366	**3-5-17**	0.0000	0.0006	0.0013	0.0019	0.0025	0.0032	0.0038	0.0044
308	**4-16-18**	0.0000	0.0005	0.0009	0.0014	0.0018	0.0023	0.0028	0.0032
250	**17**	0.0000	0.0006	0.0013	0.0019	0.0025	0.0032	0.0038	0.0044
192	**16-18-30**	0.0000	0.0005	0.0010	0.0016	0.0021	0.0026	0.0031	0.0036
134	**17-29-31**	0.0000	0.0006	0.0012	0.0017	0.0023	0.0029	0.0035	0.0040
0		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

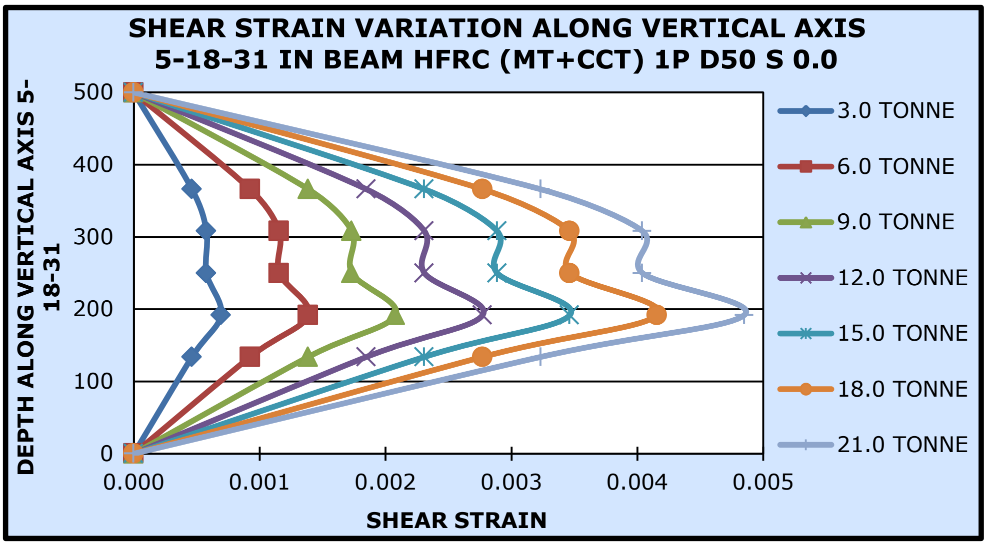
SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 5-18-31 IN HFRC (MT+CCT) 1P D50 S 0.0									
DEPTH	**LOAD**	**0.0 T**	**3.0 T**	**6.0 T**	**9.0 T**	**12.0 T**	**15.0 T**	**18.0 T**	**21.0 T**
500		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
366	**4-6-18**	0.0000	0.0005	0.0009	0.0014	0.0018	0.0023	0.0028	0.0032
308	**5-17-19**	0.0000	0.0006	0.0012	0.0017	0.0023	0.0029	0.0035	0.0040
250	**18.00**	0.0000	0.0006	0.0012	0.0017	0.0023	0.0029	0.0035	0.0040
192	**17-19-31**	0.0000	0.0007	0.0014	0.0021	0.0028	0.0035	0.0042	0.0049
134	**18-30-32**	0.0000	0.0005	0.0009	0.0014	0.0018	0.0023	0.0028	0.0032
0		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 6-19-32 IN HFRC (MT+CCT) 1P D50 S 0.0									
DEPTH	**LOAD**	**0.0 T**	**3.0 T**	**6.0 T**	**9.0 T**	**12.0 T**	**15.0 T**	**18.0 T**	**21.0 T**
500		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
366	**5-7-19**	0.0000	0.0005	0.0009	0.0014	0.0018	0.0023	0.0028	0.0032
308	**6-18-20**	0.0000	0.0004	0.0008	0.0012	0.0016	0.0020	0.0024	0.0028
250	**19.00**	0.0000	0.0004	0.0008	0.0012	0.0016	0.0020	0.0024	0.0028
192	**18-20-32**	0.0000	0.0004	0.0008	0.0012	0.0016	0.0020	0.0024	0.0028
134	**19-31-33**	0.0000	0.0006	0.0013	0.0019	0.0025	0.0032	0.0038	0.0044
0		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000


SHEAR STRAIN VARIATION ALONG VERTICAL AXIS
2-15-28 IN BEAM HFRC (MT+CCT) 1P D50 S 0.0
DEPTH ALONG VERTICAL AXIS 2-15-28
SHEAR STRAIN
500
400
300
200
100
0
0.000
0.001
0.002
0.003
0.004
0.005
3.0 TONNE
6.0 TONNE
9.0 TONNE
12.0 TONNE
15.0 TONNE
18.0 TONNE
21.0 TONNE


SHEAR STRAIN VARIATION ALONG VERTICAL AXIS
3-16-29 IN BEAM HFRC (MT+CCT) 1P D50 S 0.0
DEPTH ALONG VERTICAL AXIS 3-16-29
SHEAR STRAIN
500
400
300
200
100
0
0.000
0.001
0.002
0.003
0.004
0.005
3.0 TONNE
6.0 TONNE
9.0 TONNE
12.0 TONNE
15.0 TONNE
18.0 TONNE
21.0 TONNE


SHEAR STRAIN VARIATION ALONG VERTICAL AXIS
4-17-30 IN BEAM HFRC (MT+CCT) 1P D50 S 0.0
DEPTH ALONG VERTICAL AXIS 4-17-30
SHEAR STRAIN
500
400
300
200
100
0
0.000
0.001
0.002
0.003
0.004
0.005
3.0 TONNE
6.0 TONNE
9.0 TONNE
12.0 TONNE
15.0 TONNE
18.0 TONNE
21.0 TONNE



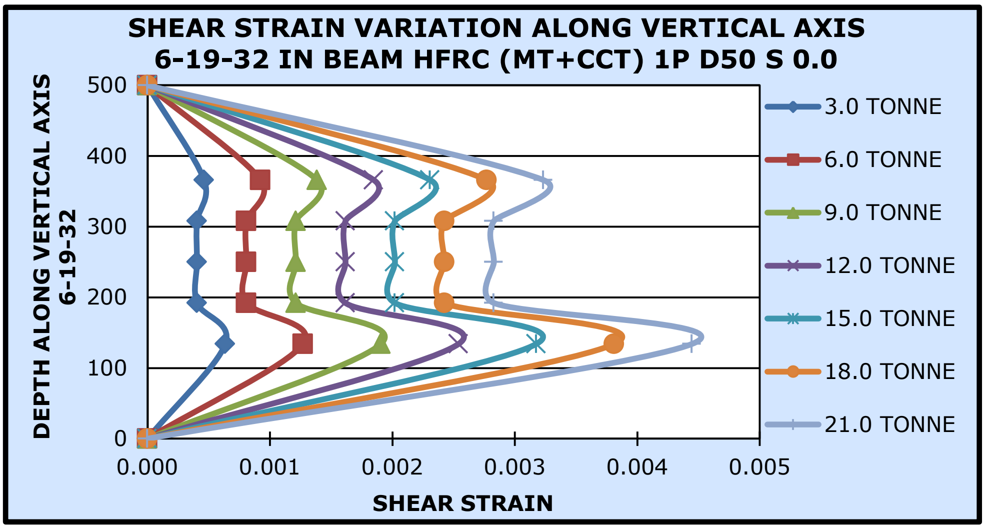
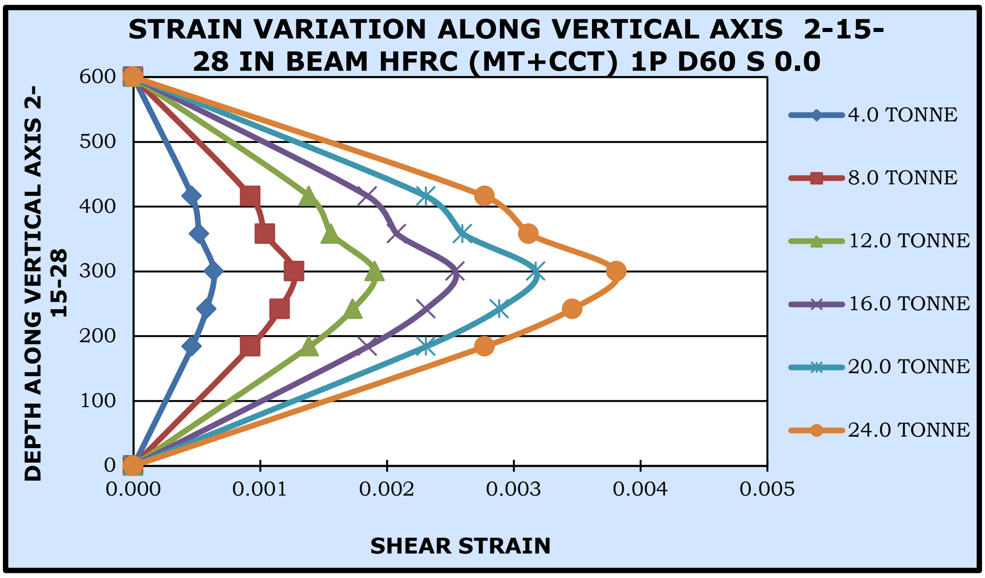
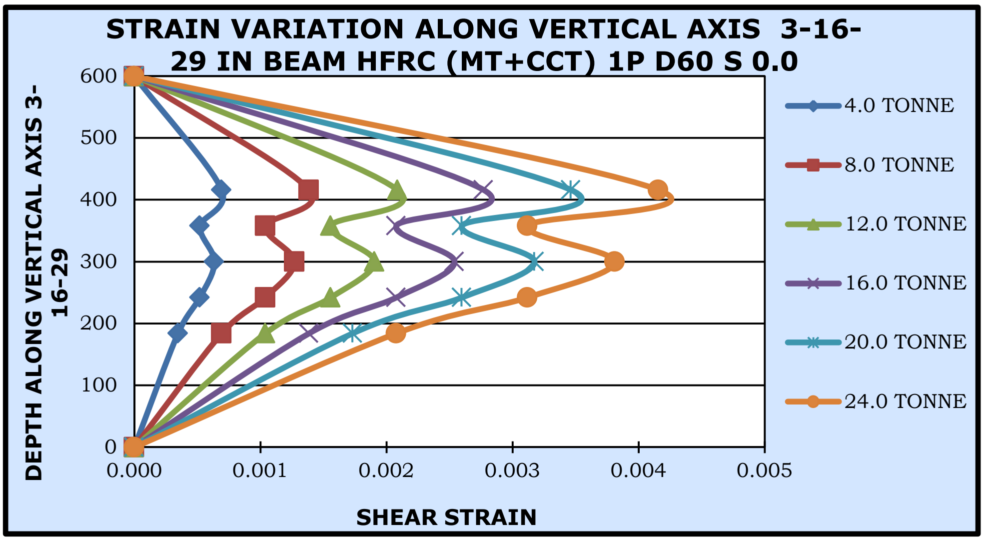
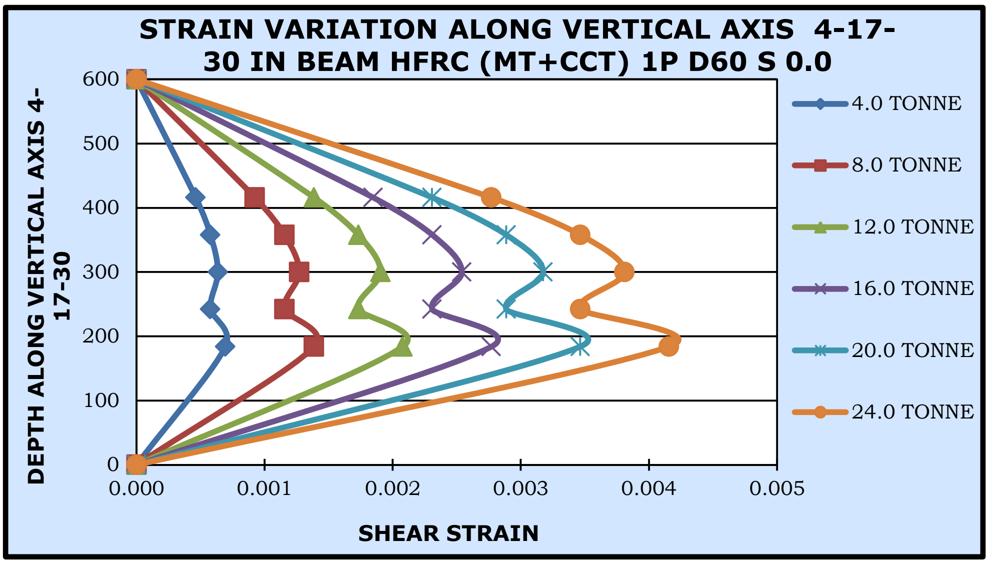
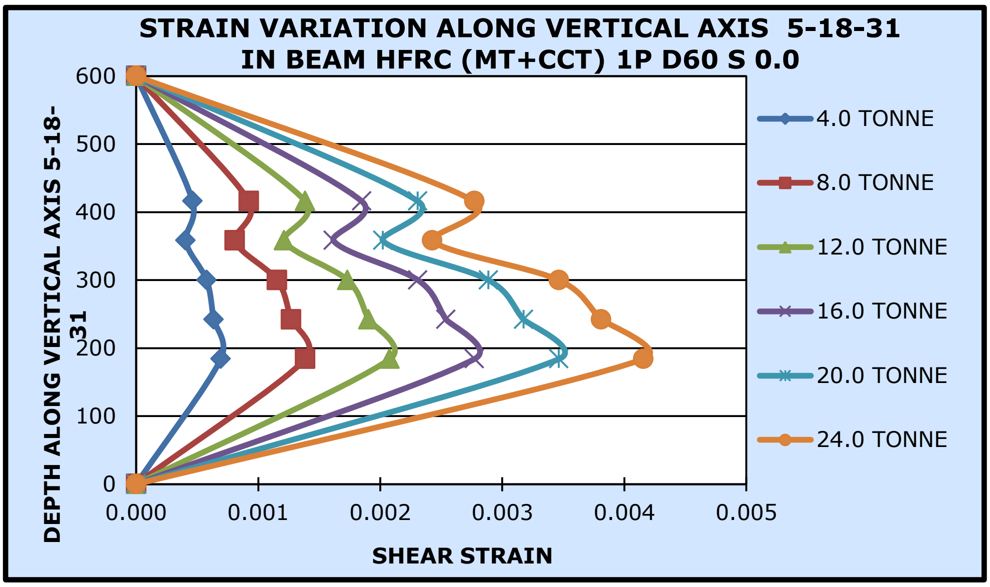


Fig. 4.29 Vertical Shear Strain Graphs Of HFRC (MT+CCT) 1P D50 S0.0


STRAIN VARIATION ALONG VERTICAL AXIS 2-15-28 IN BEAM HFRC (MT+CCT) 1P D60 S 0.0
DEPTH ALONG VERTICAL AXIS 2-15-28
SHEAR STRAIN
0
100
200
300
400
500
600
0.000
0.001
0.002
0.003
0.004
0.005
4.0 TONNE
8.0 TONNE
12.0 TONNE
16.0 TONNE
20.0 TONNE
24.0 TONNE


STRAIN VARIATION ALONG VERTICAL AXIS 3-16-29 IN BEAM HFRC (MT+CCT) 1P D60 S 0.0
DEPTH ALONG VERTICAL AXIS 3-16-29
SHEAR STRAIN
0
100
200
300
400
500
600
0.000
0.001
0.002
0.003
0.004
0.005
4.0 TONNE
8.0 TONNE
12.0 TONNE
16.0 TONNE
20.0 TONNE
24.0 TONNE


STRAIN VARIATION ALONG VERTICAL AXIS 4-17-30 IN BEAM HFRC (MT+CCT) 1P D60 S 0.0
DEPTH ALONG VERTICAL AXIS 4-17-30
SHEAR STRAIN
0
100
200
300
400
500
600
0.000
0.001
0.002
0.003
0.004
0.005
4.0 TONNE
8.0 TONNE
12.0 TONNE
16.0 TONNE
20.0 TONNE
24.0 TONNE



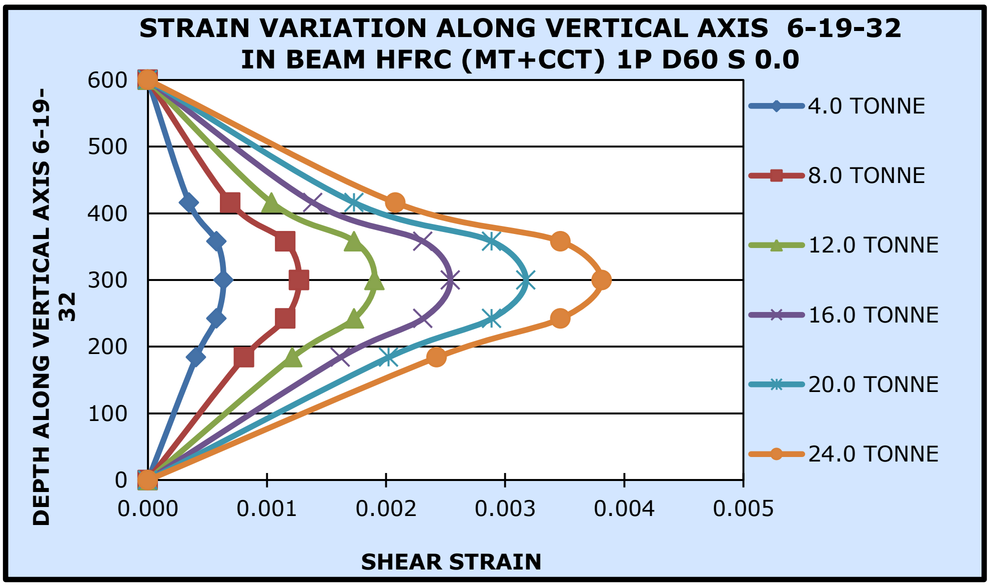
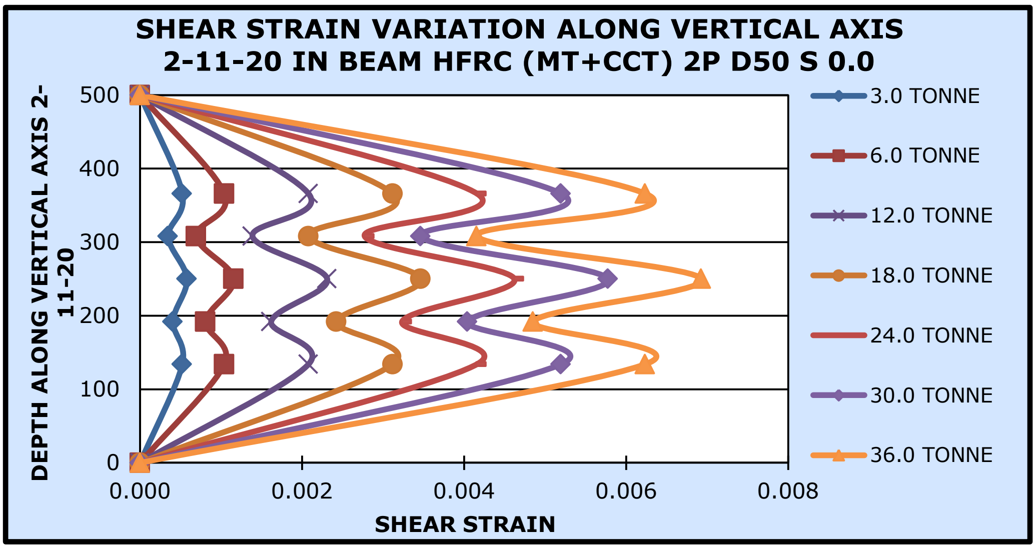
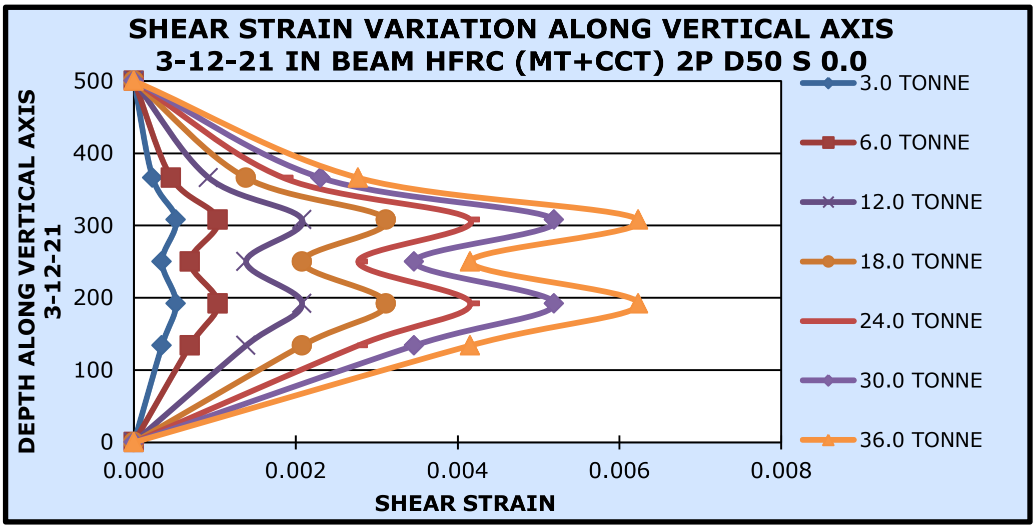


Fig.4.30 Vertical Shear Strain Graphs Of HFRC (MT+CCT) 1P D60 S 0.0





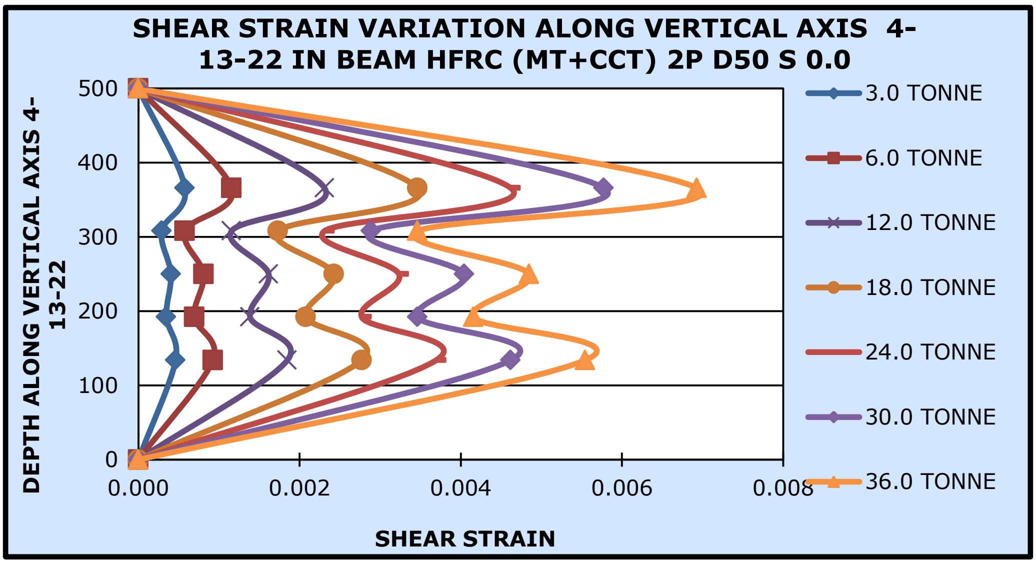
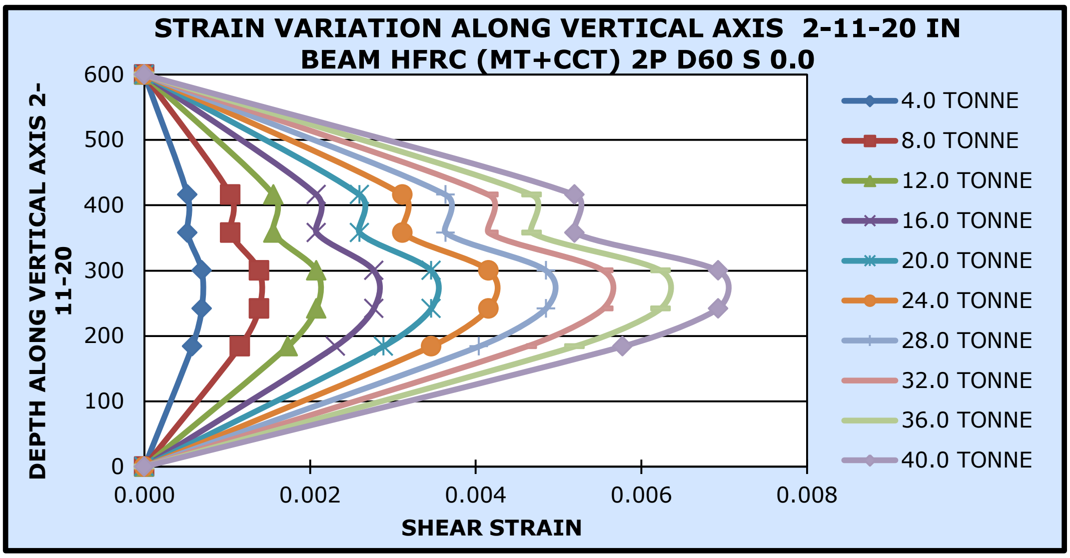
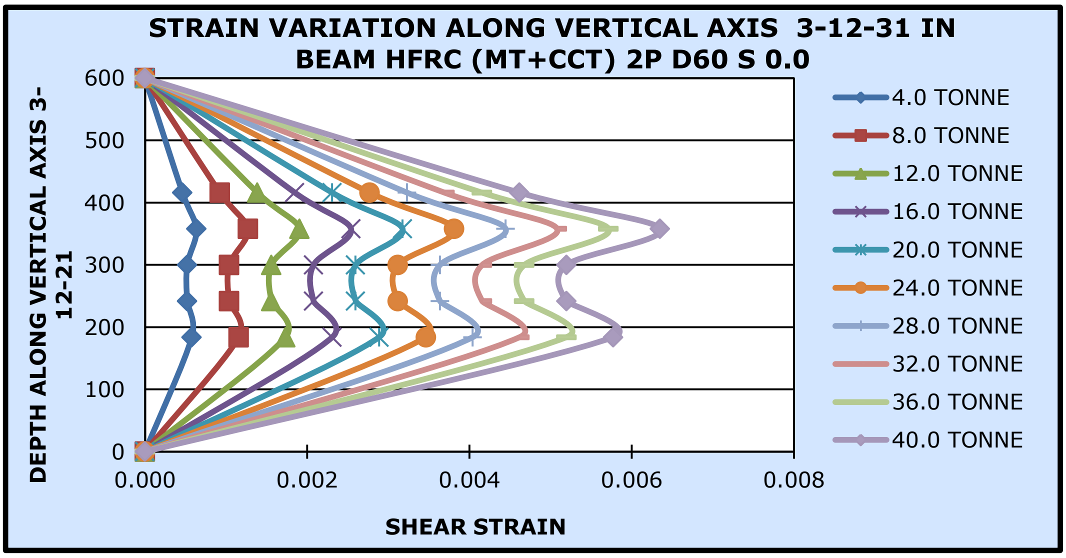


Fig.4.31 Vertical Shear Strain Graphs Of HFRC (MT+CCT) 2P D50 S 0.0





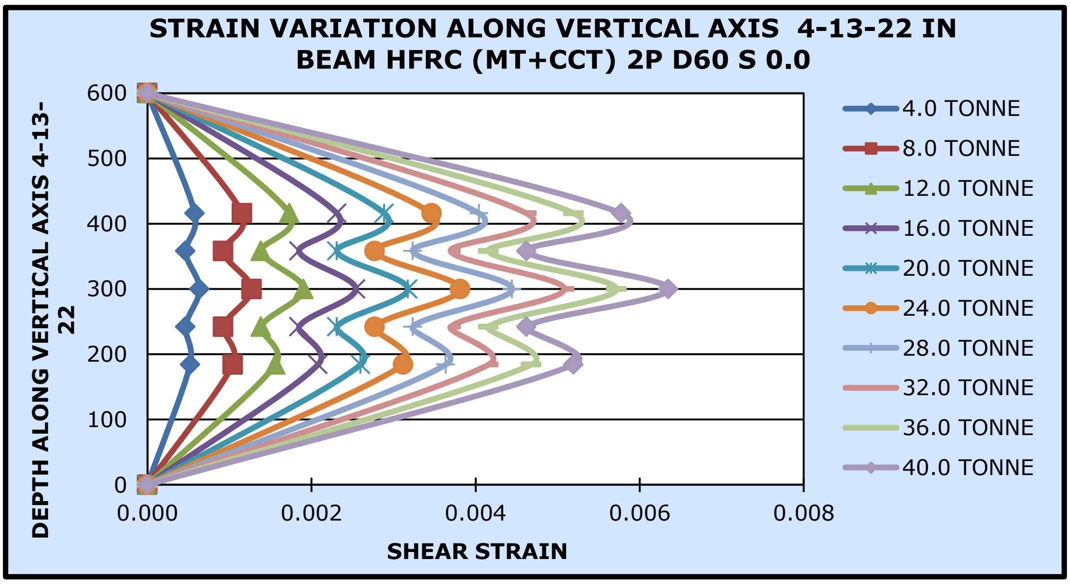


Fig.4.32 Vertical Shear Strain Graphs Of HFRC (MT+CCT) 2P D60 S 0.0

TABLE 4.4.5 Shear Strain Variation Along Vertical Axis For R.C.C. With Stirrups 1P D50 S 0.0

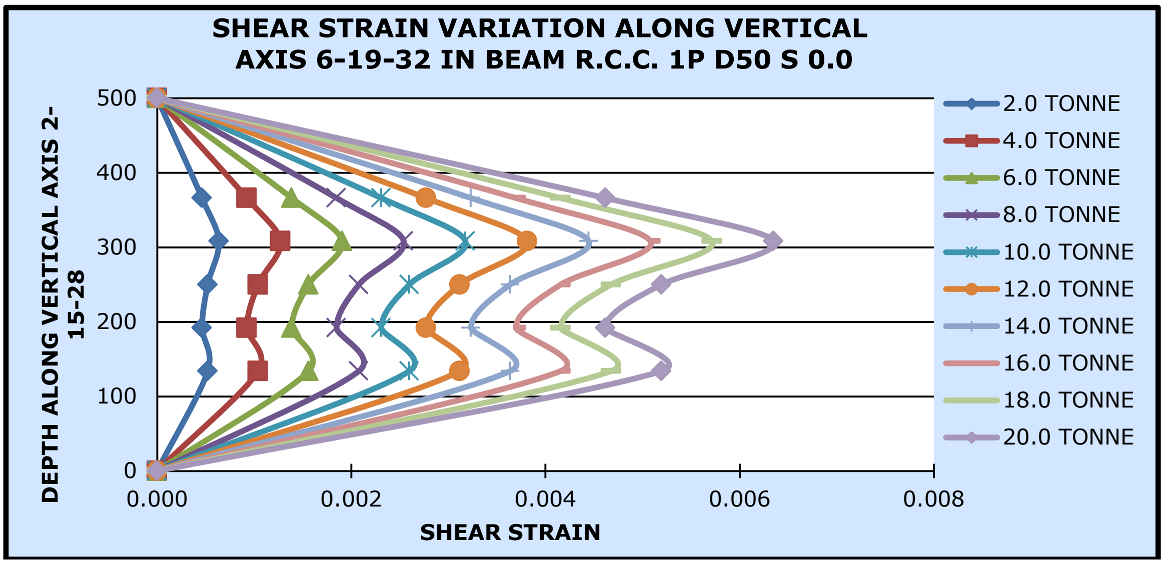
SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 2-15-28 IN R.C.C. 1P D50 S 0.0												
DEPTH	**LOAD**	**0.0 T**	**2.0 T**	**4.0 T**	**6.0 T**	**8.0 T**	**10.0 T**	**12.0 T**	**14.0 T**	**16.0 T**	**18.0 T**	**20.0 T**
500		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
366	**1-3-15**	0.0000	0.0005	0.0009	0.0014	0.0018	0.0023	0.0028	0.0032	0.0037	0.0042	0.0046
308	**2-14-16**	0.0000	0.0006	0.0013	0.0019	0.0025	0.0032	0.0038	0.0044	0.0051	0.0057	0.0064
250	**15.00**	0.0000	0.0005	0.0010	0.0016	0.0021	0.0026	0.0031	0.0036	0.0042	0.0047	0.0052
192	**14-16-28**	0.0000	0.0005	0.0009	0.0014	0.0018	0.0023	0.0028	0.0032	0.0037	0.0042	0.0046
134	**15-27-29**	0.0000	0.0005	0.0010	0.0016	0.0021	0.0026	0.0031	0.0036	0.0042	0.0047	0.0052
0		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

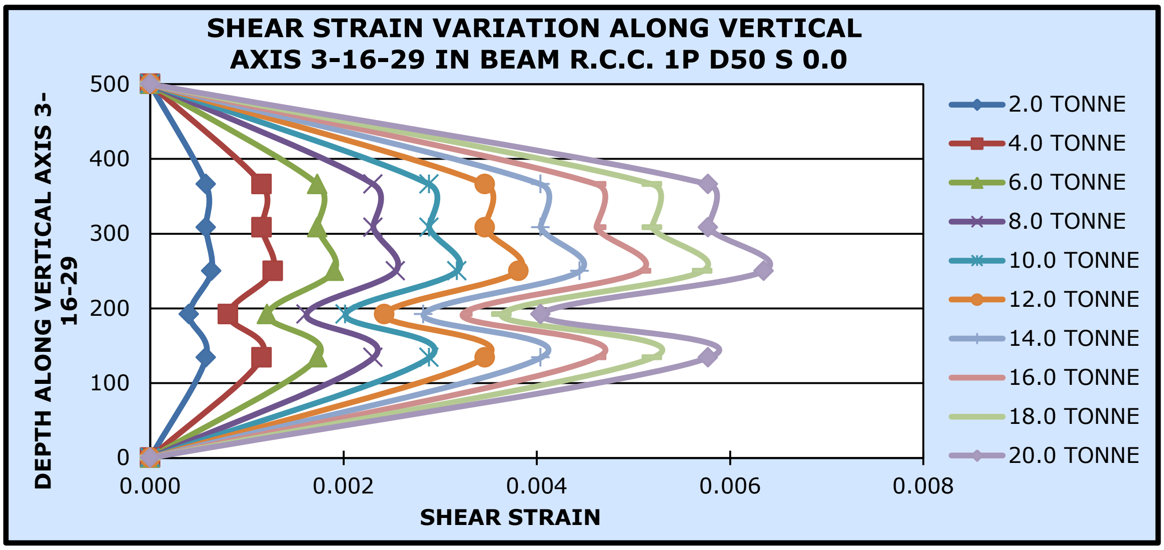
SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 3-16-29 IN R.C.C. 1P D50 S 0.0												
DEPTH	**LOAD**	**0.0 T**	**2.0 T**	**4.0 T**	**6.0 T**	**8.0 T**	**10.0 T**	**12.0 T**	**14.0 T**	**16.0 T**	**18.0 T**	**20.0 T**
500		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
366	**2-4-16**	0.0000	0.0006	0.0012	0.0017	0.0023	0.0029	0.0035	0.0040	0.0046	0.0052	0.0058
308	**3-15-17**	0.0000	0.0006	0.0012	0.0017	0.0023	0.0029	0.0035	0.0040	0.0046	0.0052	0.0058
250	**16.00**	0.0000	0.0006	0.0013	0.0019	0.0025	0.0032	0.0038	0.0044	0.0051	0.0057	0.0064
192	**15-17-29**	0.0000	0.0004	0.0008	0.0012	0.0016	0.0020	0.0024	0.0028	0.0032	0.0036	0.0040
134	**16-28-30**	0.0000	0.0006	0.0012	0.0017	0.0023	0.0029	0.0035	0.0040	0.0046	0.0052	0.0058
0		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

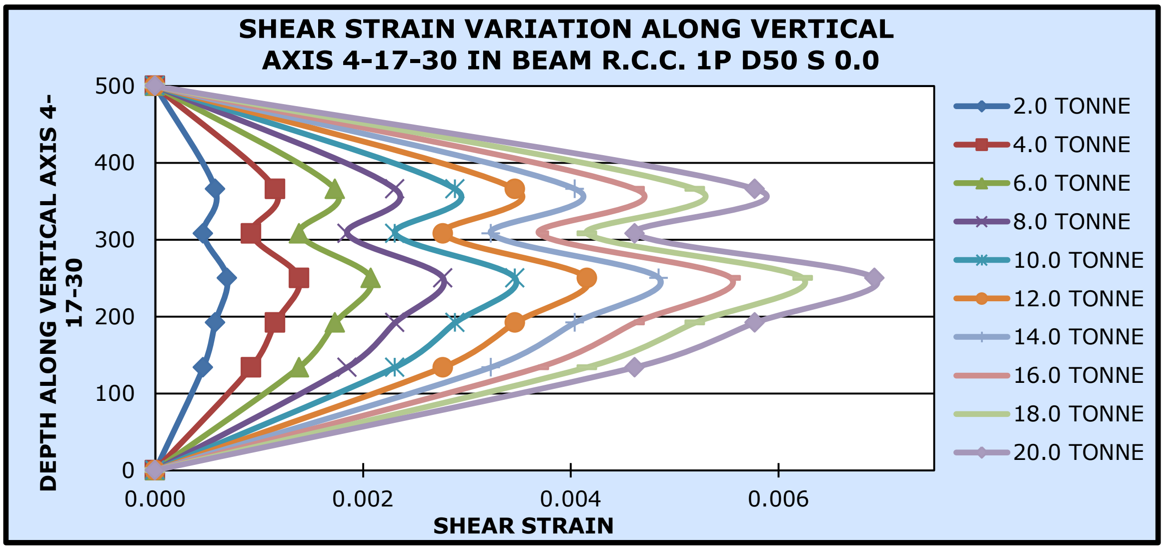
SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 4-17-30 IN R.C.C. 1P D50 S 0.0												
DEPTH	**LOAD**	**0.0 T**	**2.0 T**	**4.0 T**	**6.0 T**	**8.0 T**	**10.0 T**	**12.0 T**	**14.0 T**	**16.0 T**	**18.0 T**	**20.0 T**
500		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
366	**3-5-17**	0.0000	0.0006	0.0012	0.0017	0.0023	0.0029	0.0035	0.0040	0.0046	0.0052	0.0058
308	**4-16-18**	0.0000	0.0005	0.0009	0.0014	0.0018	0.0023	0.0028	0.0032	0.0037	0.0042	0.0046
250	**17**	0.0000	0.0007	0.0014	0.0021	0.0028	0.0035	0.0042	0.0049	0.0055	0.0062	0.0069
192	**16-18-30**	0.0000	0.0006	0.0012	0.0017	0.0023	0.0029	0.0035	0.0040	0.0046	0.0052	0.0058
134	**17-29-31**	0.0000	0.0005	0.0009	0.0014	0.0018	0.0023	0.0028	0.0032	0.0037	0.0042	0.0046
0		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

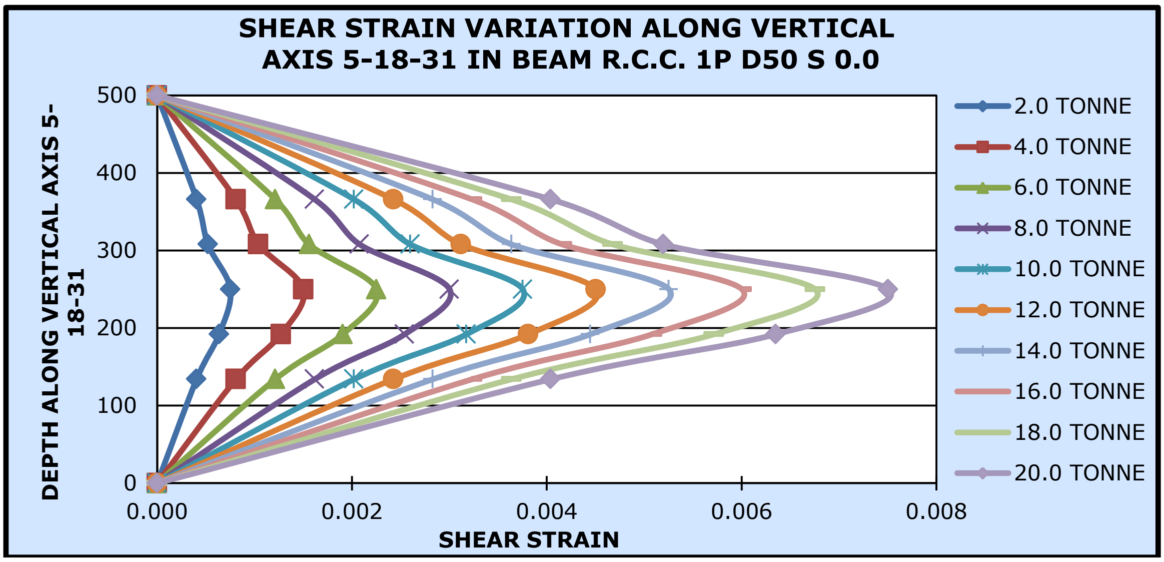
SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 5-18-31 IN R.C.C. 1P D50 S 0.0												
DEPTH	**LOAD**	**0.0 T**	**2.0 T**	**4.0 T**	**6.0 T**	**8.0 T**	**10.0 T**	**12.0 T**	**14.0 T**	**16.0 T**	**18.0 T**	**20.0 T**
500		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
366	**4-6-18**	0.0000	0.0004	0.0008	0.0012	0.0016	0.0020	0.0024	0.0028	0.0032	0.0036	0.0040
308	**5-17-19**	0.0000	0.0005	0.0010	0.0016	0.0021	0.0026	0.0031	0.0036	0.0042	0.0047	0.0052
250	**18.00**	0.0000	0.0008	0.0015	0.0023	0.0030	0.0038	0.0045	0.0053	0.0060	0.0068	0.0075
192	**17-19-31**	0.0000	0.0006	0.0013	0.0019	0.0025	0.0032	0.0038	0.0044	0.0051	0.0057	0.0064
134	**18-30-32**	0.0000	0.0004	0.0008	0.0012	0.0016	0.0020	0.0024	0.0028	0.0032	0.0036	0.0040
0		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 6-19-32 IN R.C.C. 1P D50 S 0.0												
DEPTH	**LOAD**	**0.0 T**	**2.0 T**	**4.0 T**	**6.0 T**	**8.0 T**	**10.0 T**	**12.0 T**	**14.0 T**	**16.0 T**	**18.0 T**	**20.0 T**
500		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
366	**5-7-19**	0.0000	0.0006	0.0013	0.0019	0.0025	0.0032	0.0038	0.0044	0.0051	0.0057	0.0064
308	**6-18-20**	0.0000	0.0005	0.0010	0.0016	0.0021	0.0026	0.0031	0.0036	0.0042	0.0047	0.0052
250	**19.00**	0.0000	0.0006	0.0012	0.0017	0.0023	0.0029	0.0035	0.0040	0.0046	0.0052	0.0058
192	**18-20-32**	0.0000	0.0006	0.0012	0.0017	0.0023	0.0029	0.0035	0.0040	0.0046	0.0052	0.0058
134	**19-31-33**	0.0000	0.0006	0.0013	0.0019	0.0025	0.0032	0.0038	0.0044	0.0051	0.0057	0.0064
0		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000


SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 6-19-32 IN BEAM R.C.C. 1P D50 S 0.0
DEPTH ALONG VERTICAL AXIS 2-15-28
SHEAR STRAIN
0.000
0.002
0.004
0.006
0.008
0
100
200
300
400
500
2.0 TONNE
4.0 TONNE
6.0 TONNE
8.0 TONNE
10.0 TONNE
12.0 TONNE
14.0 TONNE
16.0 TONNE
18.0 TONNE
20.0 TONNE


SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 3-16-29 IN BEAM R.C.C. 1P D50 S 0.0
DEPTH ALONG VERTICAL AXIS 3-16-29
SHEAR STRAIN
0.000
0.002
0.004
0.006
0.008
0
100
200
300
400
500
2.0 TONNE
4.0 TONNE
6.0 TONNE
8.0 TONNE
10.0 TONNE
12.0 TONNE
14.0 TONNE
16.0 TONNE
18.0 TONNE
20.0 TONNE


SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 4-17-30 IN BEAM R.C.C. 1P D50 S 0.0
DEPTH ALONG VERTICAL AXIS 4-17-30
SHEAR STRAIN
0.000
0.002
0.004
0.006
0
100
200
300
400
500
2.0 TONNE
4.0 TONNE
6.0 TONNE
8.0 TONNE
10.0 TONNE
12.0 TONNE
14.0 TONNE
16.0 TONNE
18.0 TONNE
20.0 TONNE



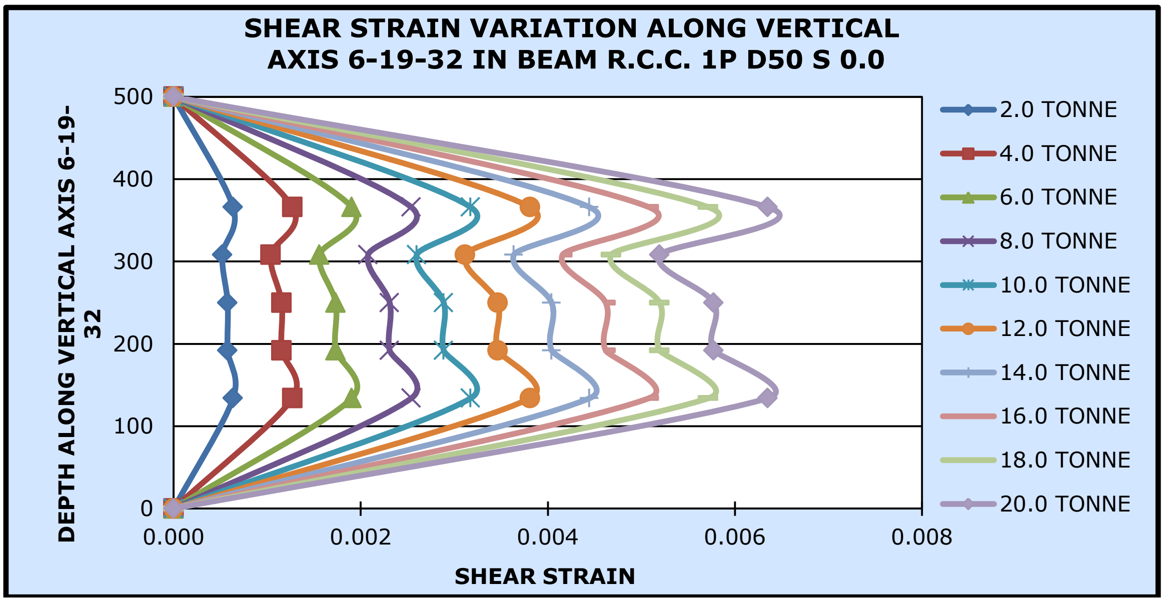
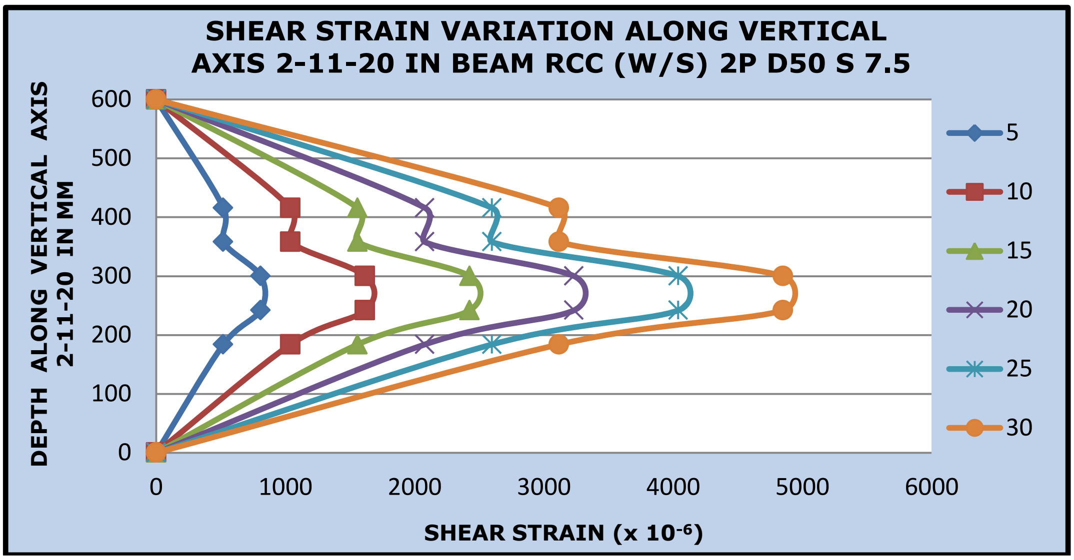
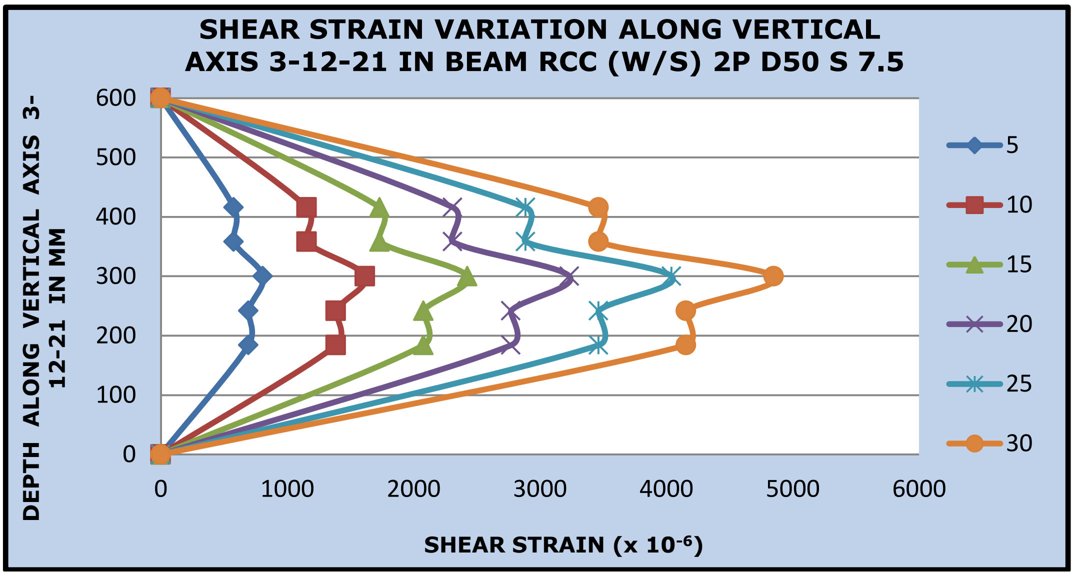


Fig. 4.33 Vertical Shear Strain Graphs Of R.C.C. 1P D50 S 0.0





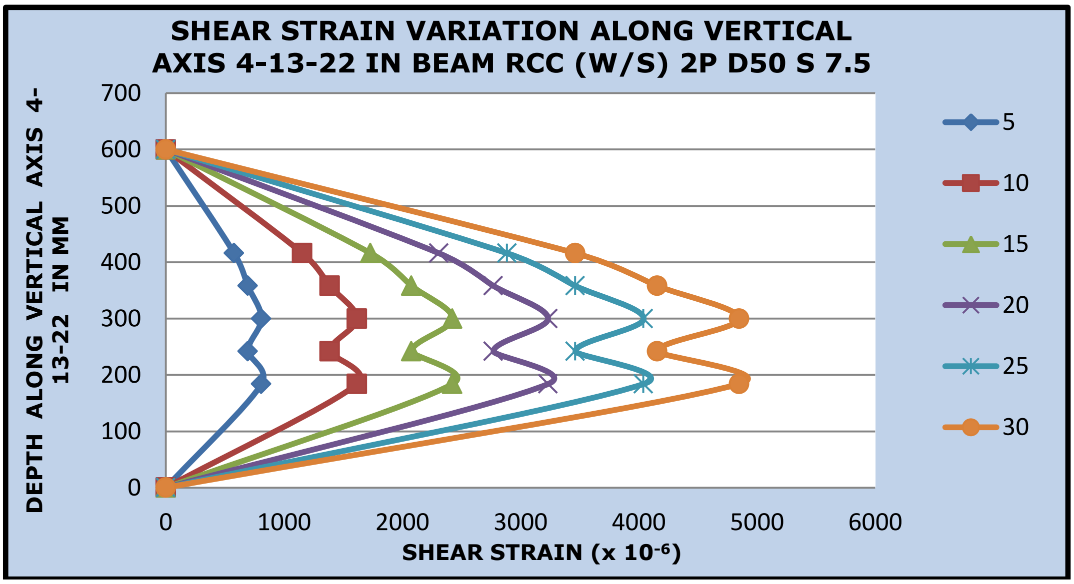


Fig. 4.34 Vertical Shear Strain Graphs Of RCC (W/S) 2P D50 S 7.5

TABLE 4.4.6 Shear Strain Variation Along Vertical Axis For R.C.C. Without Stirrups 1P D50 S 0.0

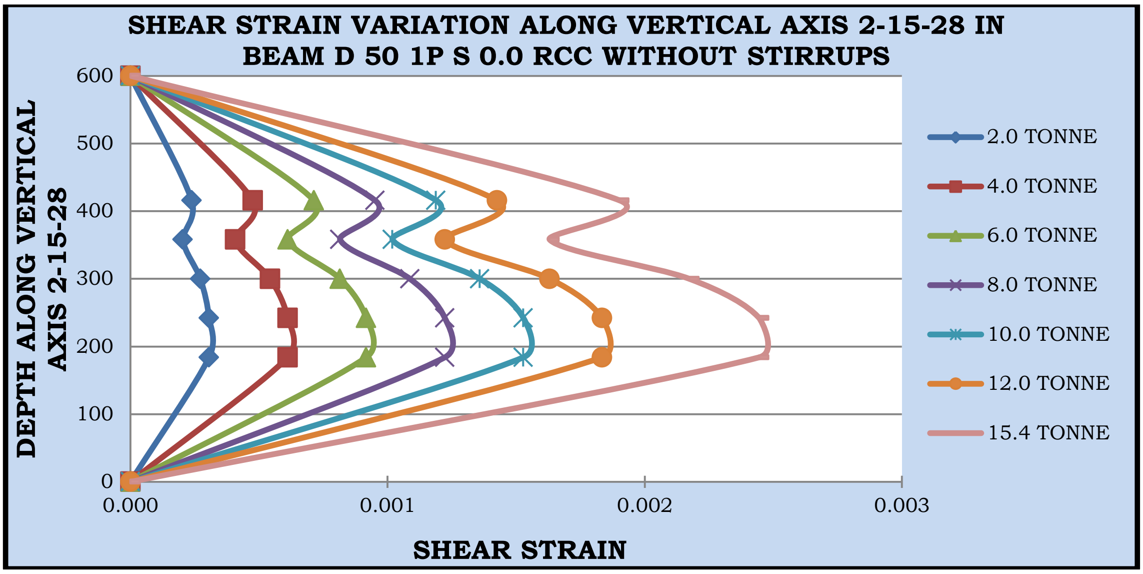
DEPTH	LOAD	0	2	4	6	8	10	12	15.4
600		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
416	1-3-15	0.00	0.000404145	0.00080829	0.001212436	0.001616581	0.002020726	0.002424871	0.002829016
358	2-14-16	0.00	0.00034641	0.00069282	0.00103923	0.001385641	0.001732051	0.002078461	0.002424871
300	15.00	0.00	0.00046188	0.00092376	0.001385641	0.001847521	0.002309401	0.002771281	0.003233162
242	14-16-28	0.00	0.000519615	0.00103923	0.001558846	0.002078461	0.002598076	0.003117691	0.003637307
184	15-27-29	0.00	0.000519615	0.00103923	0.001558846	0.002078461	0.002598076	0.003117691	0.003637307
0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

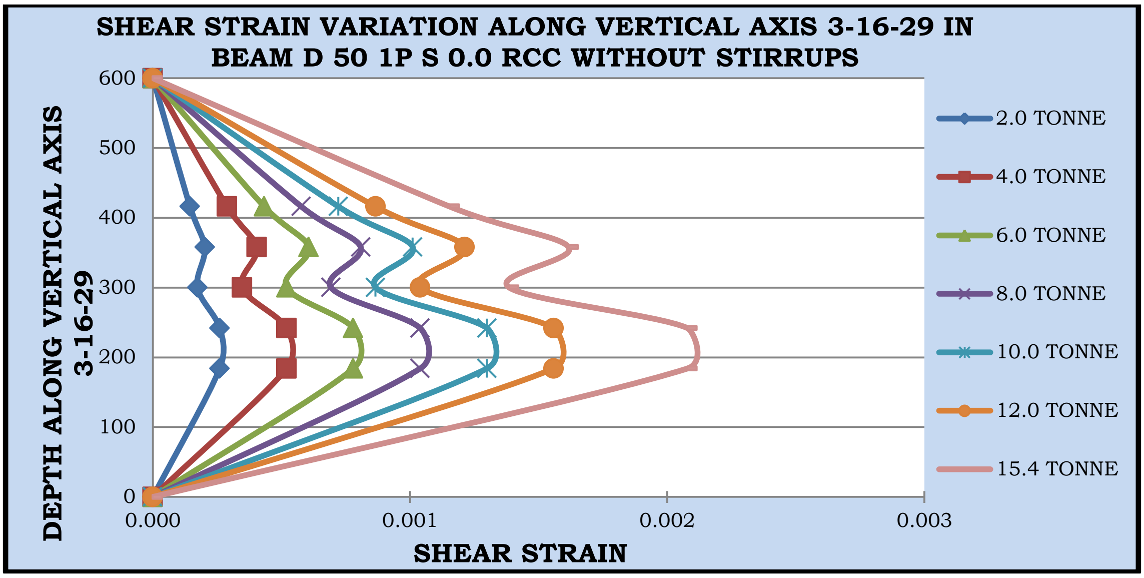
DEPTH	LOAD	0	2	4	6	8	10	12	15.4
600		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
416	2-4-16	0.00	0.000288675	0.00057735	0.000866025	0.001154701	0.001443376	0.001732051	0.002020726
358	3-15-17	0.00	0.000404145	0.00080829	0.001212436	0.001616581	0.002020726	0.002424871	0.002829016
300	16.00	0.00	0.00034641	0.00069282	0.00103923	0.001385641	0.001732051	0.002078461	0.002424871
242	15-17-29	0.00	0.000519615	0.00103923	0.001558846	0.002078461	0.002598076	0.003117691	0.003637307
184	16-28-30	0.00	0.000519615	0.00103923	0.001558846	0.002078461	0.002598076	0.003117691	0.003637307
0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

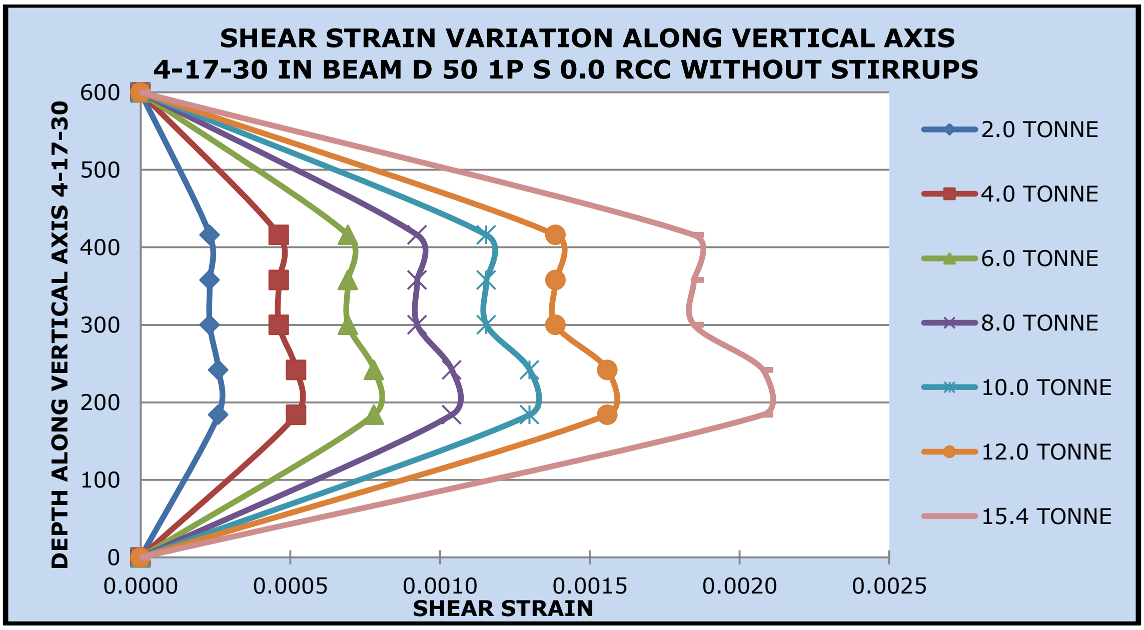
DEPTH	LOAD	0	2	4	6	8	10	12	15.4
600		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
416	3-5-17	0.00	0.00046188	0.00092376	0.001385641	0.001847521	0.002309401	0.002771281	0.003233162
358	4-16-18	0.00	0.00046188	0.00092376	0.001385641	0.001847521	0.002309401	0.002771281	0.003233162
300	17	0.00	0.00046188	0.00092376	0.001385641	0.001847521	0.002309401	0.002771281	0.003233162
242	16-18-30	0.00	0.000519615	0.00103923	0.001558846	0.002078461	0.002598076	0.003117691	0.003637307
184	17-29-31	0.00	0.000519615	0.00103923	0.001558846	0.002078461	0.002598076	0.003117691	0.003637307
0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

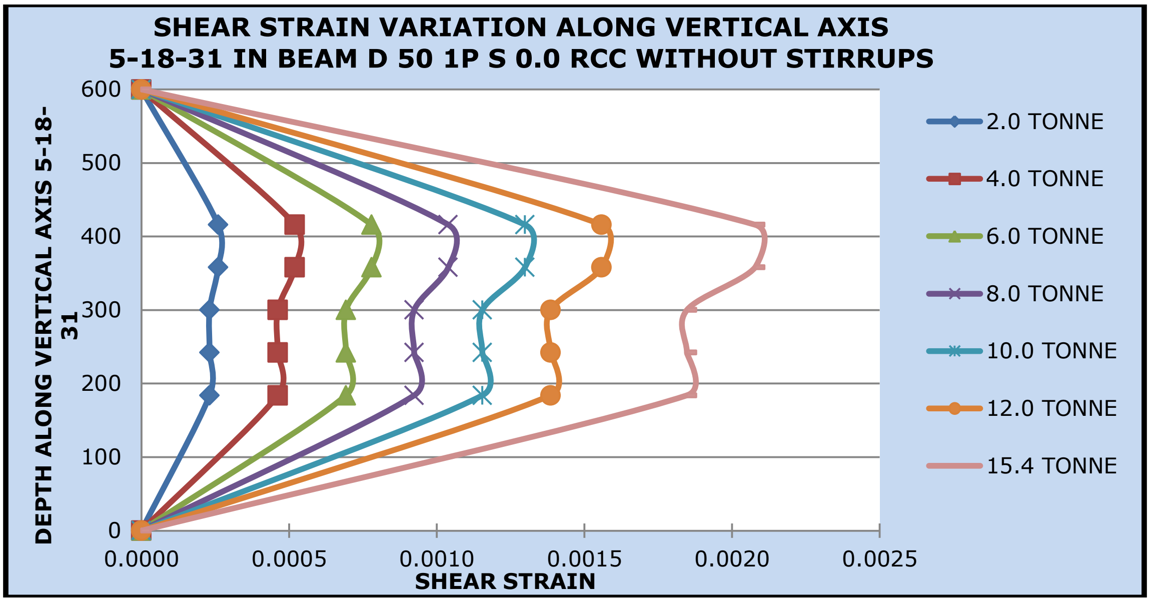
DEPTH	LOAD	0	2	4	6	8	10	12	15.4
600		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
416	**4-6-18**	0.00	0.000520	0.001039	0.001559	0.002078	0.002598	0.003118	0.003637
358	**5-17-19**	0.00	0.000520	0.001039	0.001559	0.002078	0.002598	0.003118	0.003637
300	**18.00**	0.00	0.000462	0.000924	0.001386	0.001848	0.002309	0.002771	0.003233
242	**17-19-31**	0.00	0.000462	0.000924	0.001386	0.001848	0.002309	0.002771	0.003233
184	**18-30-32**	0.00	0.000462	0.000924	0.001386	0.001848	0.002309	0.002771	0.003233
0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

DEPTH	LOAD	0	2	4	6	8	10	12	15.4
600		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
416	**5-7-19**	0.00	0.000346	0.000693	0.001039	0.001386	0.001732	0.002078	0.002425
358	**6-18-20**	0.00	0.000635	0.001270	0.001905	0.002540	0.003175	0.003811	0.004446
300	**19.00**	0.00	0.000462	0.000924	0.001386	0.001848	0.002309	0.002771	0.003233
242	**18-20-32**	0.00	0.000462	0.000924	0.001386	0.001848	0.002309	0.002771	0.003233
184	**19-31-33**	0.00	0.000462	0.000924	0.001386	0.001848	0.002309	0.002771	0.003233
0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00


SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 2-15-28 IN BEAM D 50 1P S 0.0 RCC WITHOUT STIRRUPS
DEPTH ALONG VERTICAL AXIS 2-15-28
SHEAR STRAIN
0
100
200
300
400
500
600
0.000
0.001
0.002
0.003
2.0 TONNE
4.0 TONNE
6.0 TONNE
8.0 TONNE
10.0 TONNE
12.0 TONNE
15.4 TONNE


SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 3-16-29 IN BEAM D 50 1P S 0.0 RCC WITHOUT STIRRUPS
DEPTH ALONG VERTICAL AXIS 3-16-29
SHEAR STRAIN
0
100
200
300
400
500
600
0.000
0.001
0.002
0.003
2.0 TONNE
4.0 TONNE
6.0 TONNE
8.0 TONNE
10.0 TONNE
12.0 TONNE
15.4 TONNE


SHEAR STRAIN VARIATION ALONG VERTICAL AXIS 4-17-30 IN BEAM D 50 1P S 0.0 RCC WITHOUT STIRRUPS
DEPTH ALONG VERTICAL AXIS 4-17-30
SHEAR STRAIN
0
100
200
300
400
500
600
0.0000
0.0005
0.0010
0.0015
0.0020
0.0025
2.0 TONNE
4.0 TONNE
6.0 TONNE
8.0 TONNE
10.0 TONNE
12.0 TONNE
15.4 TONNE



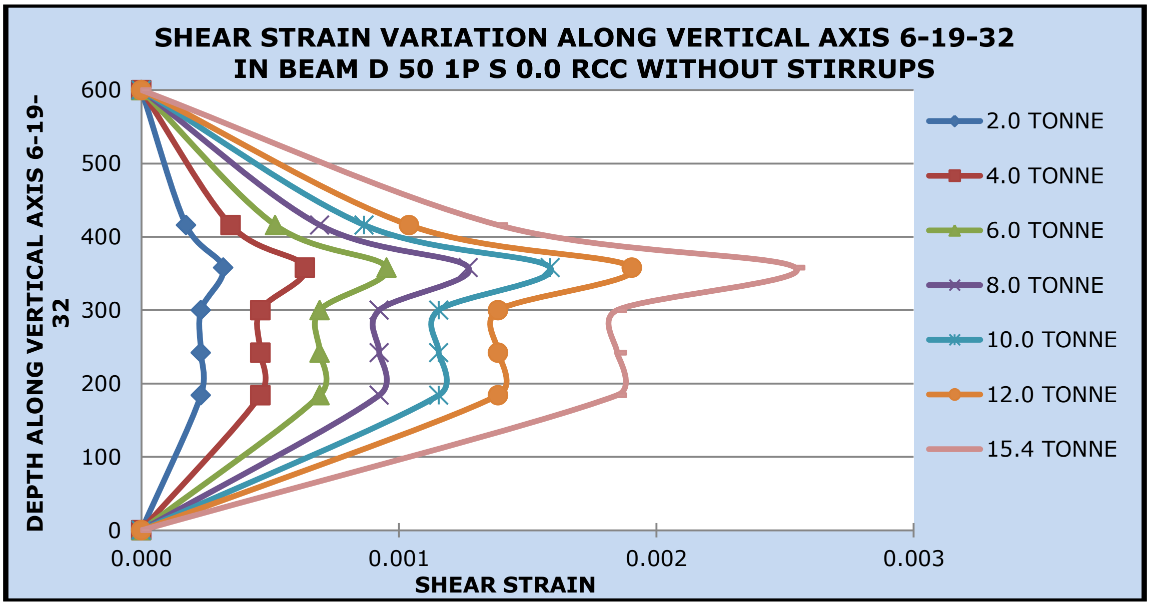
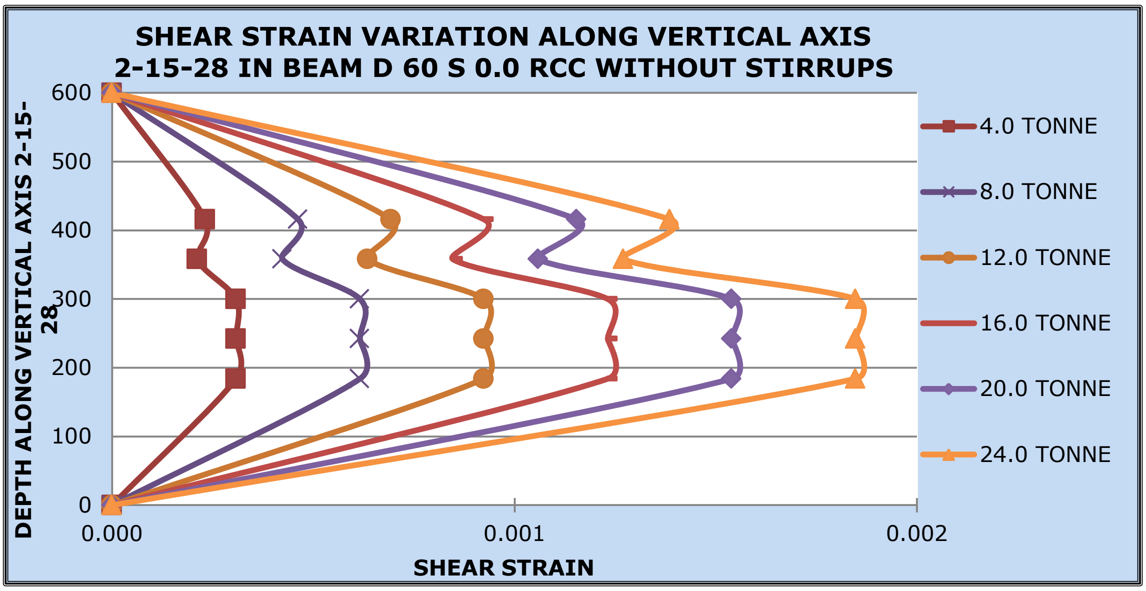
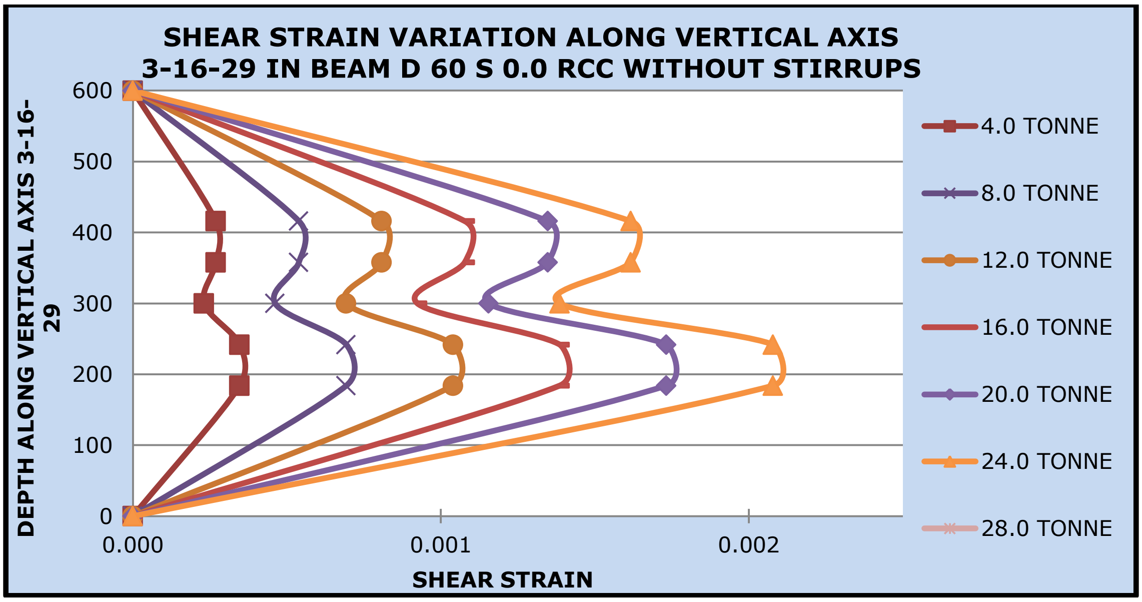
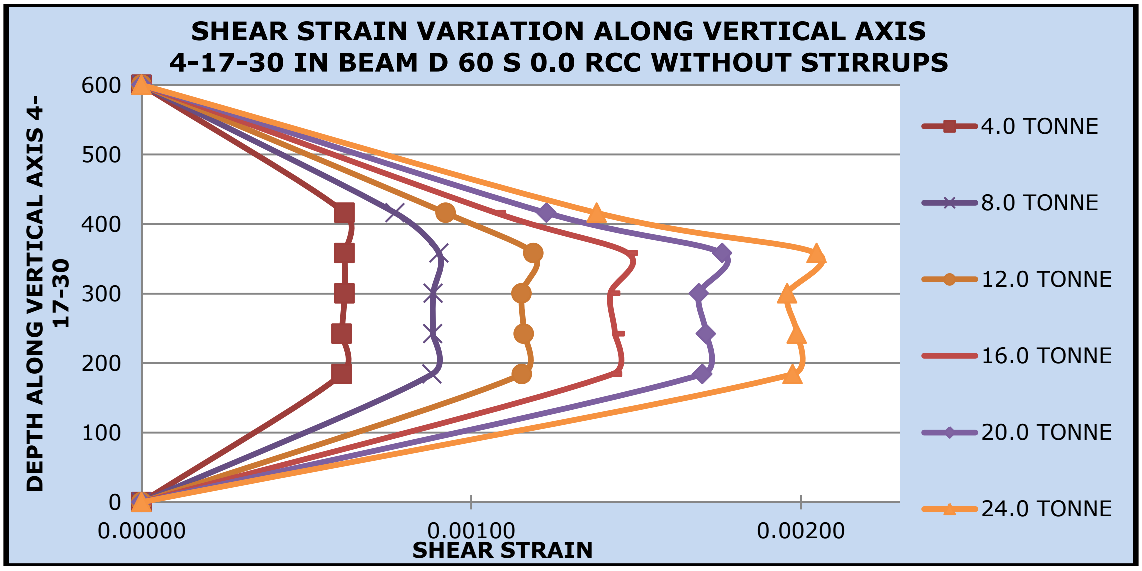
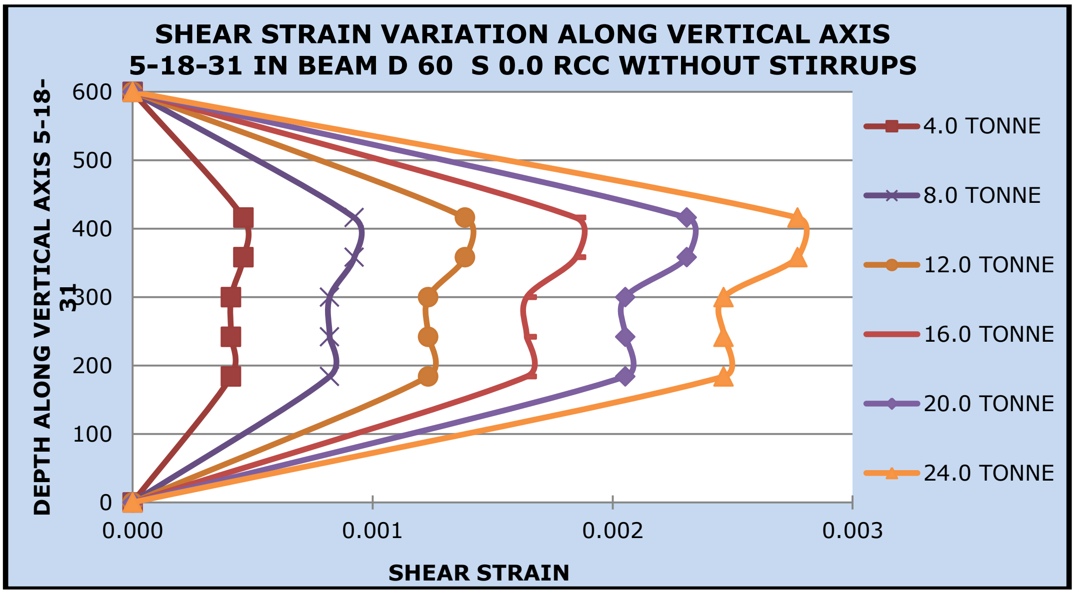


Fig. 4.35 Vertical Shear Strain Graphs Of R.C.C. (W/O/S) 1P D50 S 0.0


SHEAR STRAIN VARIATION ALONG VERTICAL AXIS
2-15-28 IN BEAM D 60 S 0.0 RCC WITHOUT STIRRUPS
DEPTH ALONG VERTICAL AXIS 2-15-28
SHEAR STRAIN
0.000
0.001
0.002
0
100
200
300
400
500
600
4.0 TONNE
8.0 TONNE
12.0 TONNE
16.0 TONNE
20.0 TONNE
24.0 TONNE


SHEAR STRAIN VARIATION ALONG VERTICAL AXIS
3-16-29 IN BEAM D 60 S 0.0 RCC WITHOUT STIRRUPS
DEPTH ALONG VERTICAL AXIS 3-16-29
SHEAR STRAIN
0.000
0.001
0.002
0
100
200
300
400
500
600
4.0 TONNE
8.0 TONNE
12.0 TONNE
16.0 TONNE
20.0 TONNE
24.0 TONNE
28.0 TONNE


SHEAR STRAIN VARIATION ALONG VERTICAL AXIS
4-17-30 IN BEAM D 60 S 0.0 RCC WITHOUT STIRRUPS
DEPTH ALONG VERTICAL AXIS 4-17-30
SHEAR STRAIN
0.00000
0.00100
0.00200
0
100
200
300
400
500
600
4.0 TONNE
8.0 TONNE
12.0 TONNE
16.0 TONNE
20.0 TONNE
24.0 TONNE



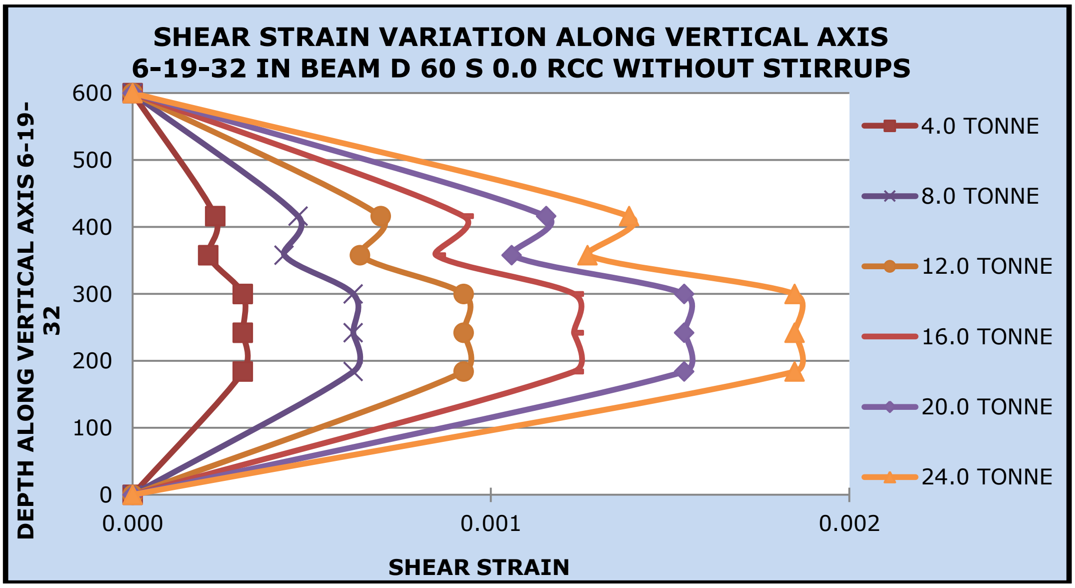
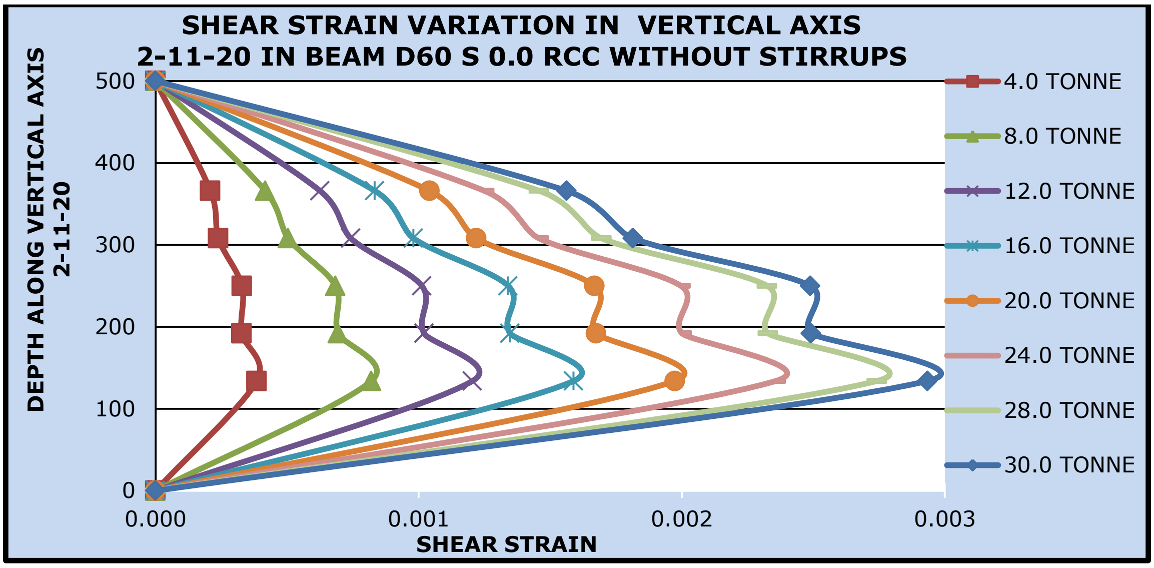
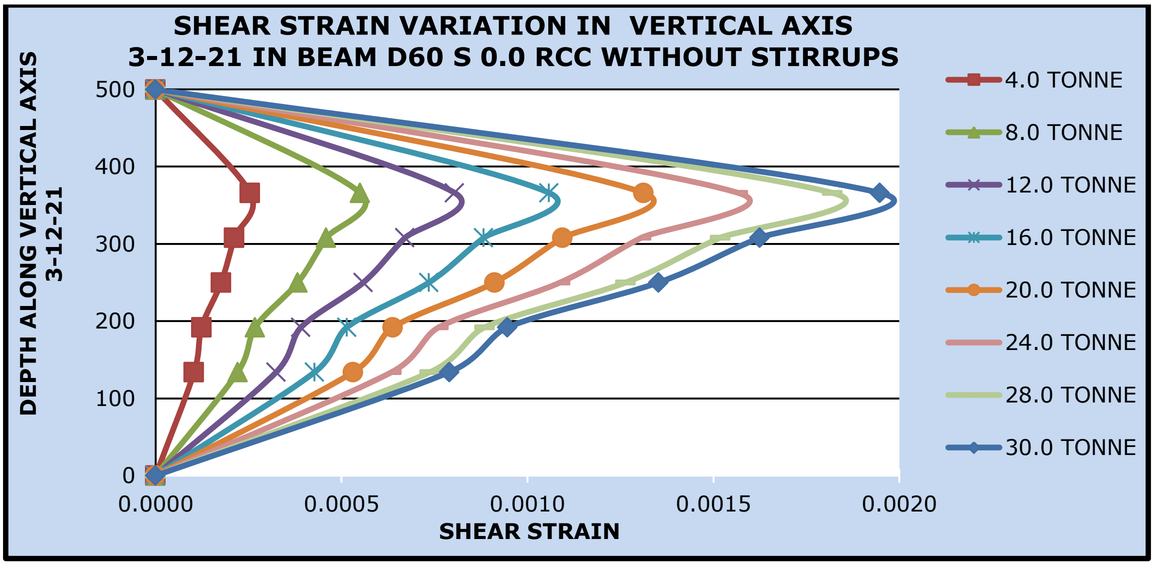


Fig. 4.36 Vertical Shear Strain Graphs Of R.C.C. (W/O/S) 1P D60 S 0.0





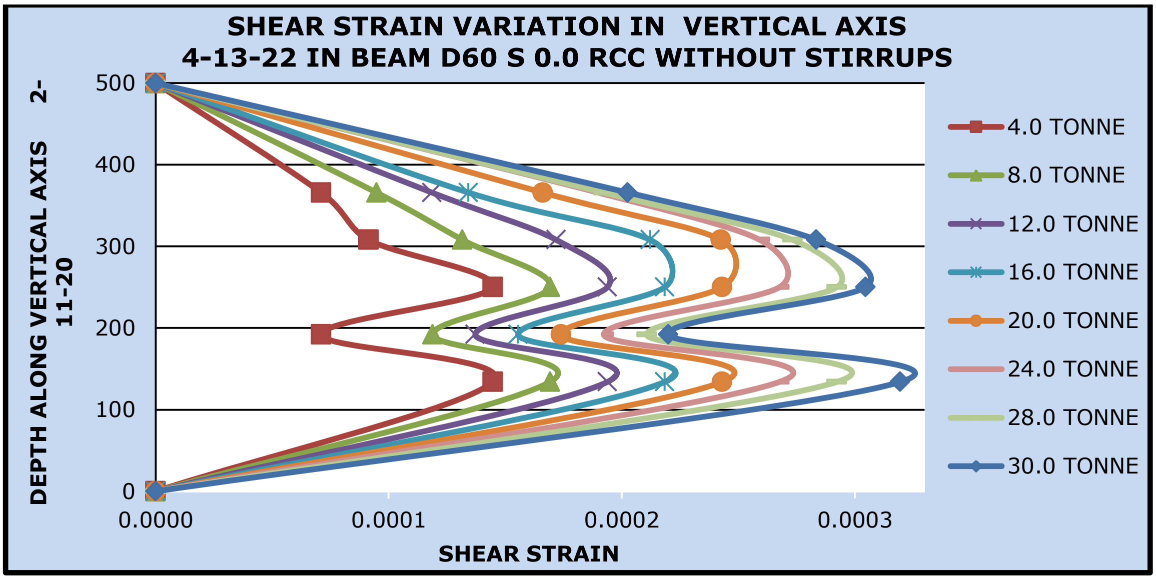
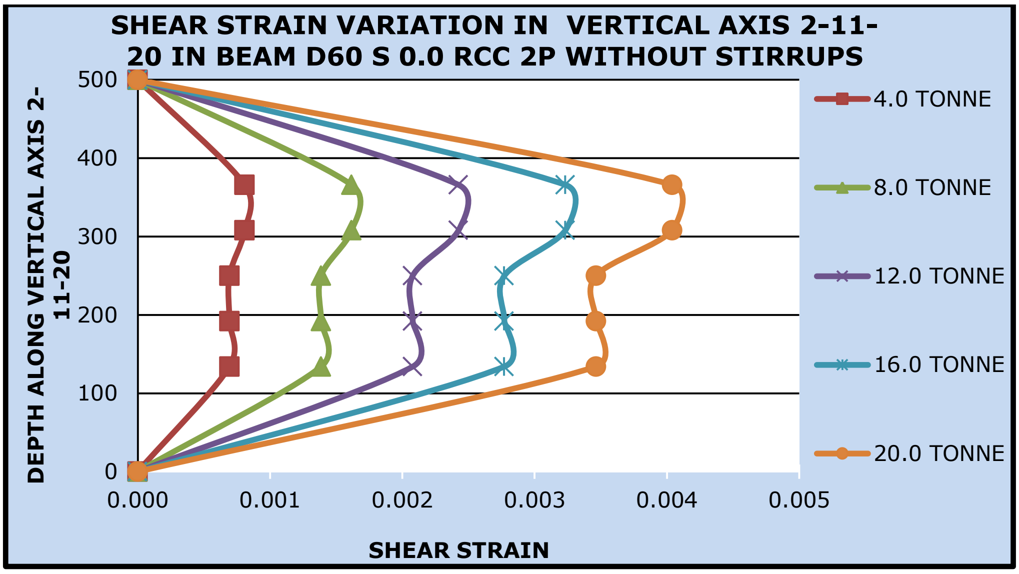
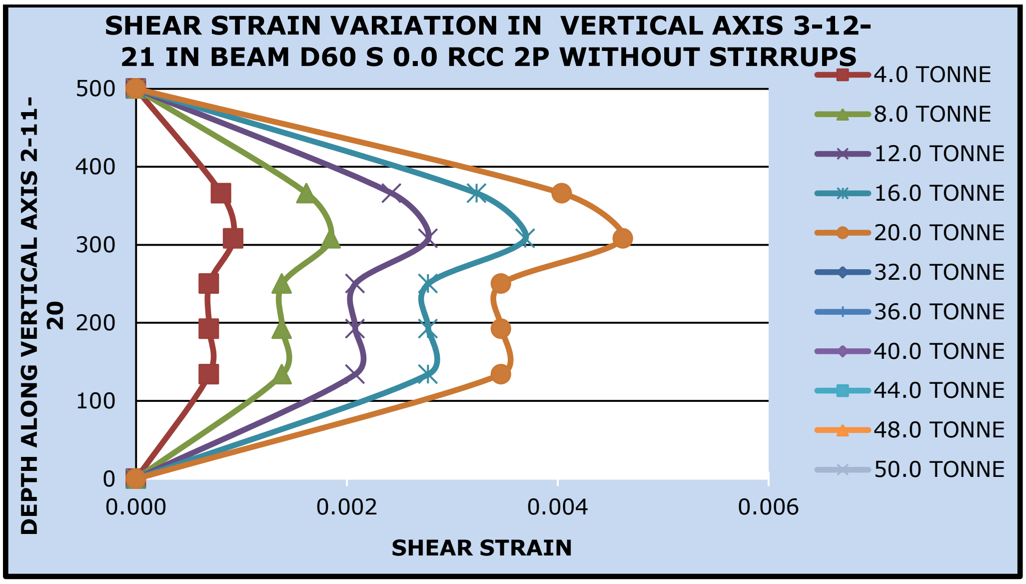


Fig.4.37 Vertical Shear Strain Graphs Of R.C.C. (W/O/S) 2P D60 S 0.0





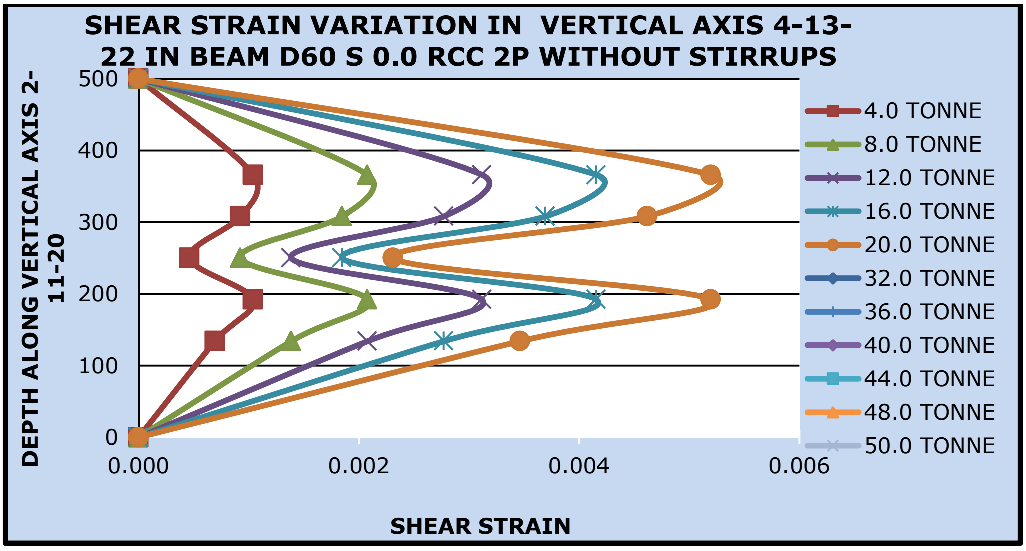


Fig.4.38 Vertical Shear Strain Graphs Of R.C.C. (W/O/S) 2P D50 S 0.0

TABLE GROUP 4.5 PRINCIPAL TENSILE STRAIN VARIATION ALONG INCLINED AXIS

TABLE 4.5.1 Principal Tensile Strain Variation Along Inclined Axis For PPFRC (MT) 1P D50 S 0.0

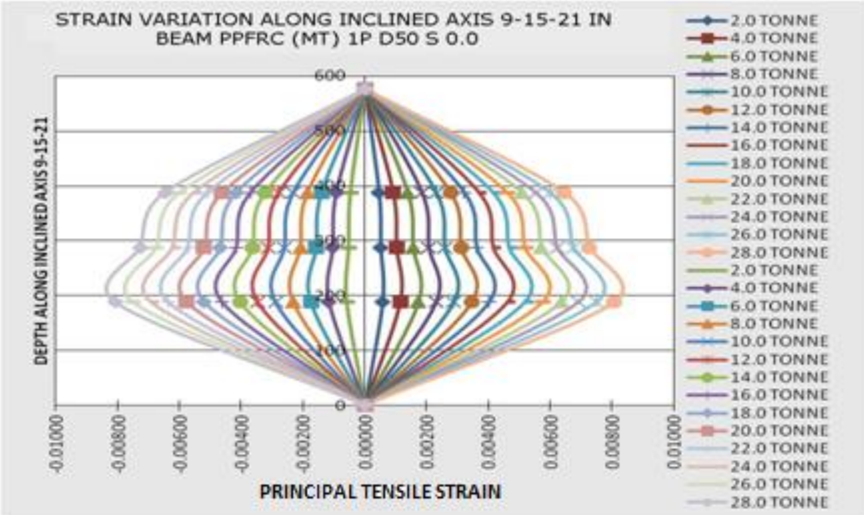
PRINCIPAL TENSILE STRAIN VARIATION ALONG INCLINED AXIS 9-15-21 IN PPFRC (MT) 1P D50 S 0.0																
DEPTH	**LOAD**	**0.0 T**	**2.0 T**	**4.0 T**	**6.0 T**	**8.0 T**	**10.0 T**	**12.0 T**	**14.0 T**	**16.0 T**	**18.0 T**	**20.0 T**	**22.0 T**	**24.0 T**	**26.0 T**	**28.0 T**
577		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
388	**9**	0.0000	0.0005	0.0009	0.0014	0.0018	0.0023	0.0028	0.0032	0.0037	0.0042	0.0046	0.0051	0.0055	0.0060	0.0065
288	**15**	0.0000	0.0005	0.0010	0.0016	0.0021	0.0026	0.0031	0.0036	0.0042	0.0047	0.0052	0.0057	0.0062	0.0068	0.0073
188	**21**	0.0000	0.0006	0.0012	0.0017	0.0023	0.0029	0.0035	0.0040	0.0046	0.0052	0.0058	0.0064	0.0069	0.0075	0.0081
0		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

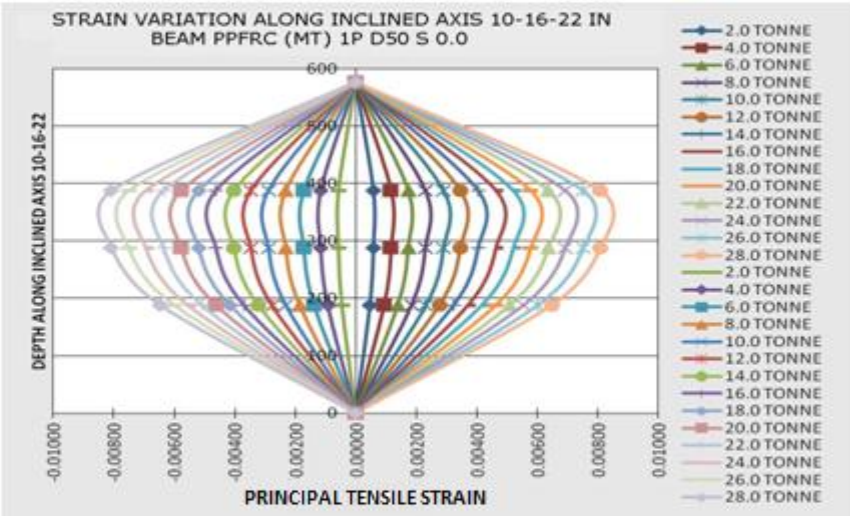
PRINCIPAL TENSILE STRAIN VARIATION ALONG INCLINED AXIS 10-16-22 IN PPFRC (MT) 1P D50 S 0.0																
DEPTH	**LOAD**	**0.0 T**	**2.0 T**	**4.0 T**	**6.0 T**	**8.0 T**	**10.0 T**	**12.0 T**	**14.0 T**	**16.0 T**	**18.0 T**	**20.0 T**	**22.0 T**	**24.0 T**	**26.0 T**	**28.0 T**
577		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
388	**10**	0.0000	0.0006	0.0012	0.0017	0.0023	0.0029	0.0035	0.0040	0.0046	0.0052	0.0058	0.0064	0.0069	0.0075	0.0081
288	**16**	0.0000	0.0006	0.0012	0.0017	0.0023	0.0029	0.0035	0.0040	0.0046	0.0052	0.0058	0.0064	0.0069	0.0075	0.0081
188	**22**	0.0000	0.0005	0.0009	0.0014	0.0018	0.0023	0.0028	0.0032	0.0037	0.0042	0.0046	0.0051	0.0055	0.0060	0.0065
0		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

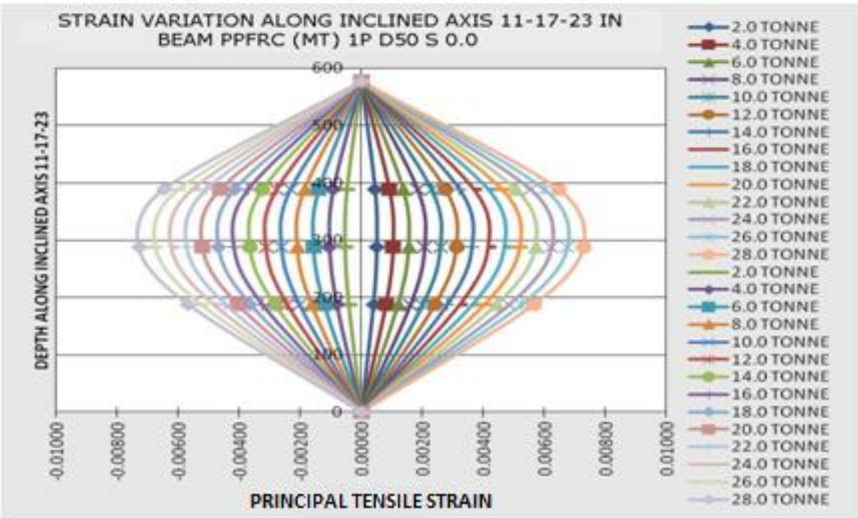
PRINCIPAL TENSILE STRAIN VARIATION ALONG INCLINED AXIS 11-17-23 IN PPFRC (MT) 1P D50 S 0.0																
DEPTH	**LOAD**	**0.0 T**	**2.0 T**	**4.0 T**	**6.0 T**	**8.0 T**	**10.0 T**	**12.0 T**	**14.0 T**	**16.0 T**	**18.0 T**	**20.0 T**	**22.0 T**	**24.0 T**	**26.0 T**	**28.0 T**
577		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
388	**11**	0.0000	0.0005	0.0009	0.0014	0.0018	0.0023	0.0028	0.0032	0.0037	0.0042	0.0046	0.0051	0.0055	0.0060	0.0065
288	**17**	0.0000	0.0005	0.0010	0.0016	0.0021	0.0026	0.0031	0.0036	0.0042	0.0047	0.0052	0.0057	0.0062	0.0068	0.0073
188	**23**	0.0000	0.0004	0.0008	0.0012	0.0016	0.0020	0.0024	0.0028	0.0032	0.0036	0.0040	0.0044	0.0049	0.0053	0.0057
0		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

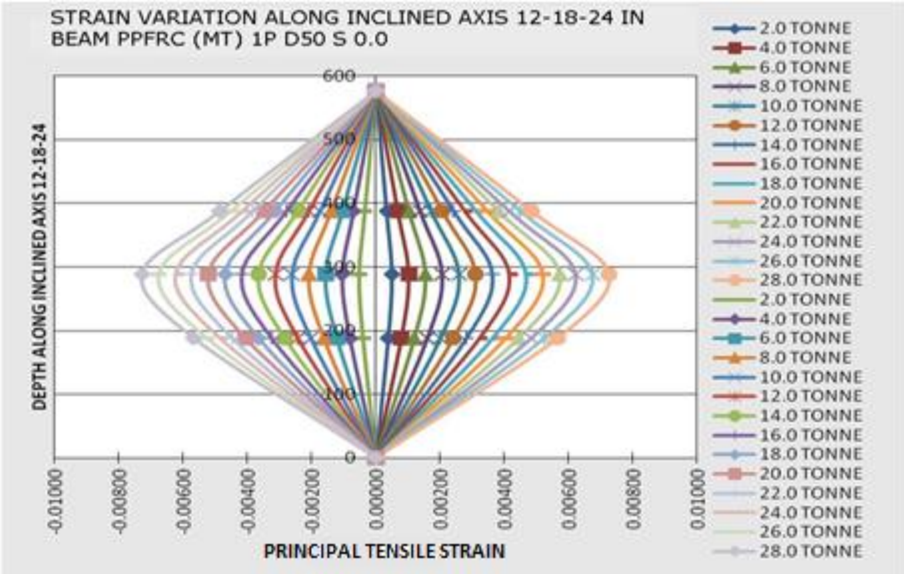
PRINCIPAL TENSILE STRAIN VARIATION ALONG INCLINED AXIS 12-18-24 IN PPFRC (MT) 1P D50 S 0.0																
DEPTH	**LOAD**	**0.0 T**	**2.0 T**	**4.0 T**	**6.0 T**	**8.0 T**	**10.0 T**	**12.0 T**	**14.0 T**	**16.0 T**	**18.0 T**	**20.0 T**	**22.0 T**	**24.0 T**	**26.0 T**	**28.0 T**
577		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
388	**12**	0.0000	0.0003	0.0007	0.0010	0.0014	0.0017	0.0021	0.0024	0.0028	0.0031	0.0035	0.0038	0.0042	0.0045	0.0049
288	**18**	0.0000	0.0005	0.0010	0.0016	0.0021	0.0026	0.0031	0.0036	0.0042	0.0047	0.0052	0.0057	0.0062	0.0068	0.0073
188	**24**	0.0000	0.0004	0.0008	0.0012	0.0016	0.0020	0.0024	0.0028	0.0032	0.0036	0.0040	0.0044	0.0049	0.0053	0.0057
0		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

PRINCIPAL TENSILE STRAIN VARIATION ALONG INCLINED AXIS 13-19-25 IN PPFRC (MT) 1P D50 S 0.0																
DEPTH	**LOAD**	**0.0 T**	**2.0 T**	**4.0 T**	**6.0 T**	**8.0 T**	**10.0 T**	**12.0 T**	**14.0 T**	**16.0 T**	**18.0 T**	**20.0 T**	**22.0 T**	**24.0 T**	**26.0 T**	**28.0 T**
577		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
388	**13**	0.0000	0.0004	0.0008	0.0012	0.0016	0.0020	0.0024	0.0028	0.0032	0.0036	0.0040	0.0044	0.0049	0.0053	0.0057
288	**19**	0.0000	0.0006	0.0012	0.0017	0.0023	0.0029	0.0035	0.0040	0.0046	0.0052	0.0058	0.0064	0.0069	0.0075	0.0081
188	**25**	0.0000	0.0005	0.0010	0.0016	0.0021	0.0026	0.0031	0.0036	0.0042	0.0047	0.0052	0.0057	0.0062	0.0068	0.0073
0		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000


STRAIN VARIATION ALONG INCLINED AXIS 9-15-21 IN BEAM PPFRC (MT) 1P D50 S 0.0
DEPTH ALONG INCLINED AXIS 9-15-21
PRINCIPAL TENSILE STRAIN
600
500
400
300
200
100
0
-0.01000
-0.00800
-0.00600
-0.00400
-0.00200
0.00000
0.00200
0.00400
0.00600
0.00800
0.01000
2.0 TONNE
4.0 TONNE
6.0 TONNE
8.0 TONNE
10.0 TONNE
12.0 TONNE
14.0 TONNE
16.0 TONNE
18.0 TONNE
20.0 TONNE
22.0 TONNE
24.0 TONNE
26.0 TONNE
28.0 TONNE
2.0 TONNE
4.0 TONNE
6.0 TONNE
8.0 TONNE
10.0 TONNE
12.0 TONNE
14.0 TONNE
16.0 TONNE
18.0 TONNE
20.0 TONNE
22.0 TONNE
24.0 TONNE
26.0 TONNE
28.0 TONNE


STRAIN VARIATION ALONG INCLINED AXIS 10-16-22 IN BEAM PPFRC (MT) 1P D50 S 0.0
DEPTH ALONG INCLINED AXIS 10-16-22
PRINCIPAL TENSILE STRAIN
600
500
400
300
200
100
0
-0.01000
-0.00800
-0.00600
-0.00400
-0.00200
0.00000
0.00200
0.00400
0.00600
0.00800
0.01000
2.0 TONNE
4.0 TONNE
6.0 TONNE
8.0 TONNE
10.0 TONNE
12.0 TONNE
14.0 TONNE
16.0 TONNE
18.0 TONNE
20.0 TONNE
22.0 TONNE
24.0 TONNE
26.0 TONNE
28.0 TONNE
2.0 TONNE
4.0 TONNE
6.0 TONNE
8.0 TONNE
10.0 TONNE
12.0 TONNE
14.0 TONNE
16.0 TONNE
18.0 TONNE
20.0 TONNE
22.0 TONNE
24.0 TONNE
26.0 TONNE
28.0 TONNE


STRAIN VARIATION ALONG INCLINED AXIS 11-17-23 IN BEAM PPFRC (MT) 1P D50 S 0.0
DEPTH ALONG INCLINED AXIS 11-17-23
PRINCIPAL TENSILE STRAIN
600
500
400
300
200
100
0
-0.01000
-0.00800
-0.00600
-0.00400
-0.00200
0.00000
0.00200
0.00400
0.00600
0.00800
0.01000
2.0 TONNE
4.0 TONNE
6.0 TONNE
8.0 TONNE
10.0 TONNE
12.0 TONNE
14.0 TONNE
16.0 TONNE
18.0 TONNE
20.0 TONNE
22.0 TONNE
24.0 TONNE
26.0 TONNE
28.0 TONNE
2.0 TONNE
4.0 TONNE
6.0 TONNE
8.0 TONNE
10.0 TONNE
12.0 TONNE
14.0 TONNE
16.0 TONNE
18.0 TONNE
20.0 TONNE
22.0 TONNE
24.0 TONNE
26.0 TONNE
28.0 TONNE



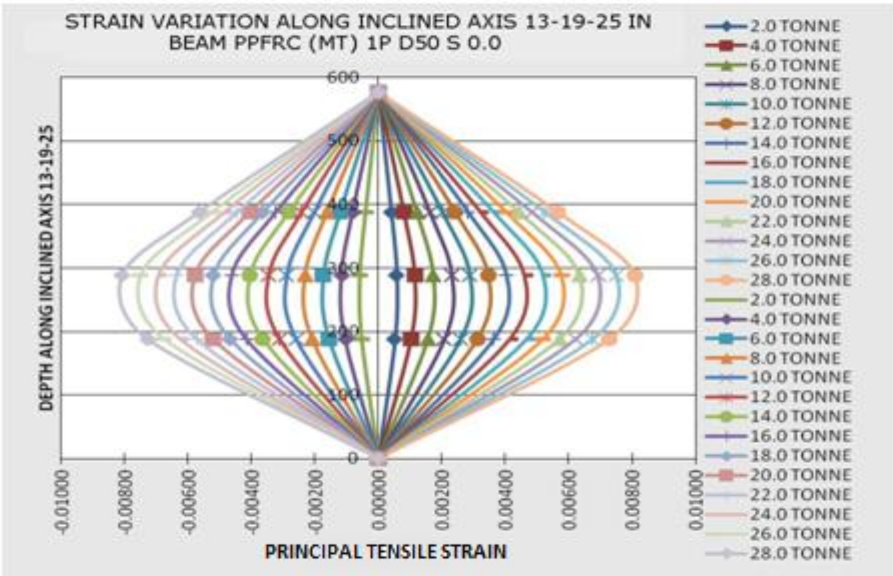
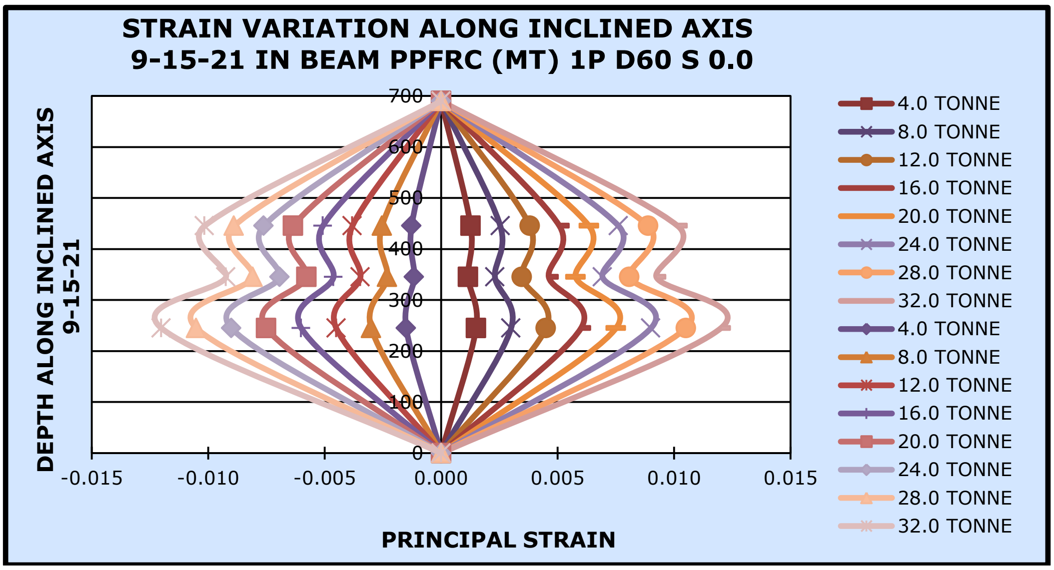
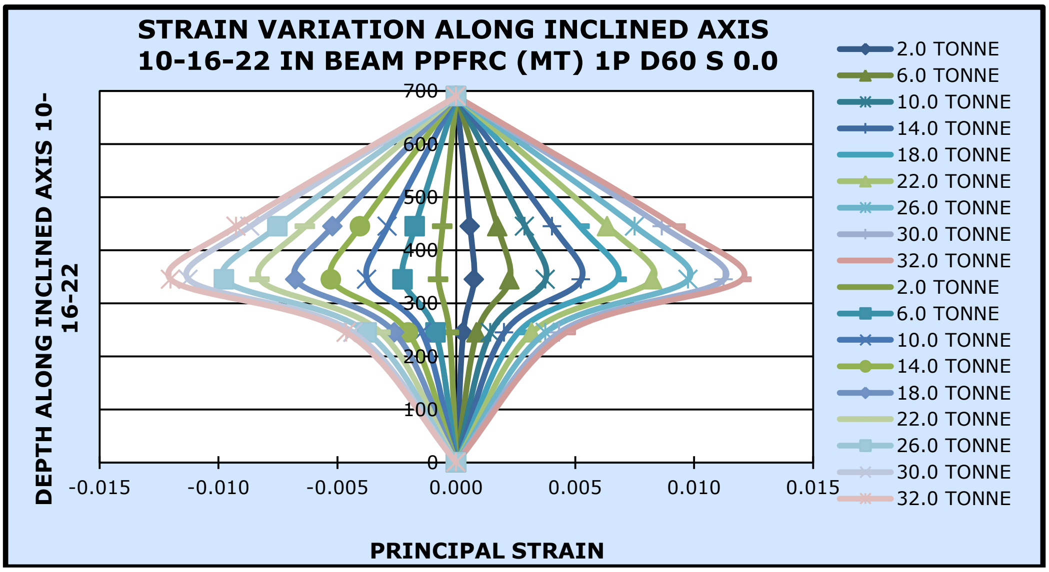
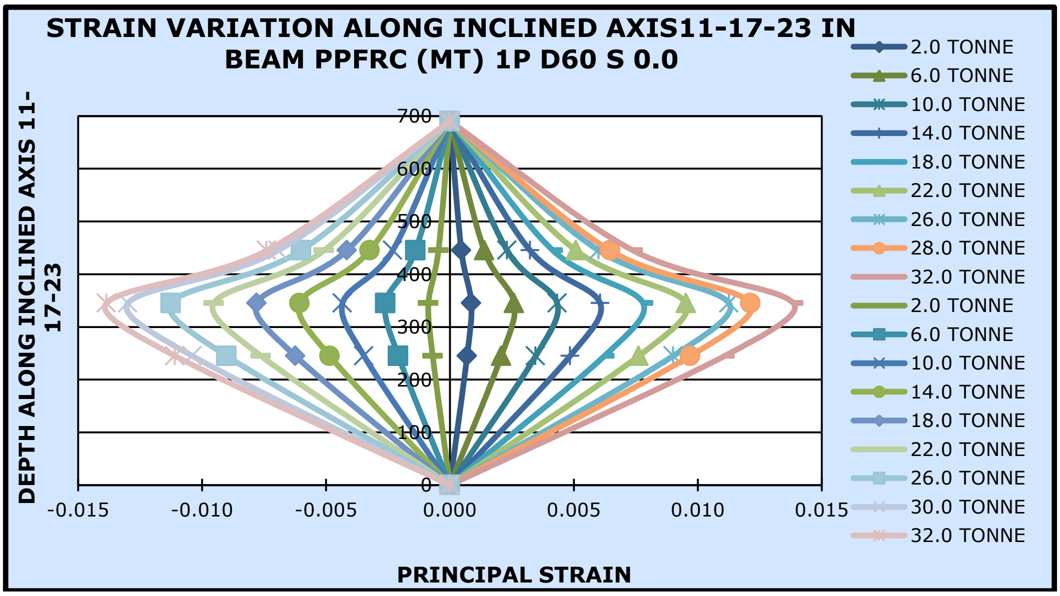
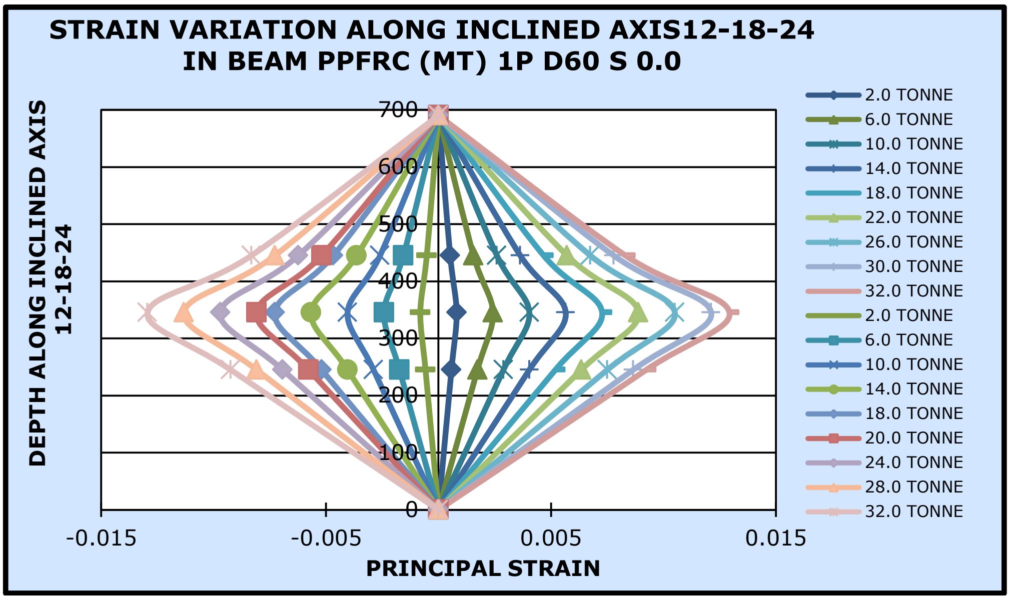


Fig.4.39 Principal Tensile Strain Along Inclined Axis Graphs Of PPFRC (MT) 1P D50 S 0.0


STRAIN VARIATION ALONG INCLINED AXIS
9-15-21 IN BEAM PPFRC (MT) 1P D60 S 0.0
DEPTH ALONG INCLINED AXIS 9-15-21
PRINCIPAL STRAIN
700
600
500
400
300
200
100
0
-0.015
-0.010
-0.005
0.000
0.005
0.010
0.015
4.0 TONNE
8.0 TONNE
12.0 TONNE
16.0 TONNE
20.0 TONNE
24.0 TONNE
28.0 TONNE
32.0 TONNE
4.0 TONNE
8.0 TONNE
12.0 TONNE
16.0 TONNE
20.0 TONNE
24.0 TONNE
28.0 TONNE
32.0 TONNE


STRAIN VARIATION ALONG INCLINED AXIS
10-16-22 IN BEAM PPFRC (MT) 1P D60 S 0.0
DEPTH ALONG INCLINED AXIS 10-16-22
PRINCIPAL STRAIN
700
600
500
400
300
200
100
0
-0.015
-0.010
-0.005
0.000
0.005
0.010
0.015
2.0 TONNE
6.0 TONNE
10.0 TONNE
14.0 TONNE
18.0 TONNE
22.0 TONNE
26.0 TONNE
30.0 TONNE
32.0 TONNE
2.0 TONNE
6.0 TONNE
10.0 TONNE
14.0 TONNE
18.0 TONNE
22.0 TONNE
26.0 TONNE
30.0 TONNE
32.0 TONNE


STRAIN VARIATION ALONG INCLINED AXIS11-17-23 IN
BEAM PPFRC (MT) 1P D60 S 0.0
DEPTH ALONG INCLINED AXIS 11-17-23
PRINCIPAL STRAIN
700
600
500
400
300
200
100
0
-0.015
-0.010
-0.005
0.000
0.005
0.010
0.015
2.0 TONNE
6.0 TONNE
10.0 TONNE
14.0 TONNE
18.0 TONNE
22.0 TONNE
26.0 TONNE
28.0 TONNE
32.0 TONNE
2.0 TONNE
6.0 TONNE
10.0 TONNE
14.0 TONNE
18.0 TONNE
22.0 TONNE
26.0 TONNE
30.0 TONNE
32.0 TONNE



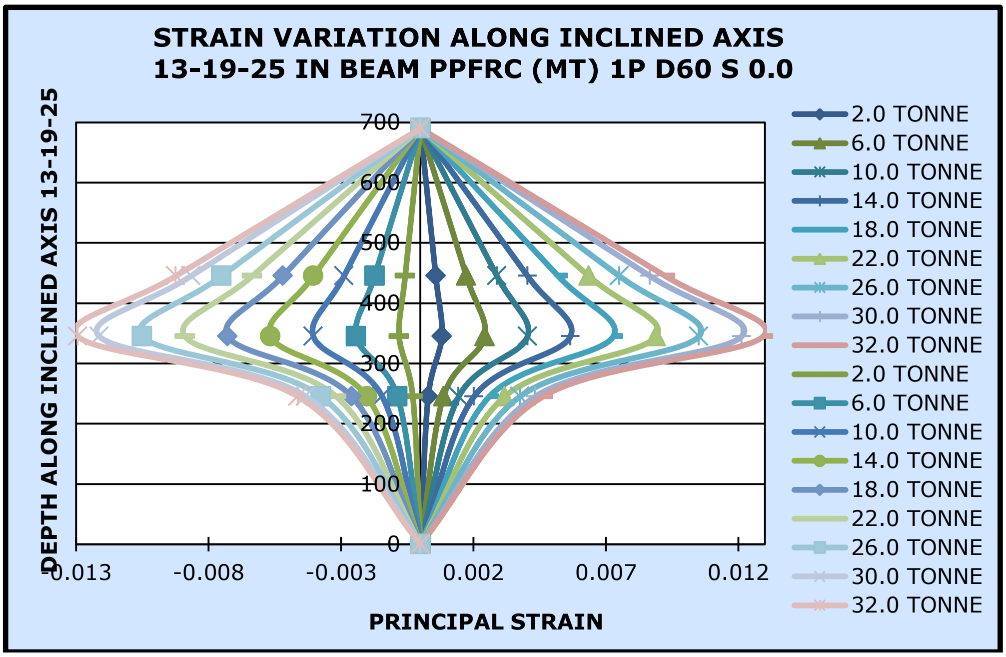
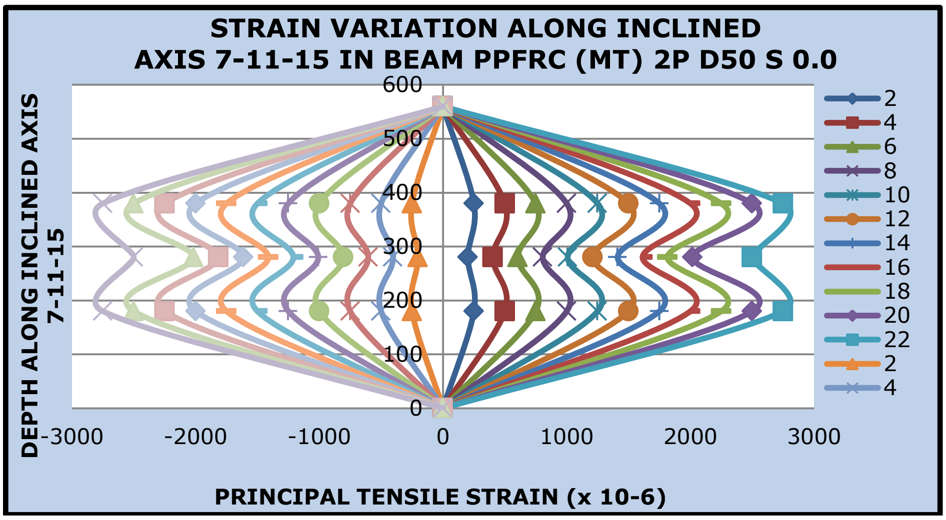
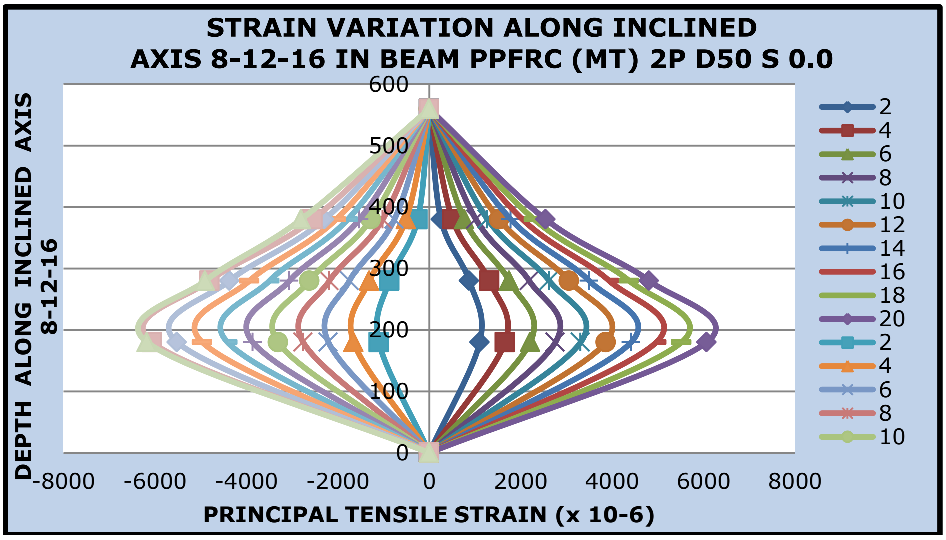


Fig.4.40 Principal Tensile Strain Along Inclined Axis Graphs Of PPFRC (MT) 1P D60 S 0.0





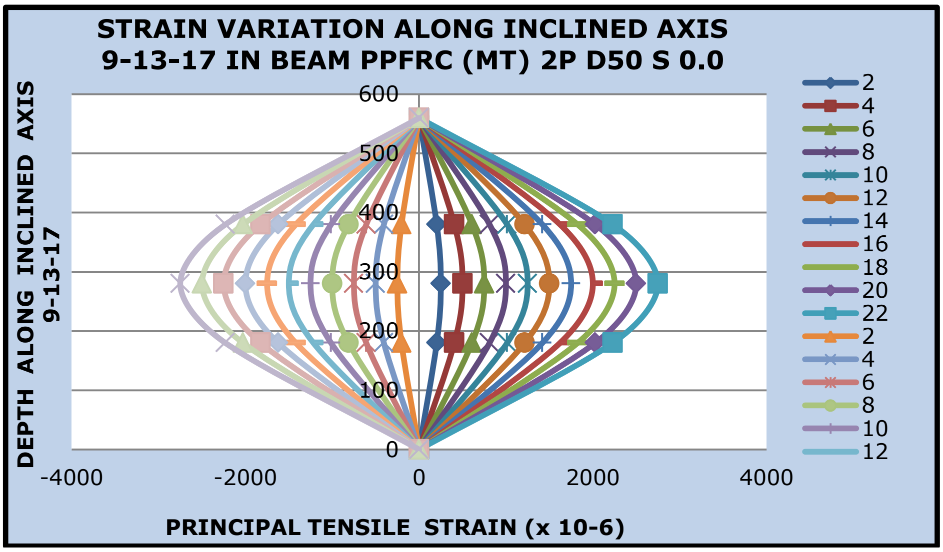
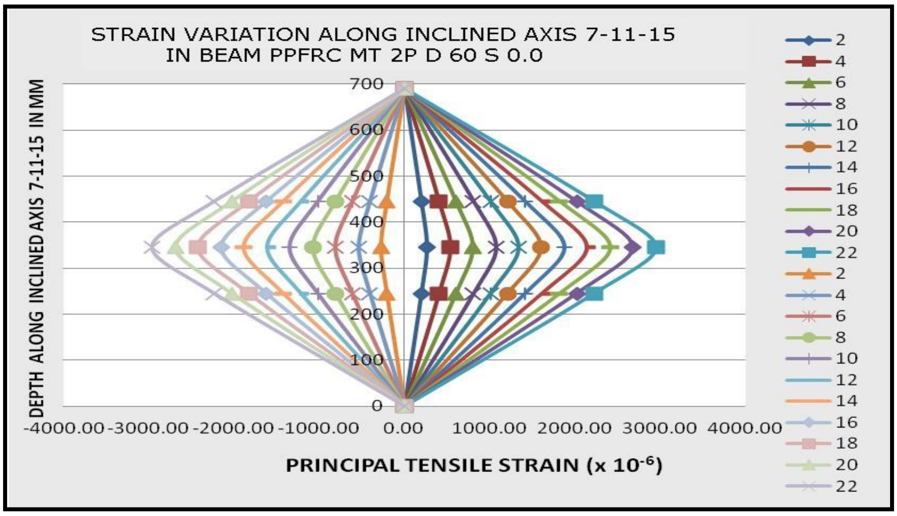
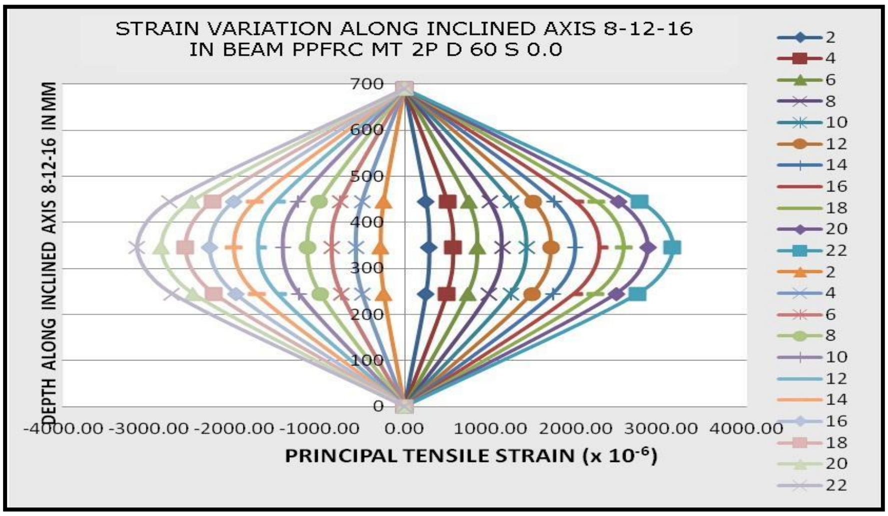


Fig.4.41 Principal Tensile Strain Along Inclined Axis Graphs Of PPFRC (MT) 2P D50 S 0.0





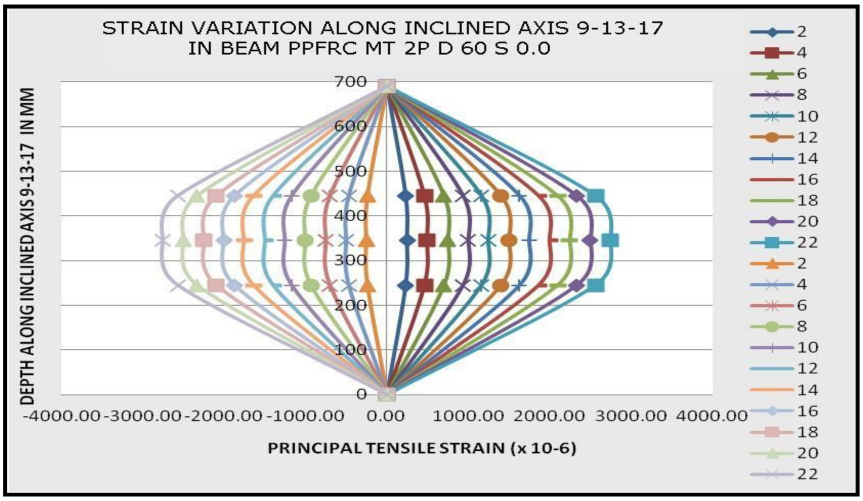
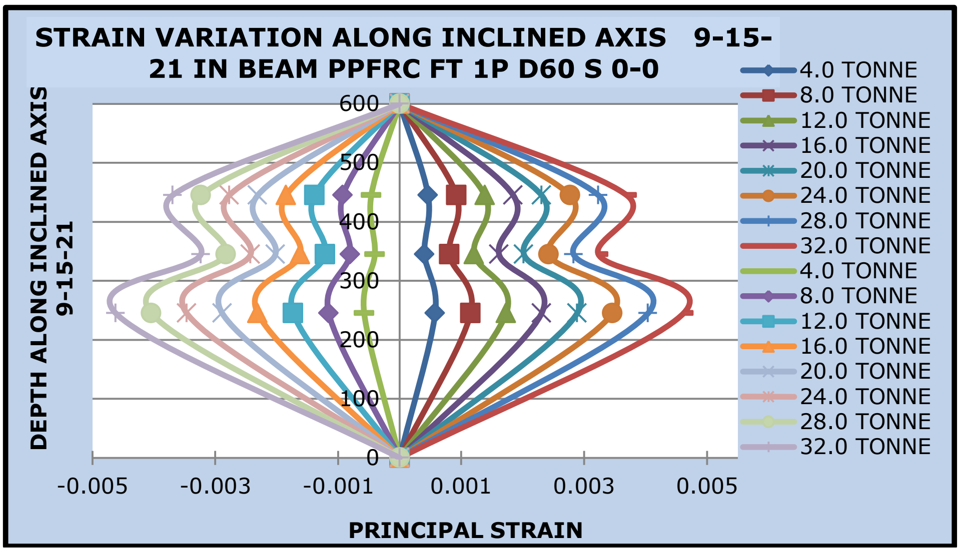
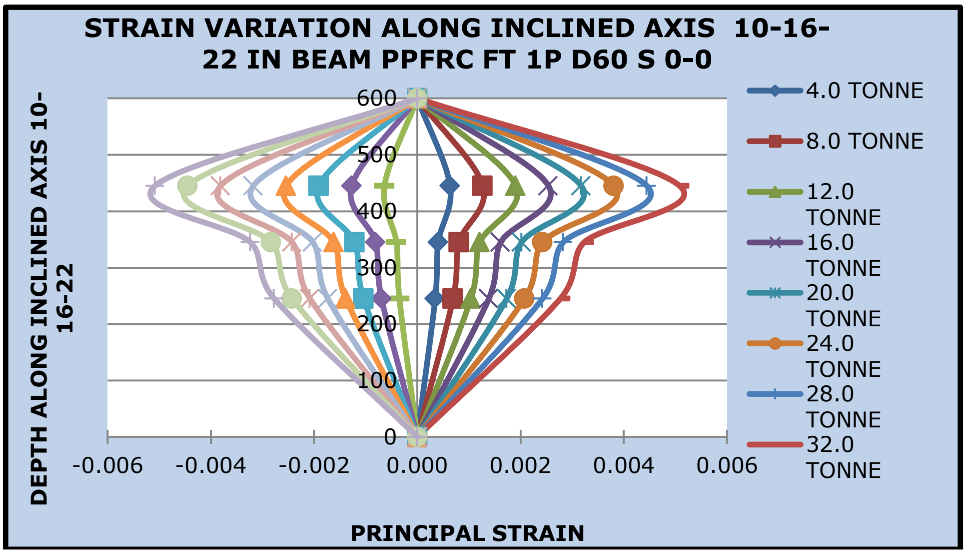
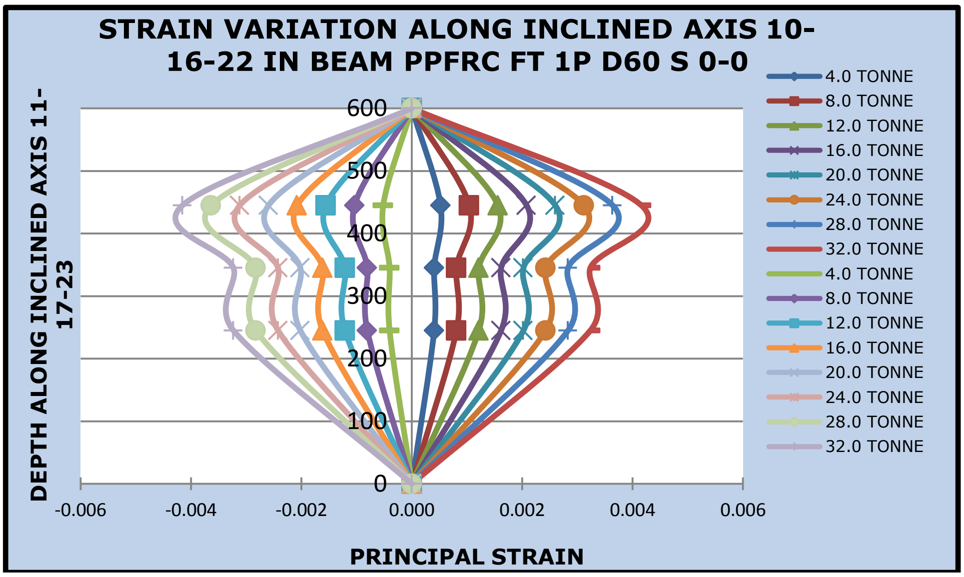
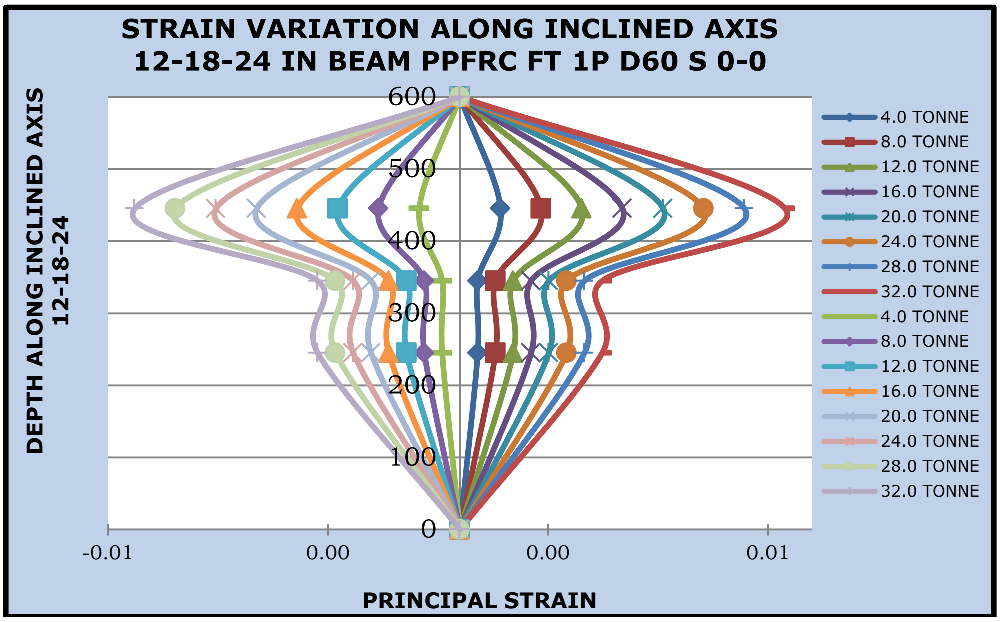


Fig. 4.42 Principal Tensile Strain Along Inclined Axis Graphs Of PPFRC (MT) 2P D60 S 0.0


STRAIN VARIATION ALONG INCLINED AXIS 9-15-21 IN BEAM PPFRC FT 1P D60 S 0-0
DEPTH ALONG INCLINED AXIS 9-15-21
PRINCIPAL STRAIN
600
500
400
300
200
100
0
-0.005
-0.003
-0.001
0.001
0.003
0.005
4.0 TONNE
8.0 TONNE
12.0 TONNE
16.0 TONNE
20.0 TONNE
24.0 TONNE
28.0 TONNE
32.0 TONNE
4.0 TONNE
8.0 TONNE
12.0 TONNE
16.0 TONNE
20.0 TONNE
24.0 TONNE
28.0 TONNE
32.0 TONNE


STRAIN VARIATION ALONG INCLINED AXIS 10-16-22 IN BEAM PPFRC FT 1P D60 S 0-0
DEPTH ALONG INCLINED AXIS 10-16-22
PRINCIPAL STRAIN
600
500
400
300
200
100
0
-0.006
-0.004
-0.002
0.000
0.002
0.004
0.006
4.0 TONNE
8.0 TONNE
12.0 TONNE
16.0 TONNE
20.0 TONNE
24.0 TONNE
28.0 TONNE
32.0 TONNE


STRAIN VARIATION ALONG INCLINED AXIS 10-16-22 IN BEAM PPFRC FT 1P D60 S 0-0
DEPTH ALONG INCLINED AXIS 11-17-23
PRINCIPAL STRAIN
600
500
400
300
200
100
0
-0.006
-0.004
-0.002
0.000
0.002
0.004
0.006
4.0 TONNE
8.0 TONNE
12.0 TONNE
16.0 TONNE
20.0 TONNE
24.0 TONNE
28.0 TONNE
32.0 TONNE
4.0 TONNE
8.0 TONNE
12.0 TONNE
16.0 TONNE
20.0 TONNE
24.0 TONNE
28.0 TONNE
32.0 TONNE



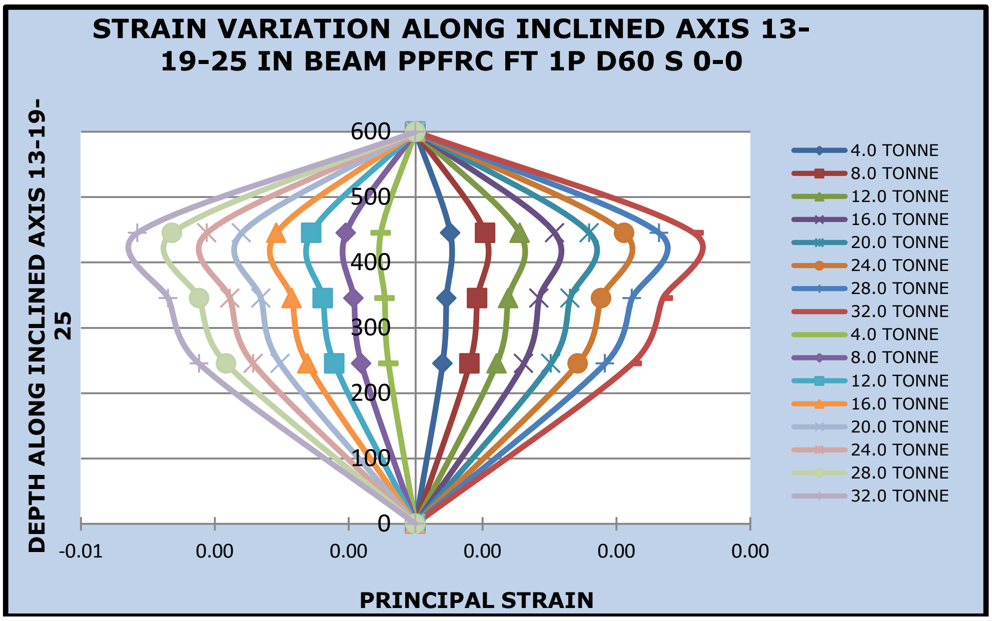
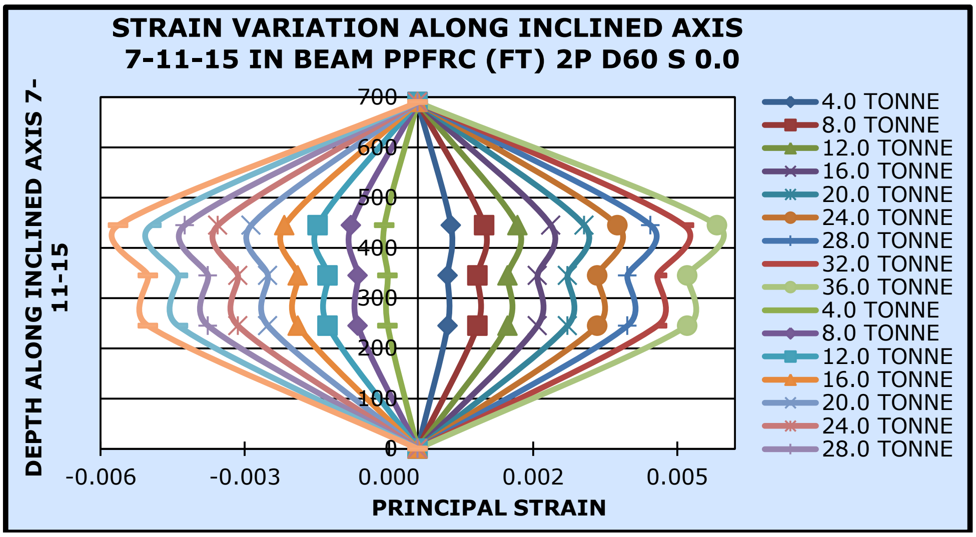
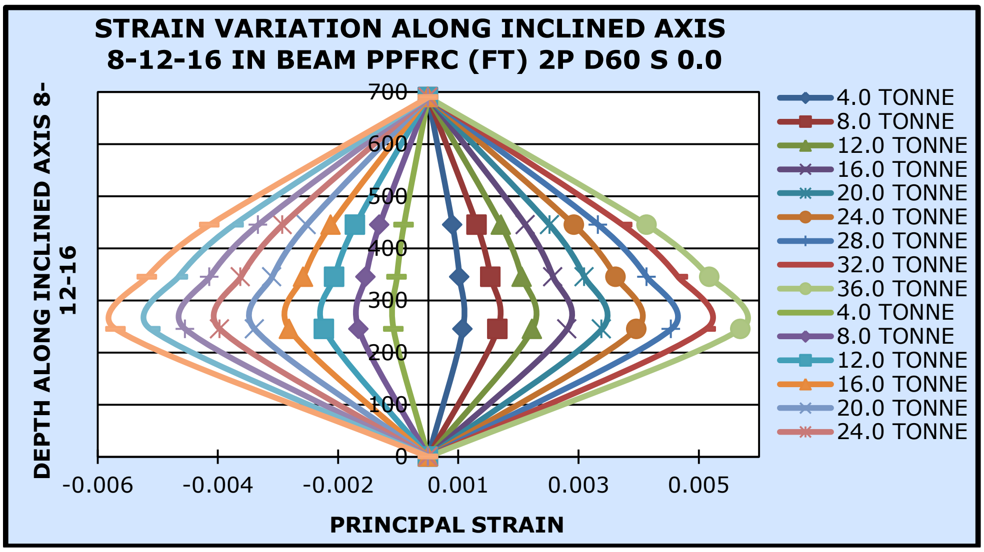


Fig.4.43 Principal Tensile Strain Along Inclined Axis Graphs Of PPFRC (FT) 1P D60 S 0.0





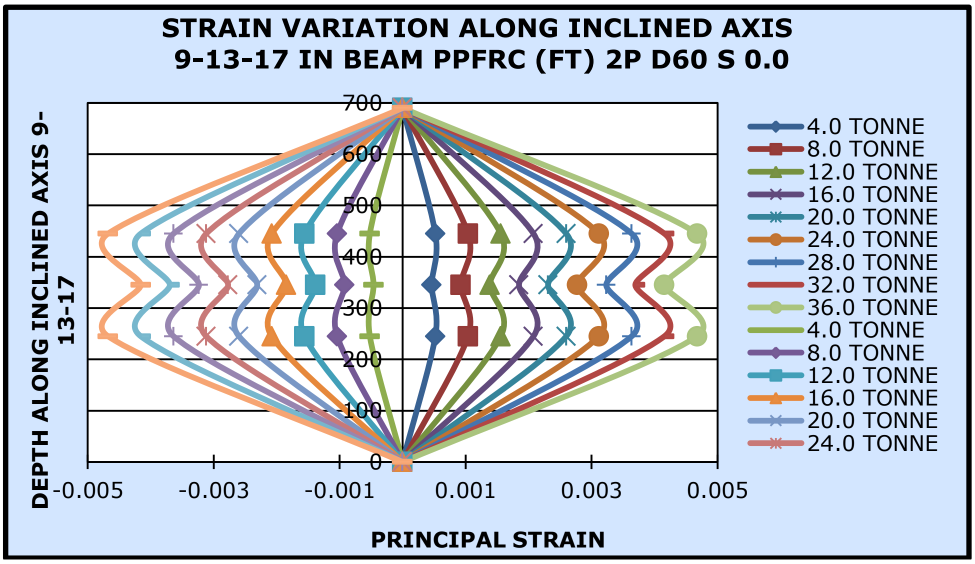
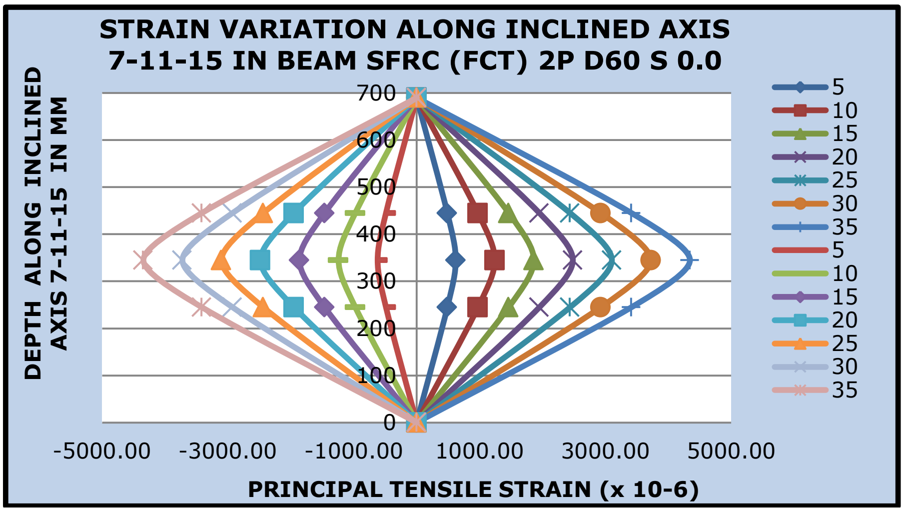
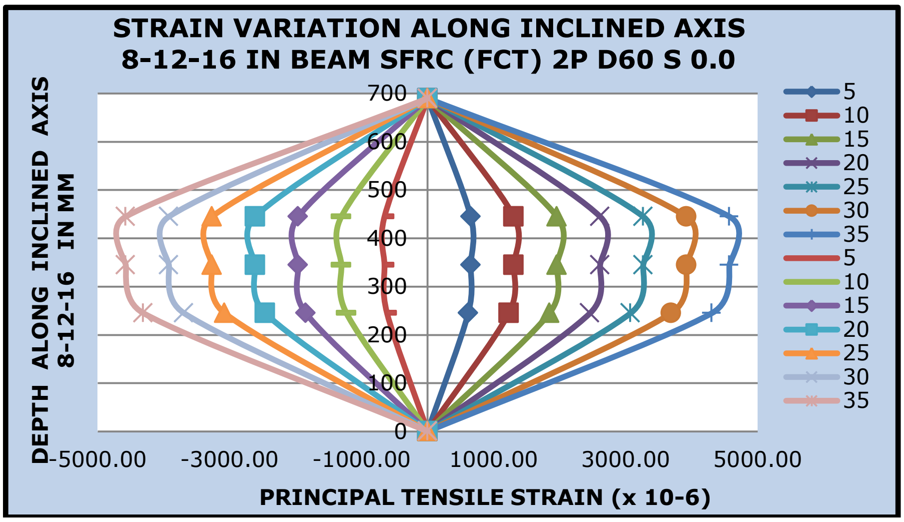


Fig.4.44 Principal Tensile Strain Along Inclined Axis Graphs Of PPFRC (FT) 2P D60 S 0.0





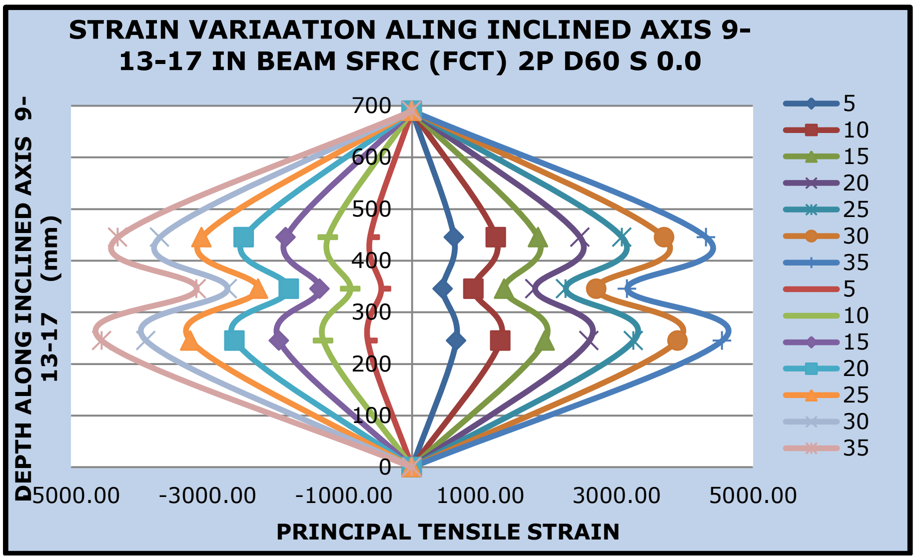
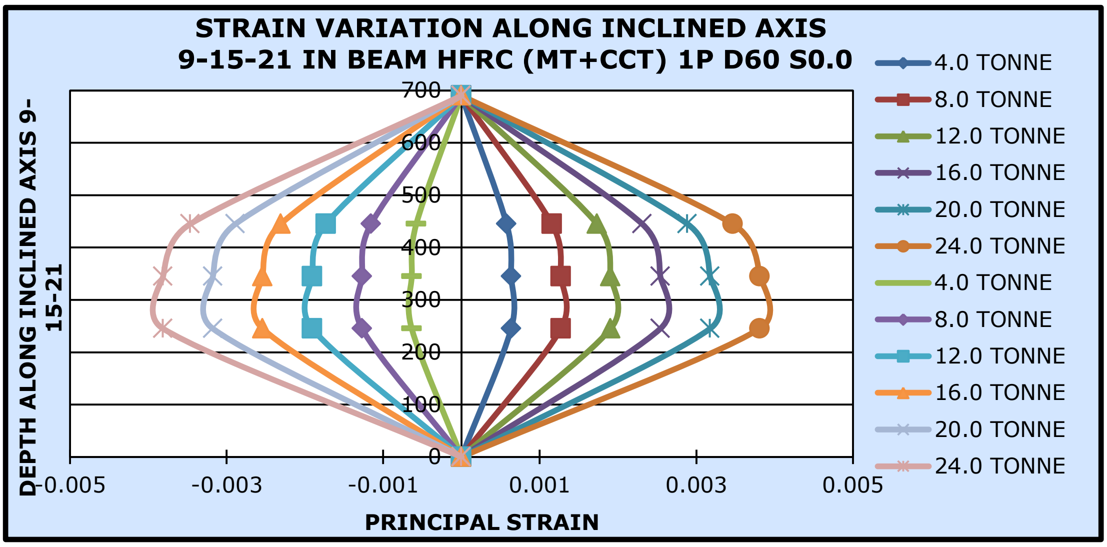
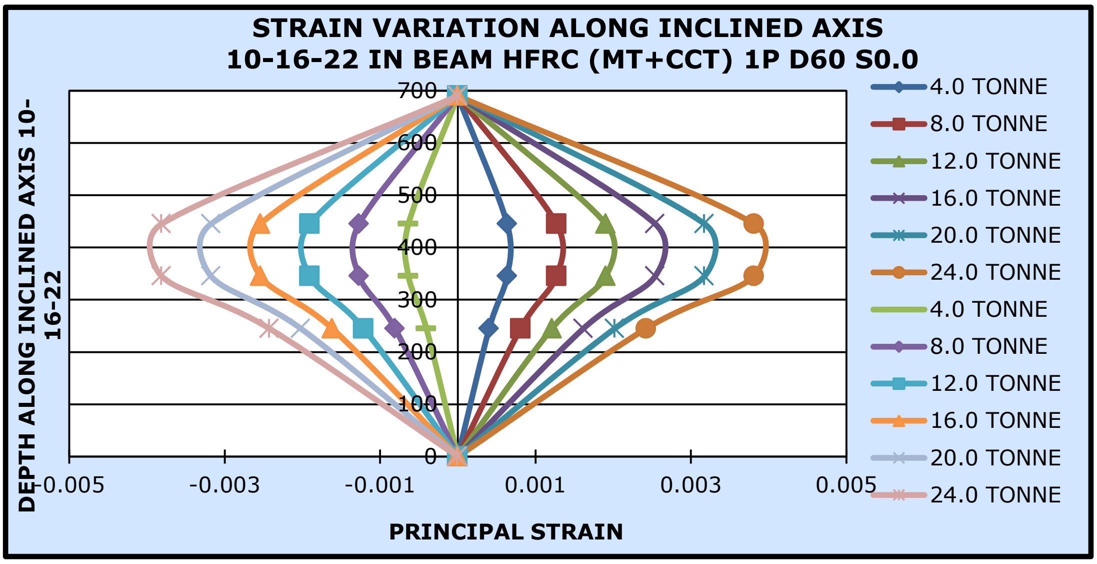
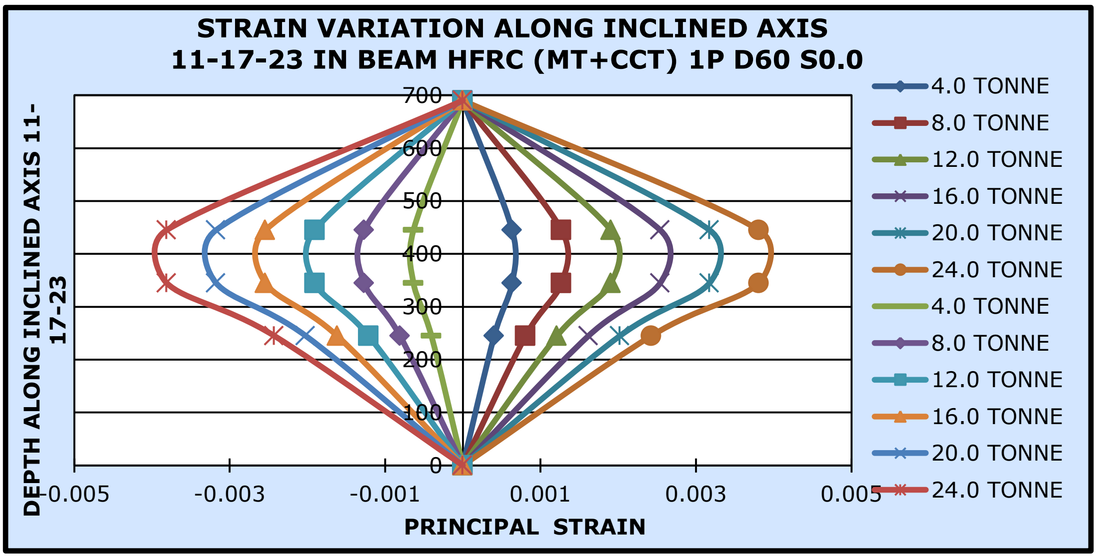
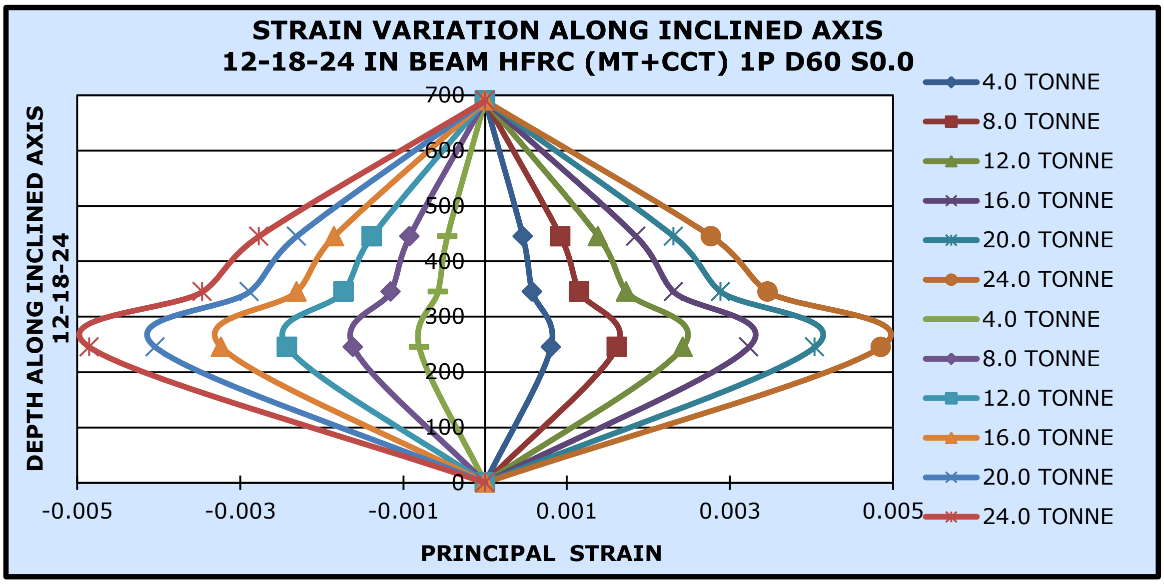


Fig.4.45 Principal Tensile Strain Along Inclined Axis Graphs Of SFRC (FCT) 2P D60 S 0.0


STRAIN VARIATION ALONG INCLINED AXIS
9-15-21 IN BEAM HFRC (MT+CCT) 1P D60 S0.0
DEPTH ALONG INCLINED AXIS 9-15-21
PRINCIPAL STRAIN
700
600
500
400
300
200
100
0
-0.005
-0.003
-0.001
0.001
0.003
0.005
4.0 TONNE
8.0 TONNE
12.0 TONNE
16.0 TONNE
20.0 TONNE
24.0 TONNE
4.0 TONNE
8.0 TONNE
12.0 TONNE
16.0 TONNE
20.0 TONNE
24.0 TONNE


STRAIN VARIATION ALONG INCLINED AXIS
10-16-22 IN BEAM HFRC (MT+CCT) 1P D60 S0.0
DEPTH ALONG INCLINED AXIS 10-16-22
PRINCIPAL STRAIN
700
600
500
400
300
200
100
0
-0.005
-0.003
-0.001
0.001
0.003
0.005
4.0 TONNE
8.0 TONNE
12.0 TONNE
16.0 TONNE
20.0 TONNE
24.0 TONNE
4.0 TONNE
8.0 TONNE
12.0 TONNE
16.0 TONNE
20.0 TONNE
24.0 TONNE


STRAIN VARIATION ALONG INCLINED AXIS
11-17-23 IN BEAM HFRC (MT+CCT) 1P D60 S0.0
DEPTH ALONG INCLINED AXIS 11-17-23
PRINCIPAL STRAIN
700
600
500
400
300
200
100
0
-0.005
-0.003
-0.001
0.001
0.003
0.005
4.0 TONNE
8.0 TONNE
12.0 TONNE
16.0 TONNE
20.0 TONNE
24.0 TONNE
4.0 TONNE
8.0 TONNE
12.0 TONNE
16.0 TONNE
20.0 TONNE
24.0 TONNE



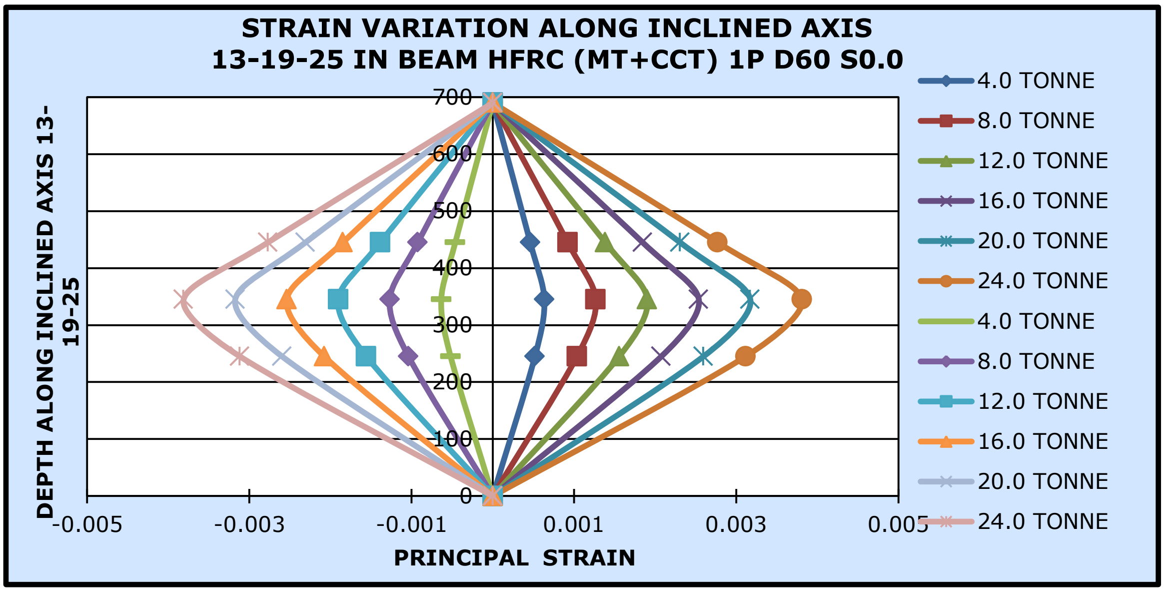
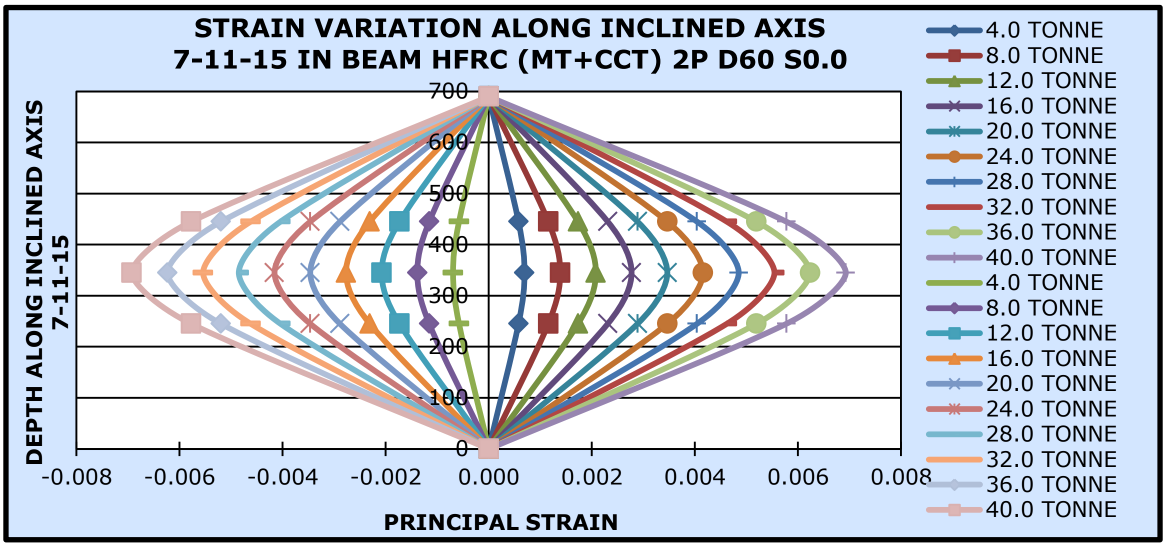
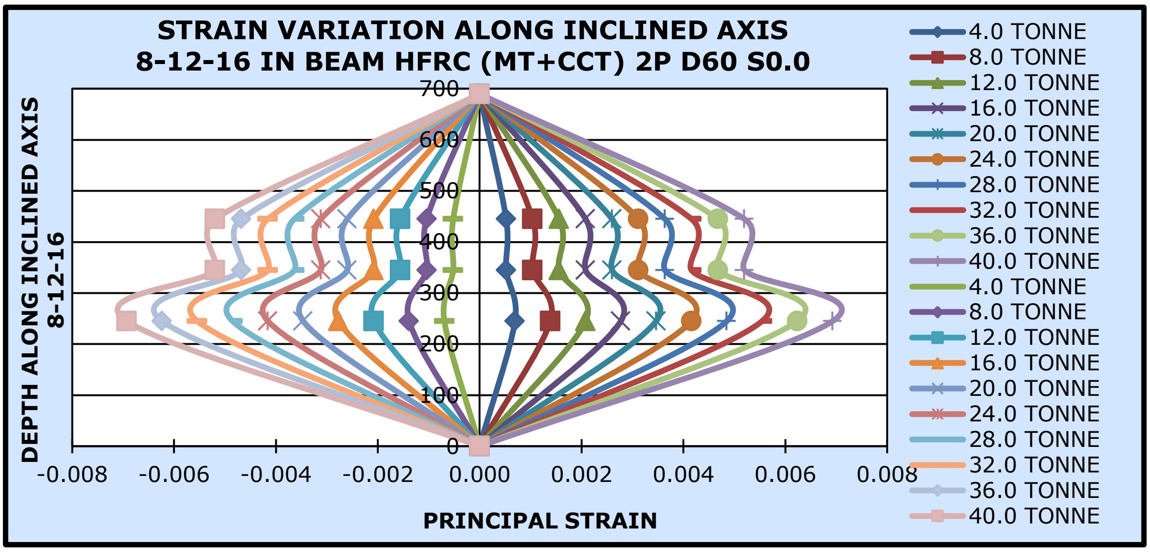


Fig.4.46 Principal Tensile Strain Along Inclined Axis Graphs Of HFRC (MT+CCT) 1P D60 S0.0





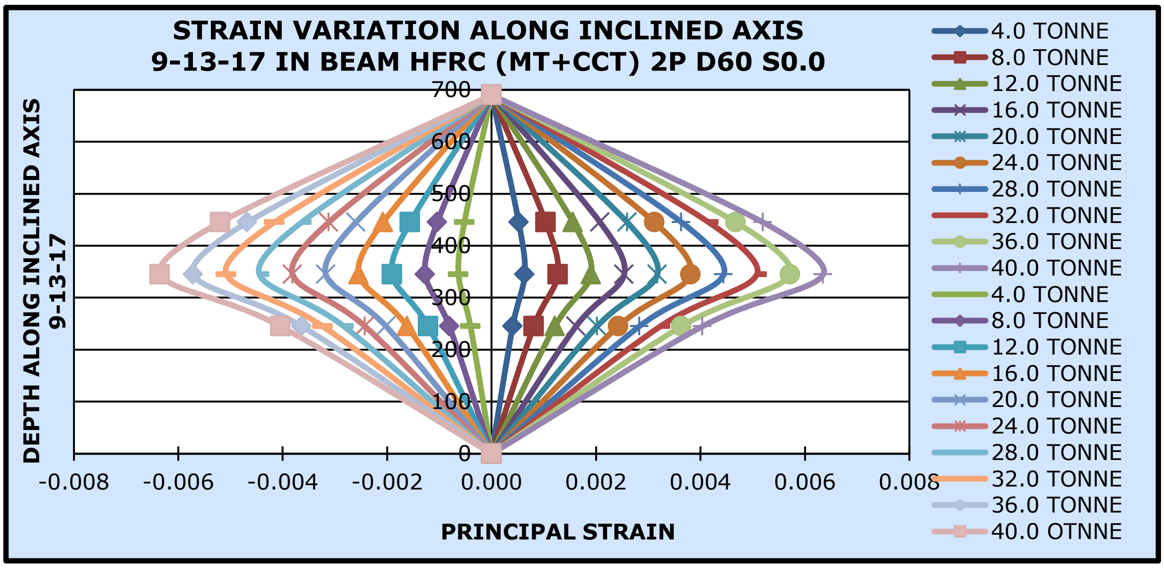
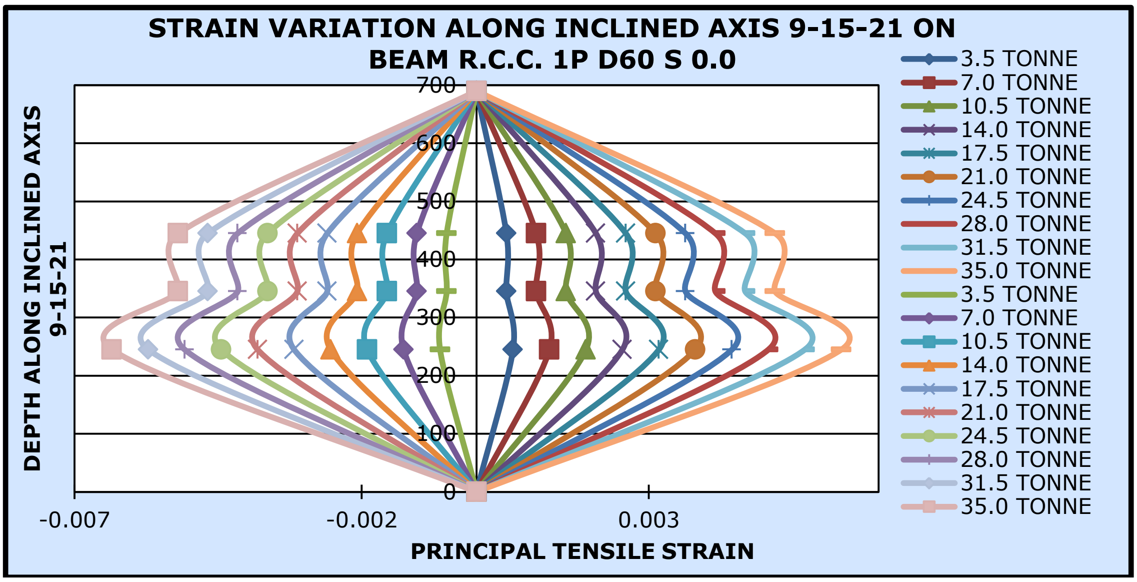
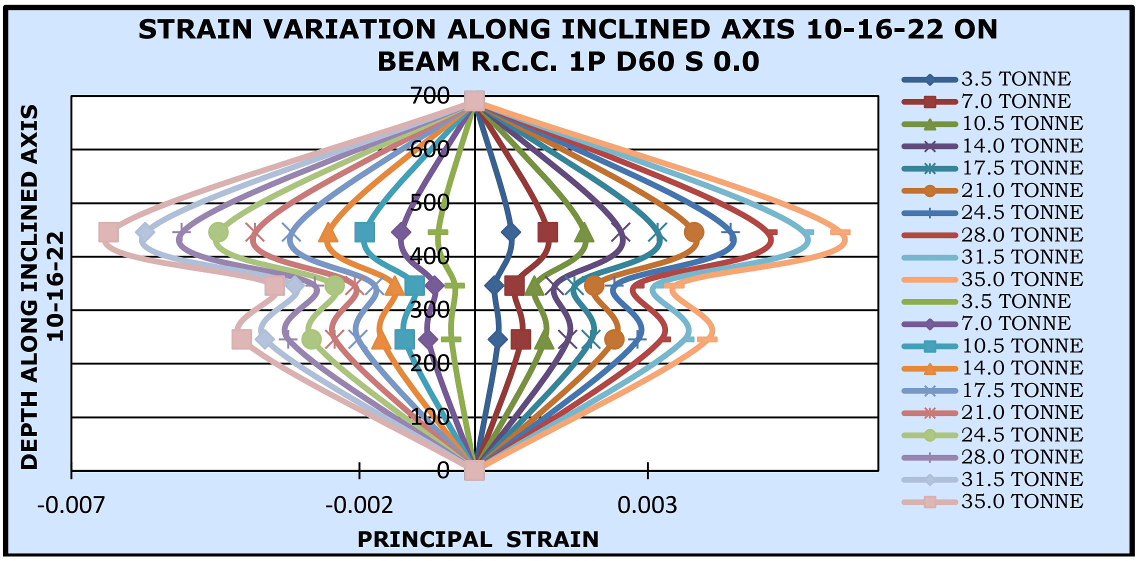
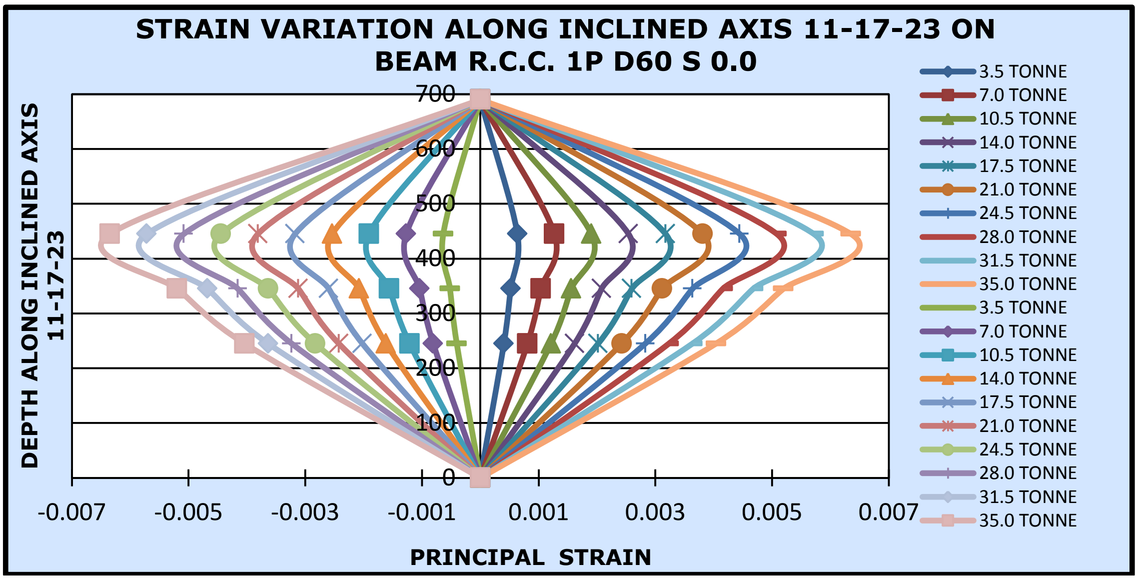
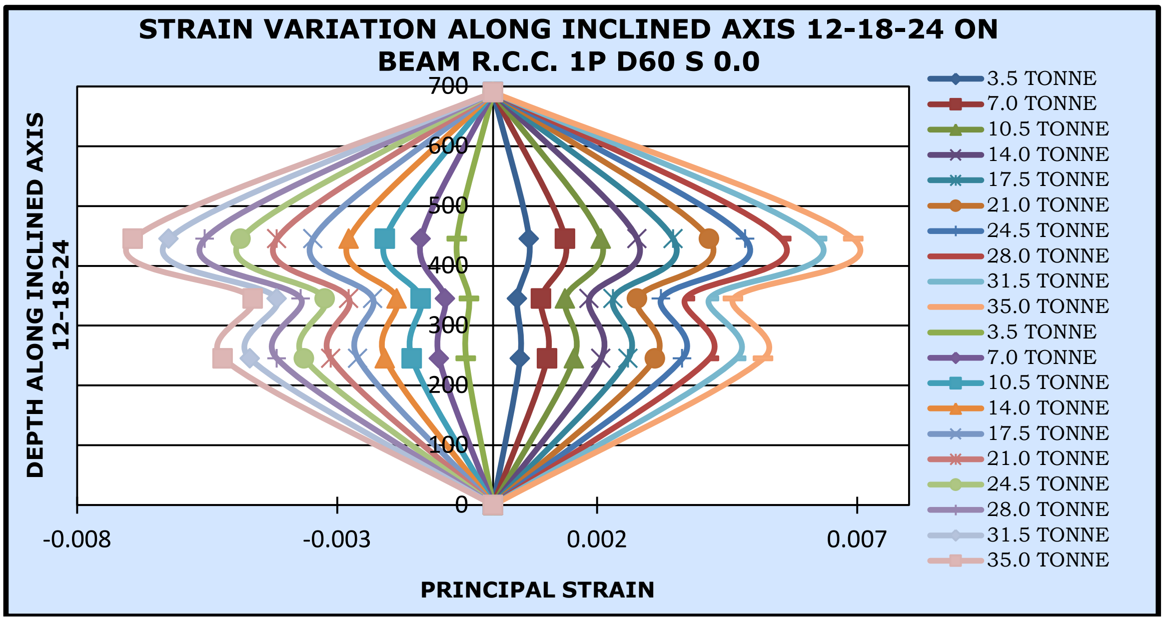


Fig.4.47 Principal Tensile Strain Along Inclined Axis Graphs Of HFRC (MT+CCT) 2P D60 S0.0


STRAIN VARIATION ALONG INCLINED AXIS 9-15-21 ON
BEAM R.C.C. 1P D60 S 0.0
DEPTH ALONG INCLINED AXIS
9-15-21
700
600
500
400
300
200
100
0
-0.007
-0.002
0.003
PRINCIPAL TENSILE STRAIN
3.5 TONNE
7.0 TONNE
10.5 TONNE
14.0 TONNE
17.5 TONNE
21.0 TONNE
24.5 TONNE
28.0 TONNE
31.5 TONNE
35.0 TONNE
3.5 TONNE
7.0 TONNE
10.5 TONNE
14.0 TONNE
17.5 TONNE
21.0 TONNE
24.5 TONNE
28.0 TONNE
31.5 TONNE
35.0 TONNE


STRAIN VARIATION ALONG INCLINED AXIS 10-16-22 ON
BEAM R.C.C. 1P D60 S 0.0
DEPTH ALONG INCLINED AXIS
10-16-22
700
600
500
400
300
200
100
0
-0.007
-0.002
0.003
PRINCIPAL STRAIN
3.5 TONNE
7.0 TONNE
10.5 TONNE
14.0 TONNE
17.5 TONNE
21.0 TONNE
24.5 TONNE
28.0 TONNE
31.5 TONNE
35.0 TONNE
3.5 TONNE
7.0 TONNE
10.5 TONNE
14.0 TONNE
17.5 TONNE
21.0 TONNE
24.5 TONNE
28.0 TONNE
31.5 TONNE
35.0 TONNE


STRAIN VARIATION ALONG INCLINED AXIS 11-17-23 ON
BEAM R.C.C. 1P D60 S 0.0
DEPTH ALONG INCLINED AXIS
11-17-23
700
600
500
400
300
200
100
0
-0.007
-0.005
-0.003
-0.001
0.001
0.003
0.005
0.007
PRINCIPAL STRAIN
3.5 TONNE
7.0 TONNE
10.5 TONNE
14.0 TONNE
17.5 TONNE
21.0 TONNE
24.5 TONNE
28.0 TONNE
31.5 TONNE
35.0 TONNE
3.5 TONNE
7.0 TONNE
10.5 TONNE
14.0 TONNE
17.5 TONNE
21.0 TONNE
24.5 TONNE
28.0 TONNE
31.5 TONNE
35.0 TONNE



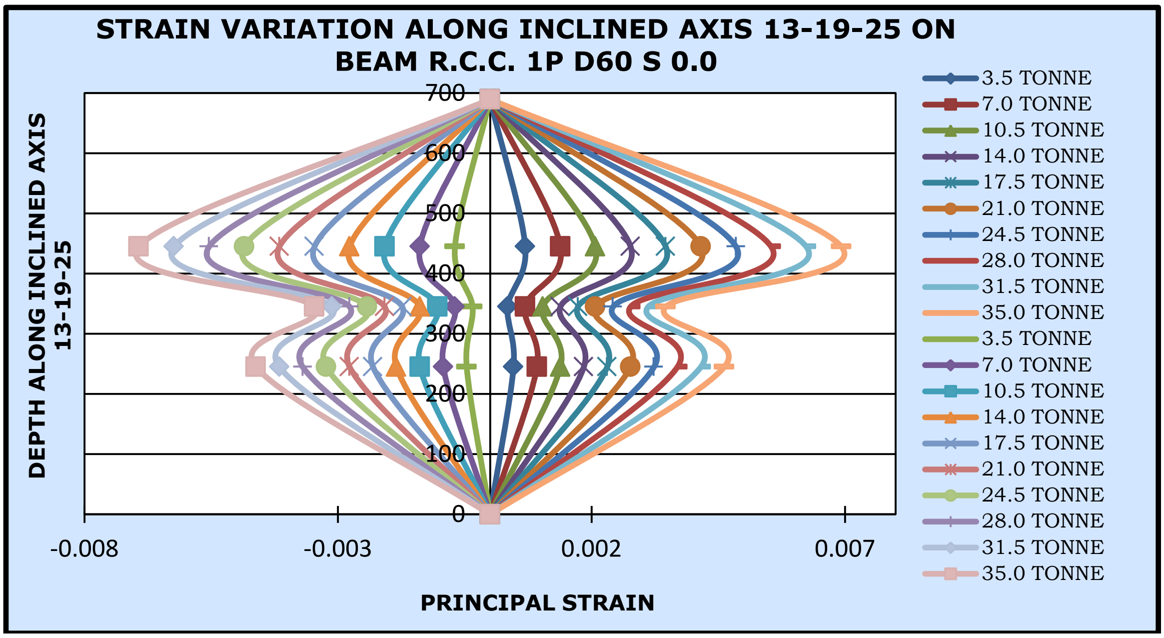
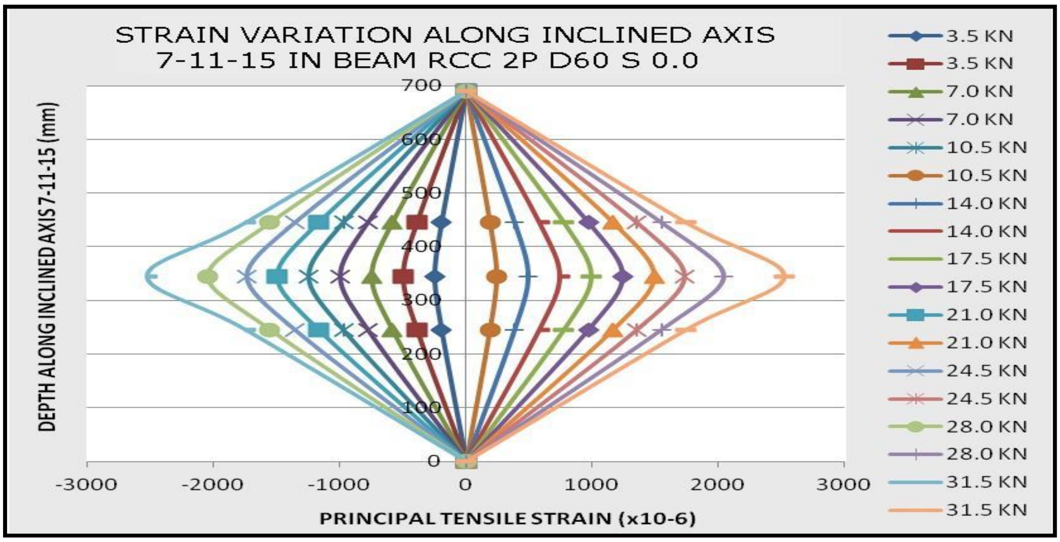
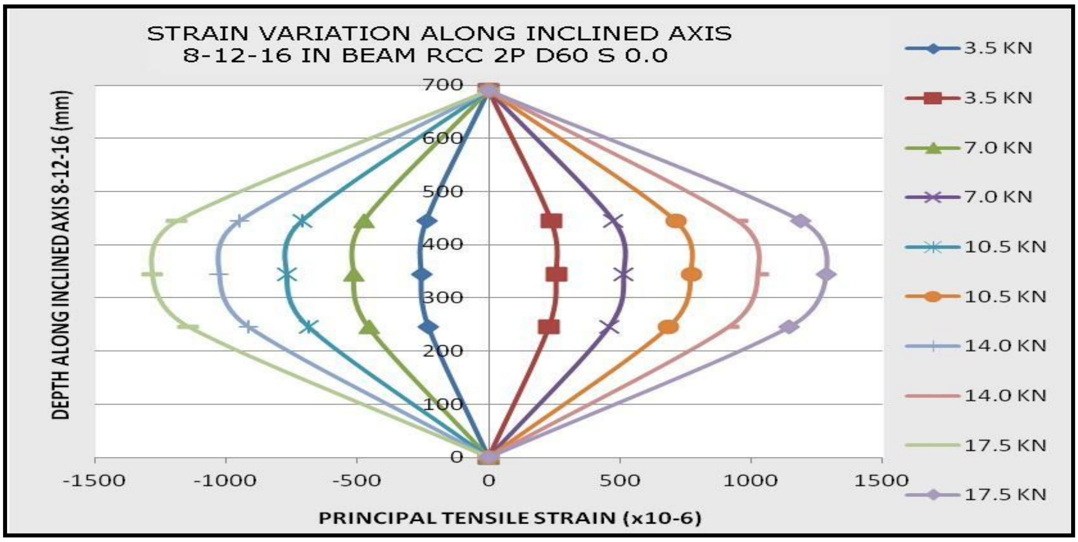


Fig.4.48 Principal Tensile Strain Along Inclined Axis Graphs Of R.C.C. 1P D60 S 0.0





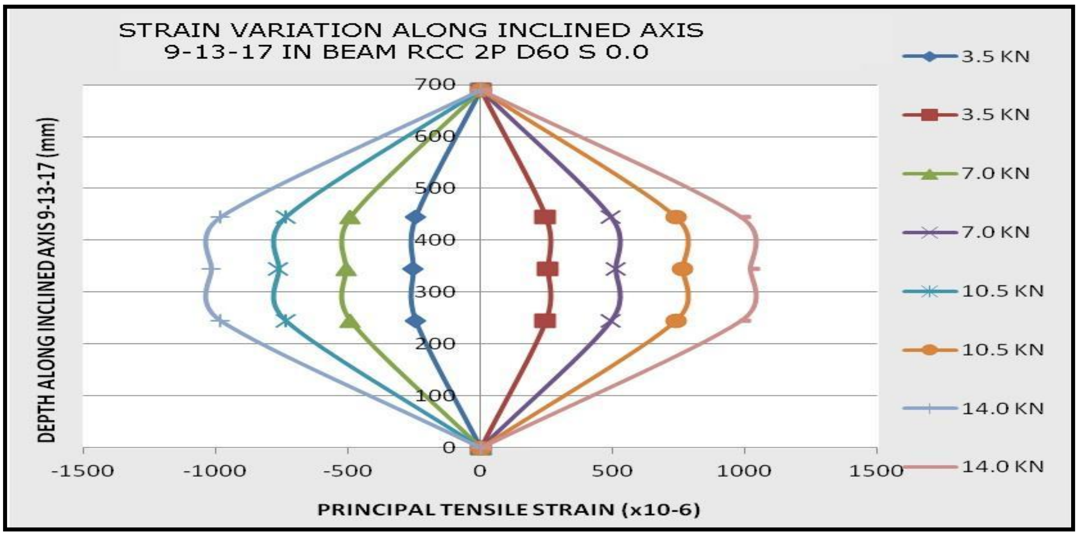


Fig.4.49 Principal Tensile Strain Along Inclined Axis Graphs Of R.C.C. 2P D60 S 0.0

TABLE GROUP 4.6 ULTIMATE STRENGTH VARIATIONS WITH CHANGE IN a/D RATIO.

TABLE 4.6.1 Ultimate Strength Variation With Change In a/D Ratio S 0.0

TYPE	BEAM S 0.0	L/D RATIO	a/D RATIO	ULTIMATE LOAD Wu (t)	MODE OF FAILURE
D 30	R.C.C. 2P	4	1.33	13.4	Flexure
	R.C.C 1P	4	2	11.5	Flexure
	PPFRC (MT) 2P	4	1.33	12.4	Flexure
	PPFRC (MT) 1P	4	2	11	Flexure
	PPFRC (FT) 2P	4	1.33	11.9	Flexure
	PPFRC (FT) 1P	4	2	9.5	Flexure-shear
	SFRC (FCT) 2P	4	1.33	12.6	Flexure
	SFRC (CCT) 1P	4	2	8.9	Flexure
	HFRC (MT+CCT) 2P	4	1.33	12.05	Flexure-shear
	HFRC (MT+CCT) 1P	4	2	10.7	Flexure
	RCC (W/O/S)(1P)	4.0	2.0	6.2	Flexure
	RCC (W/O/S)(2P)	4.0	1.33	7.0	Flexure
D 40	R.C.C. 2P	3	1	29.5	Shear-flexure
	R.C.C. 1P	3	1.5	17.2	Flexure-shear
	PPFRC (MT) 2P	3	1	23.4	Flexure-shear
	PPFRC (MT) 1P	3	1.5	16.5	Flexure-shear
	PPFRC (FT) 2P	3	1	22.3	Shear-flexure
	PPFRC (FT) 1P	3	1.5	15.5	Flexure
	SFRC (FCT) 2P	3	1	23.5	Flexure-shear
	SFRC (CCT) 1P	3	1.5	16.9	Flexure
	HFRC (MT+CCT) 2P	3	1	23.9	Shear-flexure
	HFRC (MT+CCT) 1P	3	1.5	13.08	Flexure-shear
	RCC (W/O/S)(1P)	3.0	1.5	9.9	Flexure
	RCC (W/O/S)(2P)	3.0	1.0	13.4	Flexure
D 50	R.C.C 2P	2.4	0.8	46	Shear-flexure
	R.C.C 1P	2.4	1.2	27.3	Flexure
	PPFRC (MT) 2P	2.4	0.8	40	Shear-flexure
	PPFRC (MT) 1P	2.4	1.2	26.5	Shear-flexure
	PPFRC (FT) 2P	2.4	0.8	37.4	Shear-flexure
	PPFRC (FT) 1P	2.4	1.2	27.1	Shear-flexure
	SFRC (FCT) 2P	2.4	0.8	39.76	Shear-flexure
	SFRC (CCT) 1P	2.4	1.2	27.3	Shear-flexure
	HFRC (MT+CCT) 2P	2.4	0.8	39.8	Shear-flexure
	HFRC (MT+CCT) 1P	2.4	1.2	27.16	Shear-flexure
	RCC (W/O/S)(1P)	2.4	1.2	15.2	Flexure-shear
	RCC (W/O/S)(2P)	2.4	0.8	20.4	Flexure-shear
D60	R.C.C. 2P	2	0.67	63.74	Shear
	R.C.C. 1P	2	1	45.4	Flexure-shear
	PPFRC (MT) 2P	2	0.67	53.2	Shear
	PPFRC (MT) 1P	2	1	42.8	Shear
	PPFRC (FT) 2P	2	0.67	51.3	Shear
	PPFRC (FT) 1P	2	1	40.9	Shear-flexure
	SFRC (FCT) 2P	2	0.67	53.9	Shear
	SFRC (CCT) 1P	2	1	43.7	Shear-flexure
	HFRC (MT+CCT) 2P	2	0.67	50.9	Shear
	HFRC (MT+CCT) 1P	2	1	43.8	Shear
	RCC (W/O/S)(1P)	2.0	1.0	24.0	Flexure-shear
	RCC (W/O/S)(2P)	2.0	0.67	30.0	Flexure-shear

TABLE 4.6.2 Ultimate Strength Variation With Change In a/D Ratio S 5.0

TYPE	BEAM S 5.0	L/D RATIO	a/D RATIO	ULTIMATE LOAD Wu (t)	MODE OF FAILURE
D 30	R.C.C. 2P	4	1.33	15.7	Flexure
	PPFRC (MT) 2P	4	1.33	12.3	Flexure
	PPFRC (FT) 1P	4	2	9	Flexure
	SFRC (FCT) 2P	4	1.33	12.46	Flexure
	SFRC (CCT) 1P	4	2	10.5	Flexure
D 40	R.C.C. 2P	3	1	29.0	Flexure-shear
	PPFRC (MT) 2P	3	1	24.2	Flexure
	PPFRC (FT) 1P	3	1.5	16.2	Flexure-shear
	SFRC (FCT) 2P	3	1	23.3	Flexure
	SFRC (CCT) 1P	3	1.5	16.7	Flexure
D 50	R.C.C. 2P	2.4	0.8	45.5	Shear-flexure
	PPFRC (MT) 2P	2.4	0.8	37.4	Shear-flexure
	PPFRC (FT) 1P	2.4	1.2	26.1	Shear-flexure
	SFRC (FCT) 2P	2.4	0.8	39.1	Shear-flexure
	SFRC (CCT) 1P	2.4	1.2	26.9	Shear-flexure
D60	R.C.C. 2P	2	0.67	52.2	Shear
	PPFRC (MT) 2P	2	0.67	52.2	Shear
	PPFRC (FT) 1P	2	1	41.2	Shear-flexure
	SFRC (FCT) 2P	2	0.67	53.16	Shear
	SFRC (CCT) 1P	2	1	42.75	Shear-flexure

Table 4.6.3 Ultimate Strength Variation With Change In a/D Ratio S 7.5

TYPE	BEAM S 7.5	L/D RATIO	a/D RATIO	ULTIMATE LOAD Wu (t)	MODE OF FAILURE
D 30	R.C.C. 2P	4	1.33	16.1	Flexure
	PPFRC (MT) 2P	4	1.33	12.15	Flexure-shear
	PPFRC (FT) 1P	4	2	9.2	Flexure
	SFRC (FCT) 2P	4	1.33	12.4	Flexure
	SFRC (CCT) 1P	4	2	10.2	Flexure
D 40	R.C.C. 2P	4	1	29.9	Flexure-shear
	PPFRC (MT) 2P	3	1	25	Flexure-shear
	PPFRC (FT) 1P	3	1.5	16.7	Flexure
	SFRC (FCT) 2P	3	1	23.1	Flexure-shear
	SFRC (CCT) 1P	3	1.5	16.1	Flexure
D 50	R.C.C. 2P	2.4	0.8	44.9	Shear-flexure
	PPFRC (MT) 2P	2.4	0.8	40.4	Shear-flexure
	PPFRC (FT) 1P	2.4	1.2	26.7	Shear-flexure
	SFRC (FCT) 2P	2.4	0.8	38.85	Shear-flexure
	SFRC (CCT) 1P	2.4	1.2	26.85	Flexure-shear
D 60	R.C.C. 2P	2	0.67	53.04	Shear
	PPFRC (MT) 2P	2	0.67	53.05	Shear
	PPFRC (FT) 1P	2	1	41.5	Flexur-support
	SFRC (FCT) 2P	2	0.67	52.96	Shear-flexure
	SFRC (CCT) 1P	2	1	42.6	Shear-flexure

4.7 COMPARISION OF SHEAR STRENGTH OF FRC WITH SHEAR STRENGTH OF RCC BEAMS

TABLE GROUP 4.7 COMPARISON OF ULTIMATE SHEAR STRENGTH OF FRC BEAMS WITH R.C.C. (w/s) BEAMS.

Table 4.7.1.1 Comparison of Avg. Ultimate Shear Strength Of FRC Beams With R.C.C (with Stirrups) Beams For 2P

2P		R.C.C.	PPFRC (MT)	SFRC (FCT)	PPFRC (FT)	HFRC (MT+CCT)	$\frac{\text{PPFRC(MT)}}{\text{RCC(W/S)}}$	$\frac{\text{SFRC (FCT)}}{\text{RCC(W/S)}}$	$\frac{PPFRC(FT)}{RCC(W/S)}$	$\frac{HFRC}{RCC(W/S)}$
D30	**S0.0**	6.70	6.20	6.25	5.95	6.03				
	S5.0	7.85	6.15	6.23						
	S7.5	8.05	6.075	6.20						
	AVG	**7.53**	**6.14**	**6.23**	**5.95**	**6.03**	**0.82**	**0.83**	**0.79**	**0.80**
D40	**S0.0**	14.75	11.70	11.75	11.15	11.95				
	S5.0	14.50	12.10	11.65						
	S7.5	14.45	12.50	11.55						
	AVG	**14.56**	**12.10**	**11.65**	**11.15**	**11.95**	**0.83**	**0.80**	**0.77**	**0.82**
D50	**S0.0**	23.00	20.00	19.88	18.70	19.90				
	S5.0	22.75	18.70	19.55						
	S7.5	22.45	20.20	19.43						
	AVG	**22.73**	**19.63**	**19.62**	**18.70**	**19.90**	**0.86**	**0.86**	**0.82**	**0.88**
D60	**S0.0**	31.87	26.60	26.95	25.65	25.45				
	S5.0	26.10	26.10	26.58						
	S7.5	26.52	26.52	26.48						
	AVG	**28.16**	**26.40**	**26.67**	**25.65**	**25.45**	**0.94**	**0.95**	**0.91**	**0.90**
OVER ALL AVG. OF ULTIMATE SHEAR STRENGTH							**0.86**	**0.86**	**0.82**	**0.85**

TABLE 4.7.1.2 Comparison of Avg. Ultimate Shear Strength of FRC Beams with R.C.C (with stirrups) Beams For 1P

1P		R.C.C.	PPFRC (MT)	SFRC (CCT)	PPFRC (FT)	HFRC (MT+CCT)	$\frac{\text{PPFRC(MT)}}{\text{RCC(W/S)}}$	$\frac{\text{SFRC (FCT)}}{\text{RCC(W/S)}}$	$\frac{PPFRC(FT)}{RCC(W/S)}$	$\frac{HFRC}{RCC(W/S)}$
D30	**S0.0**	5.75	5.5	4.45	4.75	5.35				
	S5.0			5.25	4.50					
	S7.5			5.1	4.60					
	AVG	**5.75**	**5.50**	**4.93**	**4.62**	**5.35**	**0.96**	**0.86**	**0.93**	**0.93**
D40	**S0.0**	8.60	8.25	8.45	7.75	6.54				
	S5.0			8.35	8.10					
	S7.5			8.05	8.35					
	AVG	**8.60**	**8.25**	**8.28**	**8.05**	**6.54**	**0.96**	**0.96**	**0.94**	**0.76**
D50	**S0.0**	13.65	13.25	13.65	13.55	13.58				
	S5.0			13.45	13.05					
	S7.5			13.43	13.35					
	AVG	**13.65**	**11**	**13.51**	**13.32**	**13.58**	**1.24**	**0.99**	**0.98**	**0.99**
D60	**S0.0**	22.70	21.40	21.85	20.45	21.90				
	S5.0			21.38	20.60					
	S7.5			21.30	20.75					
	AVG	**22.70**	**21.40**	**21.51**	**20.60**	**21.90**	**0.94**	**0.95**	**0.91**	**0.96**
OVER ALL AVG. OF ULTIMATE SHEAR STRENGTH							**0.96**	**0.94**	**0.94**	**0.91**

TABLE GROUP 4.8 COMPARISON OF ULTIMATE SHEAR STRENGTH OF FRC BEAMS WITH R.C.C. (W/O/S) BEAMS

TABLE 4.8.1.1 Comparison of Avg. Ultimate Shear Strength of FRC Beams with R.C.C (without Stirrups) Beams For 2P

2P		R.C.C. w/o/s	PPFRC (MT)	SFRC (FCT)	PPFRC (FT)	HFRC (MT+CCT)	$\frac{\text{PPFRC(MT)}}{\text{RCC(W/O/S)}}$	$\frac{\text{SFRC (FCT)}}{\text{RCC(W/O/S)}}$	$\frac{\text{PPFRC(FT)}}{\text{RCC(W/O/S)}}$	$\frac{\text{HFRC}}{\text{RCC(W/O/S)}}$
D30	S0.0	3.5	6.20	6.25	5.95	6.03				
	S5.0		6.15	6.23						
	S7.5		6.075	6.20						
	AVG	**3.5**	**6.14**	**6.23**	**5.95**	**6.03**	**1.75**	**1.78**	**1.70**	**1.72**
D40	S0.0	6.7	11.70	11.75	11.15	11.95				
	S5.0		12.10	11.65						
	S7.5		12.50	11.55						
	AVG	**6.7**	**12.10**	**11.65**	**11.15**	**11.95**	**1.81**	**1.74**	**1.66**	**1.78**
D50	S0.0	10.2	20.00	19.88	18.70	19.90				
	S5.0		18.70	19.55						
	S7.5		20.20	19.43						
	AVG	**10.2**	**19.63**	**19.62**	**18.70**	**19.90**	**1.92**	**1.92**	**1.83**	**1.95**
D60	S0.0	15	26.60	26.95	25.65	25.45				
	S5.0		26.10	26.58						
	S7.5		26.52	26.48						
	AVG	**15**	**26.40**	**26.67**	**25.65**	**25.45**	**1.76**	**1.78**	**1.71**	**1.7**
OVER ALL AVG. OF ULTIMATE SHEAR STRENGTH							**1.81**	**1.81**	**1.73**	**1.79**

TABLE 4.8.1.2 Comparison of Avg. Ultimate Shear Strength of FRC Beams with R.C.C (without stirrups) Beams For 1P

1P		RCC w/o/s	PPFRC (MT)	SFRC (CCT)	PPFRC (FT)	SFRC (CCT)	$\frac{PPFRC(MT)}{RCC(W/O/S)}$	$\frac{SFRC\ (CCT)}{RCC(W/O/S)}$	$\frac{PPFRC(FT)}{RCC(W/O/S)}$	$\frac{HFRC}{RCC(W/O/S)}$
D30	S0.0	3.1	5.5	4.45	4.75	5.35				
	S5.0			5.25	4.5					
	S7.5			5.1	4.6					
	AVG	**3.1**	**5.5**	**4.93**	**4.62**	**5.35**	**1.77**	**1.59**	**1.49**	**1.73**
D40	S0.0	4.95	8.25	8.45	7.75	6.54				
	S5.0			8.35	8.1					
	S7.5			8.05	8.35					
	AVG	**4.95**	**8.25**	**8.28**	**8.05**	**6.54**	**1.67**	**1.67**	**1.63**	**1.32**
D50	S0.0	7	11.8	13.65	13.55	13.58				
	S5.0			13.45	13.05					
	S7.5			13.43	13.35					
	AVG	**7**	**11.8**	**13.51**	**13.32**	**13.58**	**1.69**	**1.93**	**1.90**	**1.94**
D60	S0.0	12	21.4	21.85	20.45	21.9				
	S5.0			21.38	20.6					
	S7.5			21.3	20.75					
	AVG	**12**	**21.4**	**21.51**	**20.6**	**21.9**	**1.78**	**1.79**	**1.72**	**1.83**
OVER ALL AVG. OF ULTIMATE SHEAR STRENGTH							**1.73**	**1.75**	**1.68**	**1.70**

CHAPTER-5
ANALYTICAL FORMULATION

5.1 COMPUTATION OF SHEAR STRENGTH

The analysis of the Ultimate Shear strength of a Fibrous Moderate Deep Beam is based on the following assumptions:

1) The shear strength of Moderate deep beam is dependent on the compressive strength and splitting strength of fibrous concrete.
2) The approximate direction of the diagonal crack is the line joining the load point with the support point.
3) The shear capacity of Fibrous moderate Deep beams is obtained by superimposition of three components namely shear capacity of concrete, shear capacity of the fibers and shear capacity of the web reinforcement.

Brock [90] pointed out the possibility of predicting the ultimate shear strength of Reinforced Concrete Beams on the basis of the splitting strength of concrete. This is substantiated by the work of Ramkrishnan and Ananthnarayan[85], Patel S. N.[11] and others.

Using a similar approach, a method is proposed for calculating shear capacity of fibrous Moderate Deep Beam using splitting analogy. With addition to fibers, shear capacity improves. Shear resistance is built up through fibers crossing a major diagonal crack or any such similar crack. The total shear capacity of such beam is made up of the shear capacity of concrete, shear capacity of web reinforcement together with the resistance offered by the fibers in the concrete.

Total shear capacity= Shear capacity of concrete (V_{uc}) + Shear capacity of web reinforcement (V_{us}) + Shear capacity of fibers (V_{uf}).

$$\mathbf{V_u = V_{uc} + V_{us} + V_{uf}}$$

In the present research work, web reinforcement is not used so Vus=0. So the final equation is $V_u = V_{uc} + V_{uf}$

In the formulation of V_{uf}, the important parameters of concrete, fibers, area of tension steel and loading conditions are considered. Concrete parameters such as modulus of rupture of concrete, cube compressive strength of concrete, split cylinder strength of concrete are used. Fiber parameters such as fiber density, length of fiber, diameter of fiber, bond factor of fiber and volume of fiber are used. The loading conditions such as L/d ratio and a/D ratio are considered.

Regression analysis is used in formulation of proposed empirical equations for prediction of Ultimate Shear Strength of Fibrous Moderate Deep beams.

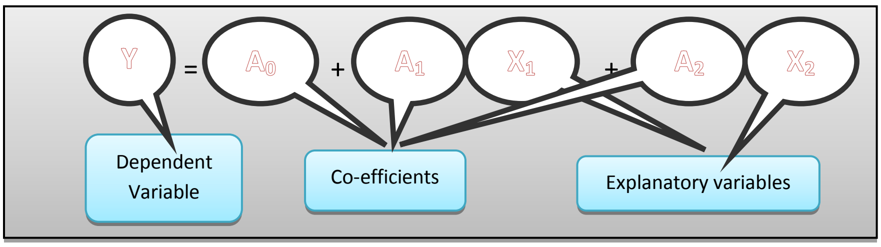
Regression analysis is a statistical technique for investigating and modeling the relationship between variables. It is possible to estimate the unknown values of one variable from known values of another variable or we can predict the other variable from this analysis. The variable which is used to predict the variable of interest is called the independent variable and the variable to be predicted is called the dependent variable.

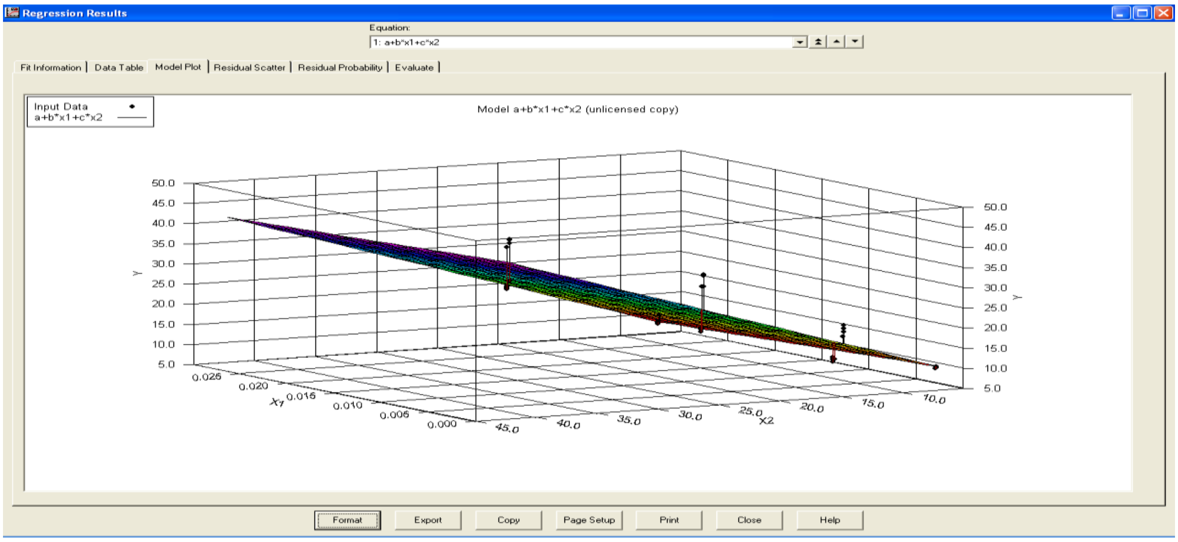
5.2 MULTIPLE LINEAR REGRESSION

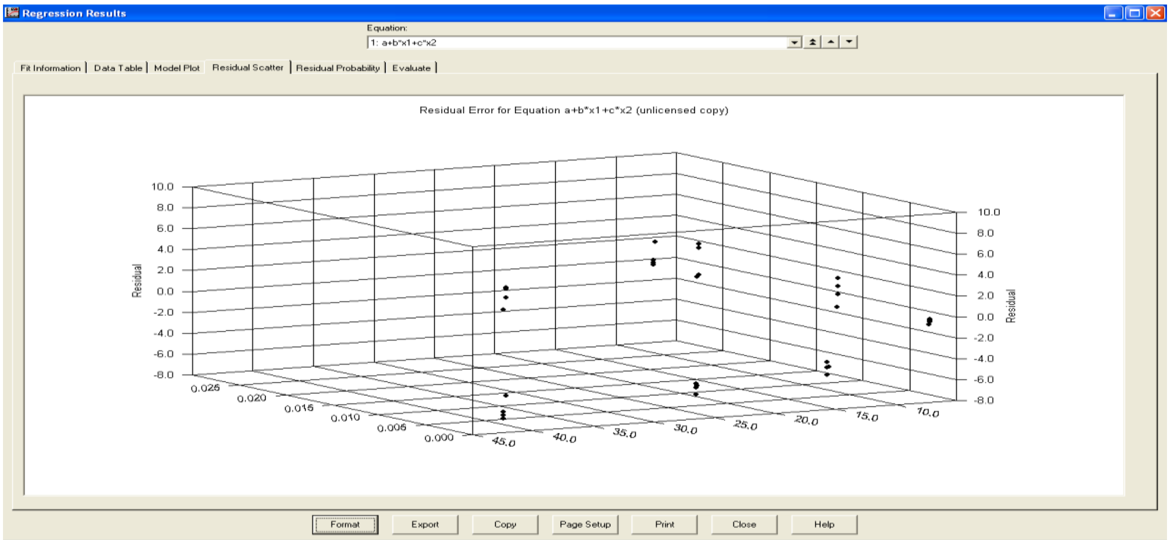
Multiple linear regression (MLR) is method used to model the linear relationship between a dependent variable and one or more independent variables. The model expresses the value of a predicted variable as a linear function of one or more predictor variables. This equation is called deterministic model. it gives an exact relationship between the variables X and Y. MLR is based on least squares: the model is fit such that the sum-of-squares of differences of observed and predicted values is minimized.

The multiple linear equation is written as,

$$Y=A_0+A_1X_1+A_2X_2+\ldots.\ A_nX_n$$







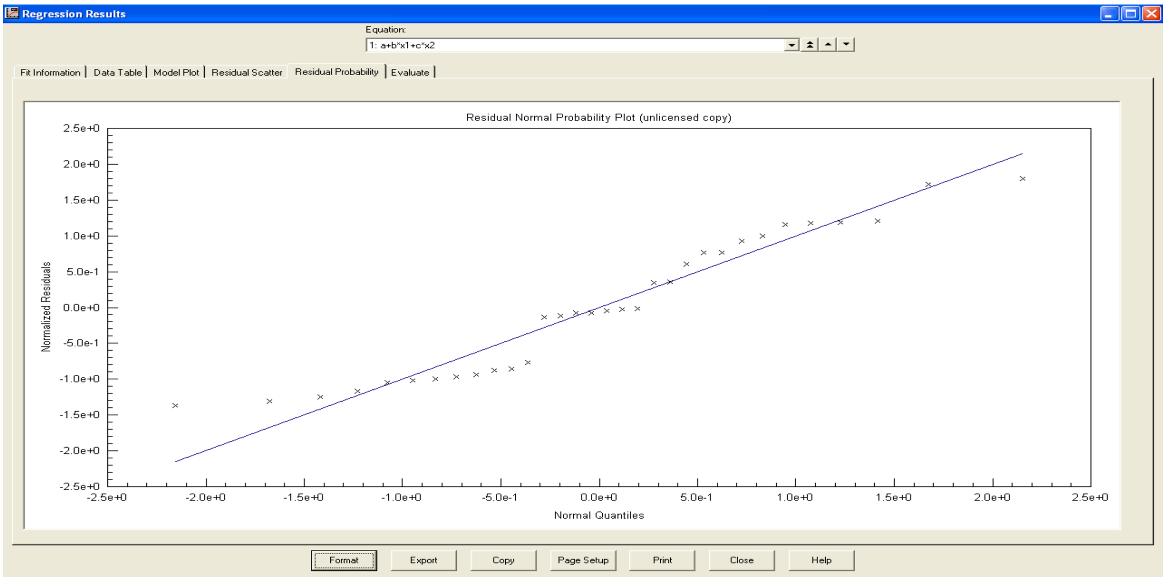


Fig. No. 5.0 Residual Scaller and Residual Probability Plot

5.3 PROPOSED EMPIRICAL EQUATION FOR PREDICTION OF ULTIMATE SHEAR STRENGTH OF PPFRC MODERATE DEEP BEAMS

$Vu = V_{uC} + Vu_{ppFRC}$........ (A)

Where,

V_u = Total shear force of deep beam with FRC.

V_{uc} = shear force resisted by concrete.

Vu_{ppFRC} = shear force resisted by FRC.

$Vu = \tau_C B\ d$ .... (B)

Where,

τ_C = Design shear strength of concrete, Is:456-2000,table-19,page 73.

B = Width of beam.

d = effective depth of beam.

+1.412.... (C)

Where,

D = overall depth of beam.

b = width of beam.

a/D = shear span to depth ratio.

v_f =Volume of fibers.

F_{crf} = modulus of rupture of concrete. = 0.7*(Fcuf) ½

F_{cuf} = Average cube compressive strength.

A_{st} = Area of longitudinal tensile reinforcement.

b = width of beam.

d = effective depth of beam.

F = fiber factor.

L = length of beam.

F_{spf} =Average split cylinder strength.

Where,

F = fiber factor

ρ_f = fiber density.

l_f = length of fiber.

β = bond factor,

(1.0 for indented fibers;0.75 for semicircular fibers; 0.50 for circular fibers).

d_f = denier of fiber.

5.4 PROPOSED EMPIRICAL EQUATION FOR PREDICTION OF ULTIMATE SHEAR STRENGTH OF SFRC MODERATE DEEP BEAMS

$Vu = Vu_C + V_{usFRC}$........(E)

Where,

V_u = Total shear force of deep beam with FRC.

V_{uc} = shear force resisted by concrete.

Vu_{sFRC} = shear force resisted by FRC.

$V_u = \tau_C\, B\, d$ ....(F)

Where,

τ_C= Design shear strength of concrete, Is:456-2000, table-19,page 73.

B = width of beam.

d = effective depth of beam.

— – – +**1.168.... (G)**

Where,

D = overall depth of beam.

b = width of beam.

a/D = shear span to depth ratio.

v_f =Volume of fibers.

F_{crf} = modulus of rupture of concrete. = 0.7*(Fcuf) ½

F_{cuf} = Average cube compressive strength.

A_{st} = Area of longitudinal tensile reinforcement.

b = width of beam.

d = effective depth of beam.

F = fiber factor.

L = length of beam.

F_{spf} = Average split cylinder strength.

Where,

F = fiber factor

ρ f = fiber density.

l_f = length of fiber, m.

β = bond factor,

(1.0 for indented fibers;0.75 for semicircular fibers; 0.50 for circular fibers).

d_f = diameter of fiber.

5.5 PROPOSED EMPIRICAL EQUATION FOR PREDICTION OF ULTIMATE SHEAR STRENGTH OF HFRC MODERATE DEEP BEAMS

$Vu = Vu_C + -[Vu_{PPFRC} + Vu_{SFRC}]$........ (I)

Where,

Vu = Total shear force of deep beam with FRC.

Vu_c = shear force resisted by concrete.

Vu_{ppFRC} = shear force resisted by PPFRC.

Vu_{sFRC} = shear force resisted by SFRC.

$Vu = \tau_C B d$ .... (J)

Where,

τ_C = Design shear strength of concrete, Is:456-2000, table-19,page 73.

B = width of beam.

d = effective depth of beam.

Vu_{ppFRC} = to calculate Vu_{ppFRC} use equation **(C) & (D)**.

Vu_{sFRC} = to calculate Vu_{sFRC} use equation **(G) & (H)**.

5.6 COMPUTATION OF MAXIMUM CRACK WIDTH

In recent years, the control of crack widths in Reinforced Concrete Design has become an important design consideration. Cracks are developed in a reinforced concrete structure as the internal stresses exceed permissible tensile strength of the concrete.

Assurances of strength adequacy of structural elements are no longer sufficient for aesthetic or safe performance acceptance. Serviceability conditions have to be met involving cracking performance at normal load conditions. In the limit state design of concrete structures, the limit state of cracking is one of the criteria which the design has to satisfy. This check is required not only for Reinforced Concrete members, but also for Fiber Reinforced Concrete and Pre-stressed Concrete members which come under Class-3 structures of the CEB-FIP classification.

In the present investigations, the critical study related to the variation of crack width with respect to the load along with the effect of different quality of fibers on crack width is studied. In order to comply with the design requirements of the present codes of practice, one has to give more emphasis on the limit state of serviceability.

Crack spacing is of little practical significances such whether it is minimum, mean or maximum. Similarly minimum and mean crack widths are also not of much importance from practical design considerations. Navy also reported the similar opinion. Only the maximum crack width is limited to certain specified values at service load, depending on the exposed environment in the design codes.

It has been observed, in the present investigations, that the crack width at a point in a cracked section is proportional to the distance of the point from the neutral axis. The same observation was made by many of the earlier investigators. The variation in the spacing of cracks was not found to be significant due to inclusion of SFRC (CCT), SFRC (FCT), PPRRC (MT), PPRRC (FT) and Hybrid fibers in the present investigation. The crack width was reported to vary linearly with load.

The modifications proposed here for the formula developed by Gergely and Lutz (1968)[46] are to transform the Fiber Reinforced Concrete Beam into an equivalent (virtual) beam reinforced with conventional steel bars. Maximum crack width for RCC beam as per Gergely is expressed as follows:

$$\mathbf{W_{max} = 0.076 \times 10^{-3} \times f_x \times B \times \overline{\qquad\qquad} \quad (in\ mm)}$$

Where A_{st}= tension area per bar; d = concrete cover of outermost bar measured from the center of that bar; f_x =– = bending stress in longitudinal bars; W_{max}= maximum crack width measured at the extreme beam bottom level; and B= ratio of distances to the neutral axis from the extreme beam bottom level and from the centroid of longitudinal bars. The above equation is modified for Fiber Reinforced Concrete Moderate Deep Beam. The various fiber parameters such as length, volume, bond of fiber have much more effect on cracking characteristics of the beam. The new empirical equation is developed considering length of fiber, types of fiber, diameter/denier of fiber, density of fiber, bond factor, bond efficiency of the fiber and volume of fiber. The empirical equations are developed for Polypropylene Fiber Reinforced Concrete Beam, Steel Fiber Reinforced Concrete Beam and Mix Fiber Reinforced Concrete Beam.

5.7 PROPOSED EMPIRICAL EQUATION OF PREDICTION OF MAXIMUM CRACK WIDTH FOR PPFRC (MT) & PPFRC (FT) MODERATE DEEP BEAMS

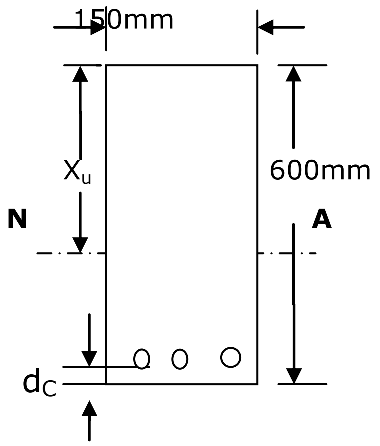


FIG.5.1 Cross Section Of FRC D60 Deep Beam

$$W_{max} = \left(\quad \overline{} \times F_{be} \times f_x \times B \times \overline{} \right) + 6.46 \quad ...(1)$$

$$W_{max} = \left(\quad \overline{} \times F_{be} \times f_x \times B \times \overline{} \right) + 6.46 \quad ....(2)$$

F = fiber factor.

V_f =Volume of fibers in concrete in percentage.

F_{be} = bond efficiency of the fibers which varies from 1 to 1.2 Depending upon fibers characteristics.

f_x= Bending stress in longitudinal bars in N/mm^2.

B=Ratio of distances to the neutral axis from the extreme beam Bottom level and from the centroid of longitudinal bars.

d_c = clear concrete cover in mm.

A_{st} = Area of longitudinal tensile reinforcement in mm^2.

F .... (a)

Where,

F = fiber factor

ρf = fiber density in kg/m^3.

lf= length of fiber in Meter.

β = bond factor,

(1.0 For indented fibers; 0.75 for semicircular fibers; 0.50 for circular fibers).

df= denier of fiber/1000.

f_x=(M/Z).....................(A)

M= (P*a)

Z= ((b*D^2)/6)

Where,

f_x= Bending stress in longitudinal bars in N/mm^2.

M=Bending moment in N mm.

Z=Section modulus of beam in mm^3.

P=Ultimate Load in Tone.

a=Shear span of beam in mm.

b = width of beam in mm.

D = overall depth of beam in mm.

L = length of beam in mm.

B= (X_u/ (X_u- d'))...... (B)

Where,

B=Ratio of distances to the neutral axis from the extreme beam Bottom level and from the centroid of longitudinal bars.

Xu=distance of neutral axis to the compression face of the beam in mm.

d' = Effective cover of concrete in mm.

A_{st}= n*(*Φ^2)/4..............(C)

n = No. of bar.

Ast = Area of longitudinal tensile reinforcement in mm^2.

Φ=Diameter of Steel Reinforcement bar in mm.

5.8 PROPOSED EMPIRICAL EQUATION OF PREDICTION OF MAXIMUM CRACK WIDTH FOR SFRC (CCT) MODERATE DEEP BEAMS

$$W_{max} = \left(8.92x \quad x\text{———}x\ F_{be} x f_x x\ B\ x \quad \overline{\qquad}\ \right) + 4.057 \ldots (3)$$

F_{CCT} = fiber factor.

V_f =Volume of fibers in concrete in percentage.

F_{be} = bond efficiency of the fibers which varies from 1 to 1.2 Depending upon fibers characteristics.

f_x= Bending stress in longitudinal bars in N/mm^2.

B=Ratio of distances to the neutral axis from the extreme beam Bottom

level and from the centroid of longitudinal bars.

d_c = clear concrete cover in mm.

A_{st} = Area of longitudinal tensile reinforcement in mm^2.

F_{CCT} .... (a)

Where,

F_{CCT} = fiber factor

ρ_f = fiber density in kg/m^3.

l_f= length of fiber in Meter.

β = bond factor,

(1.0 For indented fibers; 0.75 for semicircular fibers; 0.50 for circular fibers).

d_f= denier of fiber/1000.

f_x=(M/Z)......................(A)

M= (P*a)

Z= ((b*D^2)/6)

Where,

f_x= Bending stress in longitudinal bars in N/mm^2.

M=Bending moment in N mm.

Z=Section modulus of beam in mm^3.

P=Ultimate Load in Tone.

a=Shear span of beam in mm.

b = width of beam in mm.

D = overall depth of beam in mm.

L = length of beam in mm.

B= (X_u/ (X_u- d’))…… (B)

Where,

B=Ratio of distances to the neutral axis from the extreme beam Bottom level and from the centroid of longitudinal bars.

X_u=distance of neutral axis to the compression face of the beam in mm.

d’ = Effective cover of concrete in mm.

A_{st}= n*(*Φ^2)/4………….(C)

n = No. of bar

A_{st} = Area of longitudinal tensile reinforcement in mm^2.

Φ=Diameter of Steel Reinforcement bar in mm.

5.9 PROPOSED EMPIRICAL EQUATION OF PREDICTION OF MAXIMUM CRACK WIDTH FOR SFRC (FCT) MODERATE DEEP BEAMS

W_{max}=(———— x F_{be} x f_x x B x ———) +10.662… (4)

F_{FCT} = fiber factor.

V_f =Volume of fibers in concrete in percentage.

F_{be} = bond efficiency of the fibers which varies from 1 to 1.2 Depending upon fibers characteristics.

f_x= Bending stress in longitudinal bars in N/mm^2.

B=Ratio of distances to the neutral axis from the extreme beam

Bottom level and from the centroid of longitudinal bars.

d_c = clear concrete cover in mm.

A_{st} = Area of longitudinal tensile reinforcement in mm^2.

F_{FCT} .... (a)

Where,

F_{FCT} = fiber factor

ρ_f = fiber density in kg/m^3.

l_f= length of fiber in Meter.

β = bond factor,

(1.0 For indented fibers; 0.75 for semicircular fibers; 0.50 for circular fibers).

df= denier of fiber/1000.

f_x=(M/Z)......................(A)

M= (P*a)

Z= ((b*D^2)/6)

Where,

f_x= Bending stress in longitudinal bars in N/mm^2.

M=Bending moment in N mm.

Z=Section modulus of beam in mm^3.

P=Ultimate Load in Tone.

a=Shear span of beam in mm.

b = width of beam in mm.

D = overall depth of beam in mm.

L = length of beam in mm.

B= (X_u/ (X_u- d’))...... (B)

Where,

B=Ratio of distances to the neutral axis from the extreme beam

Bottom level and from the centroid of longitudinal bars.

Xu=distance of neutral axis to the compression face of the beam in mm.

d' = Effective cover of concrete in mm.

A_{st}= n*($*\Phi^2$)/4.............(C)

n = No. of bar

A_{st} = Area of longitudinal tensile reinforcement in mm^2.

Φ=Diameter of Steel Reinforcement bar in mm.

5.10 PROPOSED EMPIRICAL EQUATION OF PREDICTION OF MAXIMUM CRACK WIDTH FOR HFRC (MT+FCT) MODERATE DEEP BEAMS

$$W_{max}=0.5X\Big[\Big(\quad \frac{\quad}{\quad} xF_{be}xf_xxBx\Big(\frac{\quad}{\quad}\Big)+6.46\Big)+$$

$$\Big\{\quad \frac{\quad}{\quad} x\ F_{be}\ x\ f_x\ x\ Bx\Big(\frac{\quad}{\quad}\Big)+10.662\Big\}\Big]\ldots(5)$$

F_{MT} = fiber factor of Monofilament Fiber.

F_{CCT} = fiber factor of Circular corrugated Fiber.

V_f =Volume of fibers in concrete in percentage.

F_{be} = bond efficiency of the fibers which varies from 1 to 1.2 Depending upon fibers characteristics.

f_x= Bending stress in longitudinal bars in N/mm^2.

B=Ratio of distances to the neutral axis from the extreme beam Bottom level and from the centroid of longitudinal bars.

d_c = clear concrete cover in mm.

A_{st} = Area of longitudinal tensile reinforcement in mm^2.

f_x=(M/Z)………………….(A)

M= (P*a)

Z= ((b*D^2)/6)

Where,

f_x= Bending stress in longitudinal bars in N/mm^2.

M=Bending moment in N mm.

Z=Section modulus of beam in mm^3.

P=Ultimate Load in Tone.

A=Shear span of beam in mm.

b = width of beam in mm.

D = overall depth of beam in mm.

L = length of beam in mm.

B= (X_u/ (X_u- d'))…… (B)

Where,

B=Ratio of distances to the neutral axis from the extreme beam.

Bottom level and from the centroid of longitudinal bars.

X_u=distance of neutral axis to the compression face of the beam in mm.

d' = Effective cover of concrete in mm.

A_{st}= n*(*Φ^2)/4………….(C)

n = No. of bar

A_{st} = Area of longitudinal tensile reinforcement in mm^2

Φ=Diameter of Steel Reinforcement bar in mm

TABLE 5.1.1 Ultimate Shear Strength for 1P (Experimental and Theoretical)

Sr. No	TYPE	Vu(Exp.)	Vu(Theo.)	% Error
1	D30 S 0.0 PPFRC (MT) 1P	5.5	4.94	11.33
2	D40 S 0.0 PPFRC (MT) 1P	8.25	9.76	-15.47
3	D50 S 0.0 PPFRC (MT) 1P	13.25	15.79	-16.112
4	D60 S 0.0 PPFRC (MT) 1P	21.4	23.67	-9.584
5	D30 S 0.0 PPFRC (FT) 1P	4.75	4.75	0.027
6	D40 S 0.0 PPFRC (FT) 1P	7.75	9.3	-16.66
7	D50 S 0.0 PPFRC (FT) 1P	13.55	15.86	-14.554
8	D60 S 0.0 PPFRC (FT) 1P	20.45	23.77	-13.966
9	D30 S 5.0 PPFRC (FT) 1P	4.5	4.75	-5.237
10	D40 S 5.0 PPFRC (FT) 1P	8.1	9.3	-12.9
11	D50 S 5.0 PPFRC (FT) 1P	13.05	15.86	-17.707
12	D60 S 5.0 PPFRC (FT) 1P	20.6	23.77	-13.335
13	D30 S 7.5 PPFRC (FT) 1P	4.6	4.75	-3.132
14	D40 S 7.5 PPFRC (FT) 1P	8.35	9.3	-10.2
15	D50 S 7.5 PPFRC (FT) 1P	13.35	15.86	-15.815
16	D60 S 7.5 PPFRC (FT) 1P	20.75	23.77	-12.704
17	D30 S 0.0 SFRC (CCT) 1P	5.45	5.19	5.077
18	D40 S 0.0 SFRC (CCT) 1P	8.45	9.72	-13.06
19	D50 S 0.0 SFRC (CCT) 1P	13.65	16.06	-14.99
20	D60 S 0.0 SFRC (CCT) 1P	21.85	24.23	-9.836
21	D30 S 5.0 SFRC (CCT) 1P	5.25	5.19	-1.221
22	D40 S 5.0 SFRC (CCT) 1P	8.35	9.72	-14.09
23	D50 S 5.0 SFRC (CCT) 1P	13.45	16.06	-16.23
24	D60 S 5.0 SFRC (CCT) 1P	21.38	24.23	-11.79
25	D30 S 7.5 SFRC (CCT) 1P	5.1	5.19	-1.67
26	D40 S 7.5 SFRC (CCT) 1P	8.05	9.72	-17.18
27	D50 S 7.5 SFRC (CCT) 1P	13.43	16.06	-16.39
28	D60 S 7.5 SFRC (CCT) 1P	21.3	24.23	12.1
29	D30 S 0.0 HFRC (CCT+MT) 1P	5.35	5.68	3.084
30	D40 S 0.0 HFRC (CCT+MT) 1P	8.3	9.72	14.6
31	D50 S 0.0 HFRC (CCT+MT) 1P	13.58	15.93	8.668
32	D60 S 0.0 HFRC (CCT+MT) 1P	21.9	23.95	4.685

TABLE 5.1.2 Ultimate Shear Strength for 2P (Experimental and Theoretical)

Sr. No	TYPE	Vu(Exp.)	Vu(Theo.)	% Error
1	D30 S 0.0 PPFRC (MT) 2P	6.2	6.17	0.433
2	D40 S 0.0 PPFRC (MT) 2P	11.7	10.31	13.476
3	D50 S 0.0 PPFRC (MT) 2P	20	16.8	19.04
4	D60 S 0.0 PPFRC (MT) 2P	26.6	23.67	12.378
5	D30 S 5.0 PPFRC (MT) 2P	6.15	6.17	-0.377
6	D40 S 5.0 PPFRC (MT) 2P	12.1	10.31	11.31
7	D50 S 5.0 PPFRC (MT) 2P	18.7	16.8	18.355
8	D60 S 5.0 PPFRC (MT) 2P	26.1	23.67	10.266
9	D30 S 7.5 PPFRC (MT) 2P	6.08	6.17	-1.592
10	D40 S 7.5 PPFRC (MT) 2P	12.5	10.31	21.235
11	D50 S 7.5 PPFRC (MT) 2P	20.2	16.8	20.2
12	D60 S 7.5 PPFRC (MT) 2P	26.53	23.67	12.061
13	D30 S 0.0 PPFRC (FT) 2P	5.95	6.19	-3.879
14	D40 S 0.0 PPFRC (FT) 2P	11.15	10.35	7.771
15	D50 S 0.0 PPFRC (FT) 2P	18.7	15.86	17.884
16	D60 S 0.0 PPFRC (FT) 2P	25.65	23.77	7.903
17	D30 S 0.0 SFRC (FCT) 2P	6.25	6.09	2.624
18	D40 S 0.0 SFRC (FCT) 2P	11.75	10.4	3.021
19	D50 S 0.0 SFRC (FCT) 2P	19.88	16.14	3.12
20	D60 S 0.0 SFRC (FCT) 2P	26.95	24.37	0.6
21	D30 S 5.0 SFRC (FCT) 2P	6.23	6.09	2.214
22	D40 S 5.0 SFRC (FCT) 2P	11.65	10.4	2.059
23	D50 S 5.0 SFRC (FCT) 2P	19.55	16.14	1.106
24	D60 S 5.0 SFRC (FCT) 2P	26.58	24.37	9.061
25	D30 S 7.5 SFRC (FCT) 2P	6.2	6.09	1.803
26	D40 S 7.5 SFRC (FCT) 2P	11.55	10.4	1.097
27	D50 S 7.5 SFRC (FCT) 2P	19.43	16.14	0.332
28	D60 S 7.5 SFRC (FCT) 2P	26.48	24.37	8.65
29	D30 S 0.0 HFRC (CCT+MT) 2P	5.7	5.68	-0.176
30	D40 S 0.0 HFRC (CCT+MT) 2P	11.6	10.32	-5.53
31	D50 S 0.0 HFRC (CCT+MT) 2P	19.9	15.93	-9.97
32	D60 S 0.0 HFRC (CCT+MT) 2P	25.45	23.95	-2.94

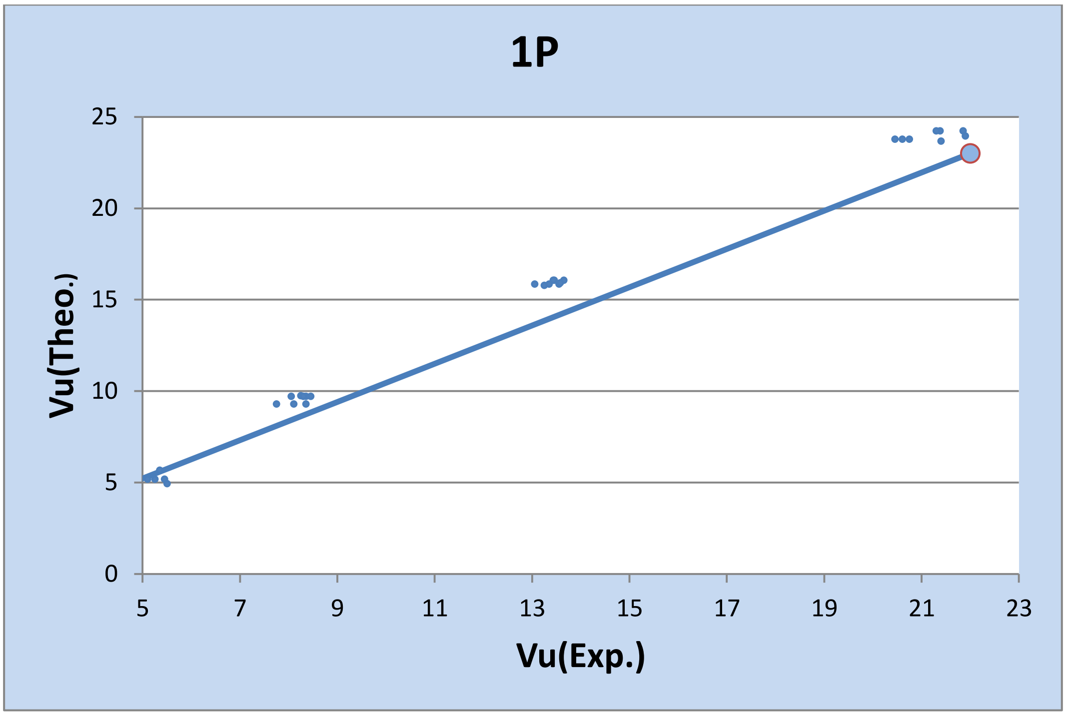


Fig. 5.2 $V_{u(Exp.)}$ Vs $V_{u(Theo.)}$ for 1P

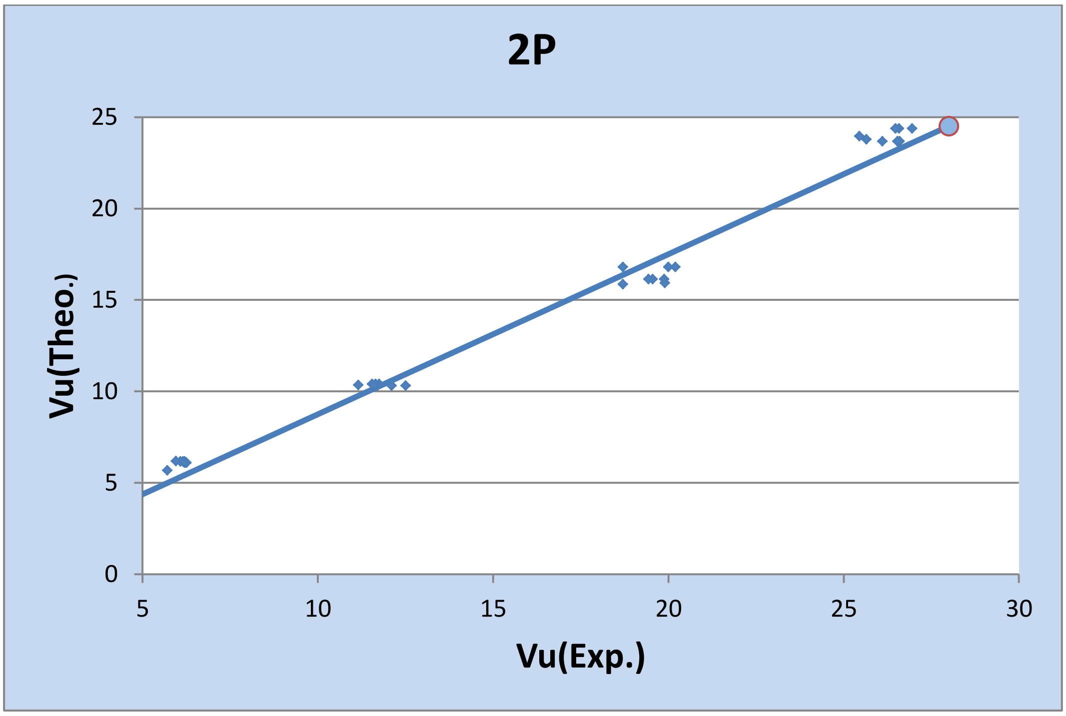


Fig. 5.3 $V_{u(Exp.)}$ Vs $V_{u(Theo.)}$ for 2P

CHAPTER-6
CRACK PATTERNS AND CRACK WIDTH PROFILE

6.1 GENERAL DESCRIPTION

Crack patterns and crack width profile is drawn as per actual observations during formation of cracks in beam. Various data regarding number of cracks, width of cracks, zone in which cracks are developed, length of crack and inclination of cracks with horizontal etc. are tabulated and compared with RCC beams, FRC beams and Hybrid FRC beams. Each above data are important for analysis of shear resistance capacity of Moderate Deep Beams. During current investigation, measurement of width of micro cracks was systematically carried out with the help of Travelling Microscope.

Travelling microscope allows image to be focused by turning the knob at side of microscope with eyepiece graticule rotated through 360º to align with direction of the crack under examination. The 4mm range of measurement has lower scale divided into 0.2mm divisions. These 0.2mm divisions are further sub - divided into 0.02mm divisions. It has calibrated graticule (scale).

When instrument is focused on concrete surface, graticule can be seen through eyepiece (it looks as if scale is on crack that allows user to accurately measure width of the crack). Current Codes of practice, state that calculated maximum crack widths should not exceed certain values: e.g. 0.3 mm in BS 8110: Part 2 for most types of environment.

6.2 CRACK PATTERNS AND CRACK WIDTH PROFILE

TABLE 6.1 D 30-S 0.0-PPFRC(MT)-1P

CRACK NAME	LOAD	ZONE	DISTANCE FROM		LENGTH	WIDTH	α	MAXIMUM WIDTH	TYPE OF FAILURE
			LHS	RHS					
	(T)		(mm)	(mm)	(mm)	(mm)		(mm)	
A1	7.6	Flexure	470		160	6.5	140°	**7.2**	**F**
A2	11	Flexure	510		172	3.01	110°		
A	**11**					**7.2**			
B1	7.8	Flexure		390	130	1.22	80°	1.25	
B2	6.30	Flexure		420	160	0.89	55°		
B	11					**1.25**			
C1	9.1	Flexure		310	70	1.1	72°	1.25	
C2	8.8	Flexure		320	85	0.84	70°		
C	11	Flexure				**1.25**			

α: Inclination with horizontal

F: crack is initiated in flexure zone and major cause of failure is flexure crack only.

L/D=4 a/D=2

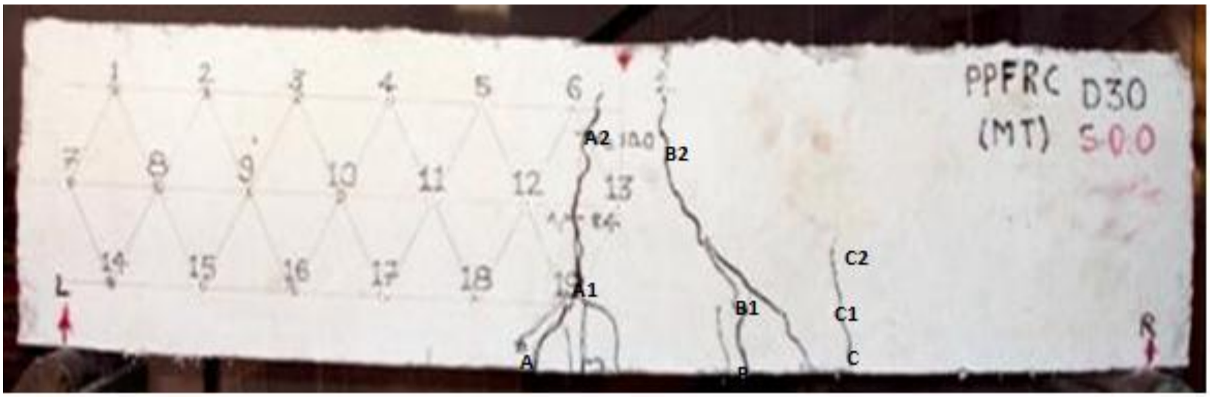


FIG. 6.1 D 30-S 0.0-PPFRC (MT)-1P

TABLE 6.2 D 40-S 0.0-PPFRC(MT)-1P

CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	9.7	Flexure		500	85	2.72	80°		
A2	11	Flexure		530	75	2.21	110°		
A3	13	Flexure		545	68	1.64	70°	3.2	
A4	9.70	Flexure		560	55	0.9	60°		
A5	16	Flexure		565	52	0.21	81°		
A	16.5					**3.2**			
B1	12	Flexure	510		140	6.25	125°		
B2	16.5	Flexure	530		180	4.25	130°	**7.5**	**FS**
B	**16.5**					**7.5**			
C1	14.1	Flexure	530		120	0.63	110°		
C2	16	Flexure	560		182	0.35	115°	1.92	
C	16.5					1.92			
D1	12	Flexure		410	120	0.32	70°		
D2	16.2	Flexure		510	240	0.22	60°	0.8	
D	16.5					**0.8**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D= 3 a/D=1.5

FIG. 6.2 D 40-S 0.0-PPFRC (MT)-1P

TABLE 6.3 D 50-S 0.0-PPFRC(MT)-1P

CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	24.4	Flexure	585		90	5	125°	**7**	**FS**
A2	26.5	Flexure	530		120	2.4	92°		
A	**26.5**					**7**			
B1	15.4	Flexure		440	420	1.05	75°	1.05	
B	26.5					1.05			
C1	20.8	Shear	190		190	0.51	135°	0.59	
C2	14.30	Shear	340		240	0.25	145°		
C	26.5					**0.59**			
D1	22	Shear		160	100	1.7	48°	1.9	
D2	21.2	Shear		320	140	1.23	45°		
D3	23.5	Shear		495	135	1.47	45°		
D	26.5					**1.9**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D= 2.4 a/D=1.2

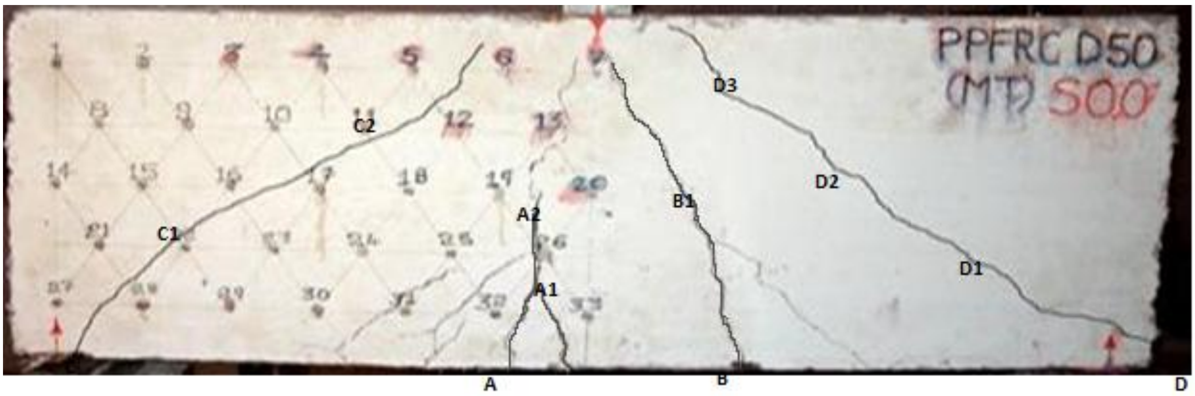
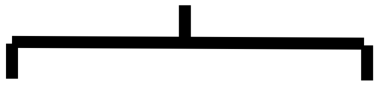


FIG. 6.3 D 50-S 0.0-PPFRC (MT)-1P

TABLE 6.4 D 60-S 0.0-PPFRC(MT)-1P



CRACK NAME	LOAD	ZONE	DISTANCE FROM		LENGTH	WIDTH	α	MAXIMUM WIDTH	TYPE OF FAILURE
			LHS	RHS					
	(T)		(mm)	(mm)	(mm)	(mm)		(mm)	
A1	24.1	Shear		120	130	3.5	60°	**7.38**	**S**
A2	26	Shear		190	135	2.5	55°		
A3	27	Shear		270	124	1.2	45°		
A4	40.6	Shear		340	138	0.8	45°		
A5	42.8	Shear		498	120	0.8	45°		
A	**42.8**					**7.38**			
B1	21.4	Flexure	420		110	0.15	140°	0.16	
B2	26	Flexure	564		100	0.12	128°		
B	42.5					**0.16**			
C1	28.2	Shear	260		240	1.75	120°	2.01	
C2	29.4	Shear	390		270	1.45	140°		
C	42.8					**2.01**			

α: Inclination with horizontal

S: Crack is initiated in flexure zone but major cause of failure is inclined shear crack only.

L/D= 2 a/D=1

FIG. 6.4 D 60-S 0.0-PPFRC (MT)-1P

TABLE 6.5 D30-S 0.0-PPFRC(MT)-2P

CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	7.80	flexure	545		60	4.38	90°	**6.88**	**F**
A2	9.2	flexure	530		65	2.54	78°		
A3	12.2	flexure	540		75	1.28	98°		
A4	12.4	flexure	520		80	1.2	120°		
A	**12.4**					**6.88**			
B1	9.5	flexure	430		85	1.2	90°	1.52	
B2	12.2	flexure	405		170	0.9	90°		
B	12.4					**1.52**			
C1	10.2	flexure		470	110	2.8	110°	3.2	
C2	11.2	flexure		490	130	1.2	110°		
C	12.4					**3.2**			

α: Inclination with horizontal

F: crack is initiated in flexure zone and major cause of failure is flexure crack only.

L/D= 4 a/D=1.33

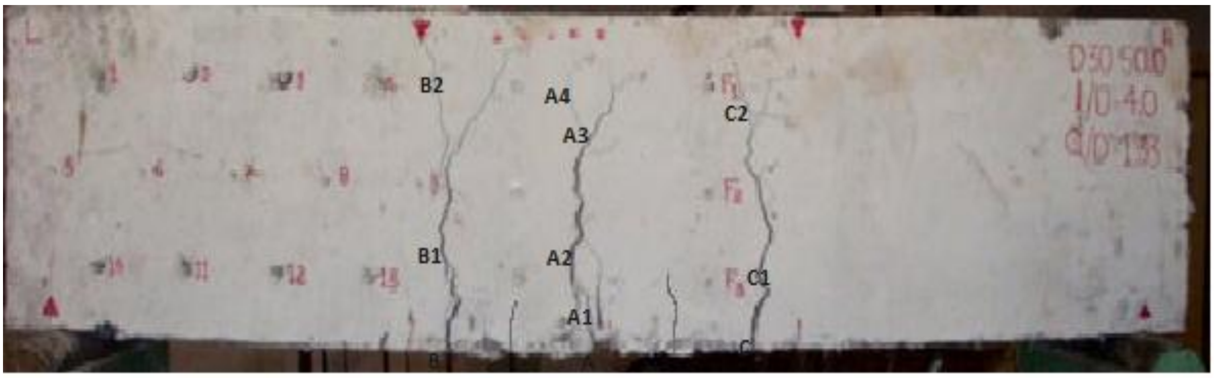


FIG. 6.5 D 30-S 0.0-PPFRC (MT)-2P

TABLE 6.6 D 40-S 0.0-PPFRC(MT)-2P

CRACK NAME	LOAD	ZONE	DISTANCE FROM		LENGTH	WIDTH	α	MAXIMUM WIDTH	TYPE OF FAILURE
			LHS	RHS					
	(T)		(mm)	(mm)	(mm)	(mm)		(mm)	
A1	11	flexure	470		75	5.12	98°	**7.3**	**FS**
A2	19.8	flexure	495		115	4.32	90°		
A3	23.4	flexure	515		130	2.12	110°		
A	**23.4**					**7.3**			
B1	13.2	flexure		430	85	3.29	88°	5.65	
B2	20.2	flexure		480	110	1.56	86°		
B3	21.4	flexure		520	125	0.65	80°		
B	23.4					**5.65**			
C1	12.2	flexure	480		120	2.3	110°	2.6	
C2	18.5	flexure	490		95	1.2	90°		
C	23.4					**2.6**			
D1	22.7	flexure		560	210	0.9	90°	0.9	
D	23.4				-	**0.9**	-		
E1	15.7	flexure		320	80	2.25	79°	2.7	
E2	19.8	flexure		340	89	2.05	95°		
E3	20.2	flexure		420	120	1.85	79°		
E4	22.5	flexure		490	115	0.9	70°		
E	23.4					**2.7**	-		
F1	16.4	flexure	340		135	0.8	120°	1.2	
F2	19.3	flexure	410		210	0.6	125°		
F	23.4					**1.2**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D= 3 a/D=1

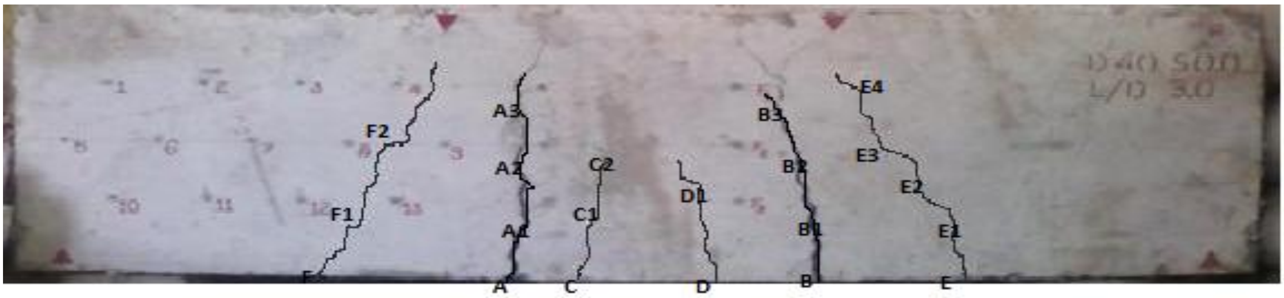


FIG. 6.6 D 40-S 0.0-PPFRC (MT)-2P

TABLE 6.7 D 50-S 0.0-PPFRC(MT)-2P

CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	20	flexure	600		85	2.8	90°		
A2	25.2	flexure	595		97	1.4	75°	3.2	
A3	28.3	flexure	585		115	0.8	70°		
A	40					**3.2**			
B1	20.8	shear		120	80	0.9	80°		
B2	28.7	shear		290	105	0.8	75°	1.2	
B3	32.5	shear		410	120	0.4	70°		
B	40					**1.2**			
C1	16	shear	180		80	4.2	135°		
C2	29.5	shear	295		110	3.8	145°	**5.98**	**FS**
C3	40	shear	390		120	1.2	140°		
C	**40**					**5.98**			
D1	22.2	flexure	280		120	0.8	125°		
D2	35	flexure	340		210	0.6	115°	1.5	
D	40					**1.5**			
E1	35.5	flexure	460		105	1.8	115°		
E2	38	flexure	520		240	0.85	110°	2.2	
E	40					**2.2**			
F1	20.2	flexure		380	95	1.2	80°		
F2	28.4	flexure		440	110	0.95	75°	1.5	
F3	32.3	flexure		530	140	0.76	60°		
F	40					**1.5**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D= 2.4 a/D=0.8

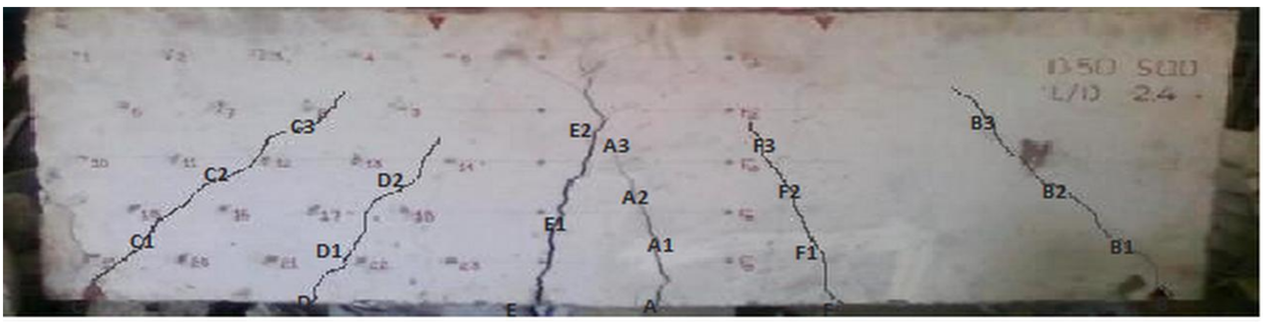


FIG. 6.7 D 50-S 0.0-PPFRC (MT)-2P

TABLE 6.8 D 60-S 0.0-PPFRC(MT)-2P

CRACK NAME	LOAD	ZONE	DISTANCE FROM		LENGTH	WIDTH	α	MAXIMUM WIDTH	TYPE OF FAILURE
			LHS	RHS					
	(T)		(mm)	(mm)	(mm)	(mm)		(mm)	
A1	20.5	shear		85	85	2.2	65°	3.2	
A2	27.2	shear		180	90	1.8	60°		
A3	33.8	shear		290	95	1.2	65°		
A4	39.6	shear		390	120	0.9	60°		
A5	44.8	shear		440	110	0.6	65°		
A	53.2					**3.2**			
B1	19.40	shear	120		105	4.8	120°	**6.2**	**S**
B2	25.3	shear	160		140	4.1	110°		
B3	32.7	shear	310		160	3.6	135°		
B4	45.6	shear	440		180	2.2	140°		
B	**53.2**					**6.2**			

α: Inclination with horizontal

S: Crack is initiated in flexure zone but major cause of failure is inclined shear crack only.

L/D= 2 a/D=0.67

FIG. 6.8 D 60-S 0.0-PPFRC (MT)-2P

TABLE 6.9 D 30-S 5.0-PPFRC(MT)-2P

CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	7.20	flexure	507		80	5.28	78°	**6.83**	**F**
A2	12.3	flexure	495		85	3.83	105°		
A	**12.3**					**6.83**			
B1	8.4	flexure		390	75	4.1	90°	4.54	
B2	9.2	flexure		380	85	2.3	78°		
B3	12.1	flexure		410	90	8.34	70°		
B	12.3					**4.54**			
C1	9.2	flexure	410		80	1.9	110°	2.4	
C2	10.5	flexure	380		85	1.5	80°		
C3	12.2	flexure	430		110	0.9	105°		
C	12.3					**2.4**			

α: Inclination with horizontal

F: crack is initiated in flexure zone and major cause of failure is flexure crack only.

L/D=4 a/D=1.33

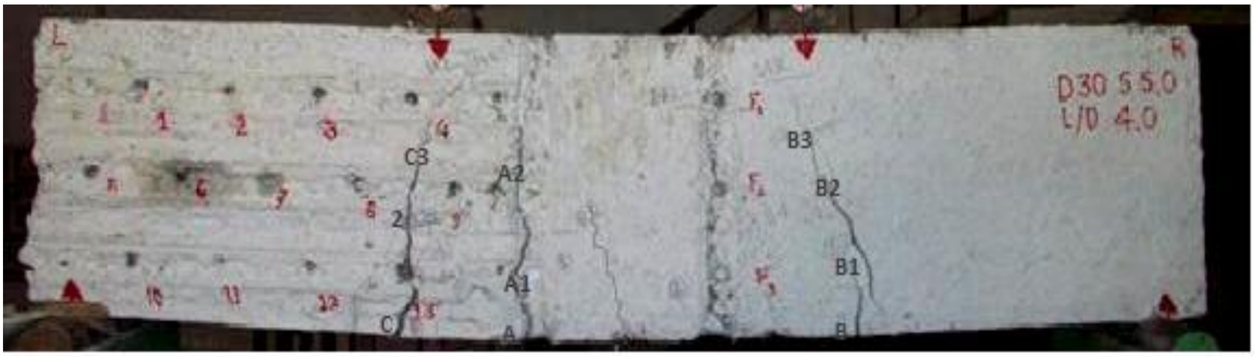


FIG. 6.9 D 30-S 5.0-PPFRC (MT)-2P

TABLE 6.10 D 40-S 5.0-PPFRC(MT)-2P

CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	11.6	flexure		540	50	4.28	86°	**6.3**	**F**
A2	24.2	flexure		560	65	2.83	90°		
A	**24.2**					**6.3**			
B1	11.8	flexure	48		65	4.23	90°	4.82	
B2	14.5	flexure	490		80	1.35	105°		
B3	16.8	flexure	470		90	2.3	70°		
B4	19.2	flexure	475		110	1.82	110°		
B	24.2					**4.82**			
C1	12.2	flexure		390	95	4.4	85°	5.6	
C2	15.3	flexure		420	68	2.8	75°		
C3	17.2	flexure		440	75	1.6	75°		
C	24.2					**5.6**			

α: Inclination with horizontal

F: crack is initiated in flexure zone and major cause of failure is flexure crack only.

L/D=3 a/D=1

FIG. 6.10 D 40-S 5.0-PPFRC (MT)-2P

TABLE 6.11 D 50-S 5.0-PPFRC(MT)-2P

CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	18.2	flexure	545		65	2.89	110°		
A2	19.8	flexure	585		85	1.23	95°		
A3	22.3	flexure	570		95	0.85	90°	3.85	
A4	28.2	flexure	575		110	0.69	110°		
A	37.4					**3.85**			
B1	16.8	shear	65		65	5.28	110°		
B2	22.4	shear	110		75	4.89	112°		
B3	28.2	shear	190		80	3.8	115°		
B4	32.4	shear	280		83	2.52	118°	**6.62**	**FS**
B5	37.4	shear	310		90	1.62	120°		
B	**37.4**					**6.62**			
C1	20.2	shear		65	68	3.1	75°		
C2	30.8	shear		95	92	2.85	85°	3.43	
C3	35.2	shear		120	108	1.43	70°		
C	37.4					**3.43**			
D1	22	shear	320		90	1	120°		
D2	35.2	shear	330		105	0.9	115°	1.3	
D	37.4	shear				1.3			
E1	18.4	flexure		310	110	2	75°	2	
E	37.4					**2**			
F1	25.3	shear	510		90	1.2	110°	1.2	
F	37.4					**1.2**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=2.4 a/D=0.8

FIG. 6.11 D 50-S 5.0-PPFRC (MT)-2P

TABLE 6.12 D 60-S 5.0-PPFRC(MT)-2P

CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	18.40	flexure	590		60	2	88°	2.4	
A2	25.2	flexure	580		85	1.3	90°		
A3	32.4	flexure	572		90	0.8	85°		
A	52.2					**2.4**			
B1	16.4	shear		65	105	5	90°	**5.4**	**S**
B2	22.8	shear		110	85	3.2	68°		
B3	38.6	shear		185	75	2	65°		
B4	52.2	shear		290	105	1.4	60°		
B	**52.2**					**5.4**			
C1	20.5	shear	80		210	1.5	130°	2.5	
C2	35.8	shear	180		180	1.2	150°		
C3	45.9	shear	240		170	0.9	145°		
C	52.2					**2.5**			

α: Inclination with horizontal

S: Crack is initiated in flexure zone but major cause of failure is inclined shear crack only.

L/D=2 a/D=0.67

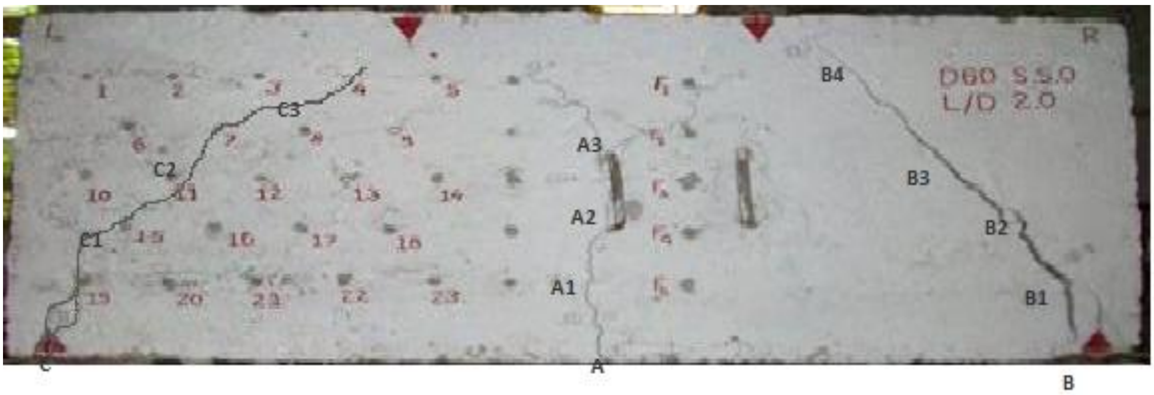


FIG. 6.12 D 60-S 5.0-PPFRC (MT)-2P

TABLE 6.13 D 30-S 7.5-PPFRC(MT)-2P

CRACKNAME	LOAD	ZONE	DISTANCE FROM		LENGTH	WIDTH	α	MAXIMUM WIDTH	TYPE OF FAILURE
			LHS	RHS					
	(T)		(mm)	(mm)	(mm)	(mm)		(mm)	
A1	8	flexure	580		45	6.2	90°	**6.5**	**FS**
A2	12.2	flexure	570		85	3.2	100°		
A3	12.15	flexure	560		70	1.2	110°		
A	**12.15**					**6.5**			
B1	9.2	flexure		490	105	5.2	82°	6.2	
B2	10.4	flexure		530	75	3.2	80°		
B	12.15					**6.2**			
C1	8.6	Shear	390		95	3	125°	3.2	
C2	10.2	Shear	420		120	2.4	120°		
C3	12	Shear	470		85	1.5	145°		
C	12.15					**3.2**			
D1	8.8	Shear		375	65	2.9	80°	3.0	
D2	9.2	Shear		390	75	2.2	70°		
D3	10.8	Shear		420	85	1.2	65°		
D4	11	Shear		510	80	0.8	70°		
D	12.15					**3.0**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=4 a/D=1.33

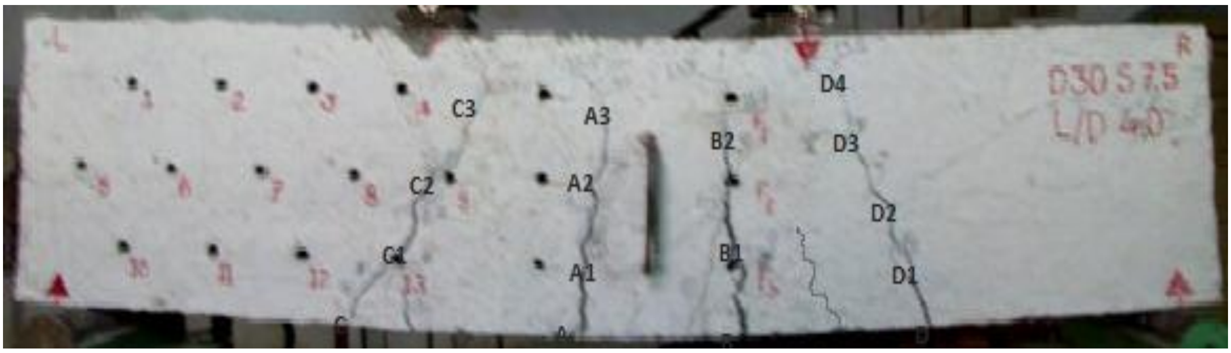


FIG. 6.13 D 30-S 7.5-PPFRC (MT)-2P

TABLE 6.14 D 40-S 7.5-PPFRC(MT)-2P

CRACKNAME	LOAD	ZONE	DISTANCE FROM		LENGTH	WIDTH	α	MAXIMUM WIDTH	TYPE OF FAILURE
			LHS	RHS					
	(T)		(mm)	(mm)	(mm)	(mm)		(mm)	
A1	11.4	flexure		580	70	6.32	130°	**7.08**	**FS**
A2	17.2	flexure		510	85	5.82	120°		
A3	20.8	flexure		525	110	4.36	85°		
A4	25	flexure		520	105	2.35	110°		
A	**25**					**7.08**			
B1	11.8	shear	110		70	4.85	145°	6.82	
B2	15.2	shear	195		85	3.92	150°		
B3	18.2	shear	320		120	2.64	150°		
B4	22.4	shear	410		140	1.8	150°		
B	25					**6.82**			
C1	14.2	shear		75	85	5.92	65°	6.9	
C2	16.8	shear		130	120	4.65	60°		
C3	22.4	shear		285	90	3.85	65°		
C	25					**6.9**			
D1	16.5	flexure	320		105	0.8	120°	1.2	
D2	20.8	flexure	340		110	0.6	140°		
D	25					**1.2**			
E1	18.2	flexure	420		95	0.5	90°	1	
E2	22.4	flexure	480		110	0.4	125°		
E	25					**1**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=3 a/D=1

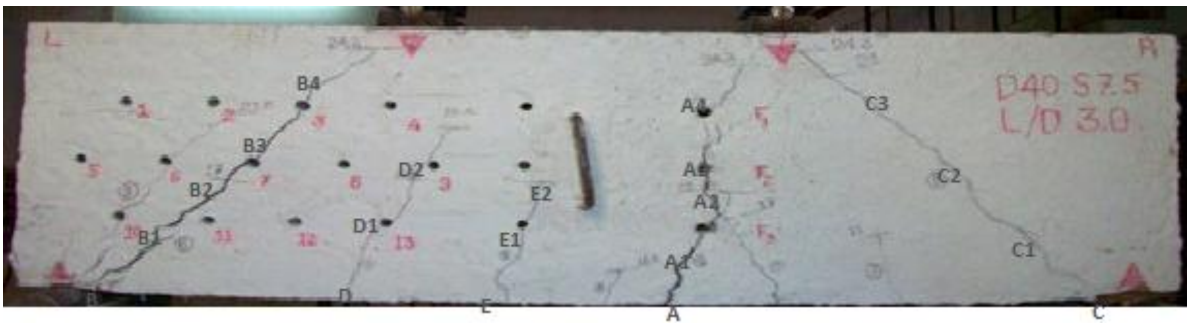


FIG. 6.14 D 40-S 7.5-PPFRC (MT)-2P

TABLE 6.15 D 50-S 7.5-PPFRC(MT)-2P

CRACKNAME	LOAD	ZONE	DISTANCE FROM		LENGTH	WIDTH	α	MAXIMUM WIDTH	TYPE OF FAILURE
			LHS	RHS					
	(T)		(mm)	(mm)	(mm)	(mm)		(mm)	
A1	20.8	flexure	550		105	4.1	120°	5.8	
A2	32.2	flexure	570		110	2.6	130°		
A3	39.8	flexure	590		125	1.8	90°		
A	40.4					**5.8**			
B1	22.4	flexure	450		85	4.9	92°	5.6	
B2	28.8	flexure	430		120	3.1	115°		
B3	38.2	flexure	490		150	1.6	120°		
B	40.4					**5.6**			
C1	19.8	shear		305	85	6.8	85°	**7.35**	**FS**
C2	25.4	shear		325	95	4.5	80°		
C3	33.7	shear		340	120	3.9	65°		
C4	38.2	shear		390	82	2.6	110°		
C5	40.4	shear		480	210	1.35	65°		
C	**40.4**					**7.35**			
D1	25.2	shear		110	75	5.7	45°	6.2	
D2	30.4	shear		205	180	4.3	55°		
D3	40.2	shear		390	230	3.2	52°		
D	40.4					**6.2**			
E1	20.5	shear	90		90	0.9	140°	1.2	
E2	25.3	shear	170		120	0.8	130°		
E3	28.4	shear	240		130	0.7	135°		
E4	39.8	shear	390		80	0.6	140°		
E	40.4					**1.2**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=2.4 a/D=0.8

FIG. 6.15 D 50-S 7.5-PPFRC (MT)-2P

TABLE 6.16 D 60-S 7.5-PPFRC(MT)-2P

CRACK NAME	LOAD	ZONE	DISTANCE FROM		LENGTH	WIDTH	α	MAXIMUM WIDTH	TYPE OF FAILURE
			LHS	RHS					
	(T)		(mm)	(mm)	(mm)	(mm)		(mm)	
A1	28.4	flexure	510		80	3.4	90°	5.25	
A2	35.8	flexure	540		110	4.25	110°		
A	53.05					**5.25**			
B1	32.2	flexure		560	80	4.8	90°	5.9	
B2	42.4	flexure		530	130	3.9	79°		
B	53.05					**5.9**			
C1	28.2	shear	80		85	4.8	120°	5.32	
C2	38.2	shear	190		210	3.32	140°		
C3	40.5	shear	300		200	1.2	140°		
C	53.05					**5.32**			
D1	24.8	shear		85	140	5.2	75 °	**6.7**	**S**
D2	53.05	shear		130	210	3.4	60°		
D	**53.05**					**6.7**			

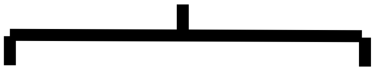
α: Inclination with horizontal

S: Crack is initiated in flexure zone but major cause of failure is inclined shear crack only.

L/D=2 a/D=0.67

FIG. 6.16 D 60-S 7.5-PPFRC (MT)-2P

TABLE 6.17 D 30-S 0.0-PPFRC(FT)-1P



CRACK NAME	LOAD	ZONE	DISTANCE FROM		LENGTH	WIDTH	α	MAXIMUM WIDTH	TYPE OF FAILURE
			LHS	RHS					
	(T)		(mm)	(mm)	(mm)	(mm)		(mm)	
A1	6	Flexure		570	80	4.8	85°	**6.22**	**FS**
A2	8.3	Flexure		585	75	2.5	90°		
A3	9.5	Flexure		580	85	1.4	80°		
A4	9.5	Flexure		575	75	1.2	85°		
A	**9.5**					**6.22**			
B1	6	Flexure	540		100	3.2	90°	4	
B2	9.5	Flexure	615		150	1.1	110°		
B	9.5					**4**			
C1	6.7	Shear	386		65	3.2	135°	3.8	
C2	8.3	Shear	470		110	1.9	130°		
C3	9.5	Shear	545		120	0.6	135°		
C	9.5					**3.8**			
D1	8.3	Flexure		510	105	2.05	70°	2.12	
D2	9	Flexure		590	110	1.36	65°		
D	9.5					**2.12**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=4 a/D=2

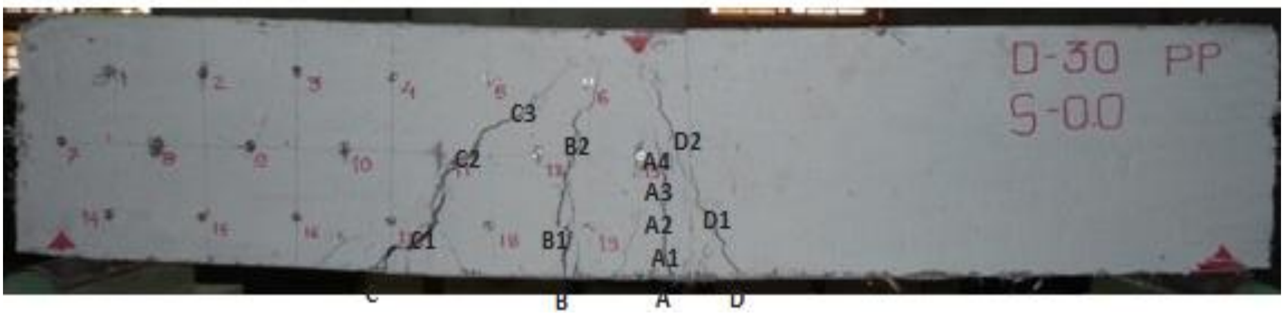


FIG. 6.17 D 30-S 0.0-PPFRC (FT)-1P

TABLE 6.18 D 40-S 0.0-PPFRC(FT)-1P

CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	7.3	Flexure	495		40	3.8	70°	**5.4**	**F**
A2	7.9	Flexure	550		45	3.62	110°		
A3	8.3	Flexure	520		80	2.55	105°		
A4	9.5	Flexure	540		90	2.12	70°		
A5	9.8	Flexure	535		65	1.56	90°		
A6	10.2	Flexure	560		50	0.45	105°		
A7	15.5	Flexure	540		35	0.18	80°		
A	**15.5**					**5.4**			
B1	9.6	Flexure		540	43	0.58	90°	0.64	
B2	10.3	Flexure		590	54	0.31	80°		
B	15.5					**0.64**			

α: Inclination with horizontal

F: crack is initiated in flexure zone and major cause of failure is flexure crack only.

L/D=3 a/D=1.5

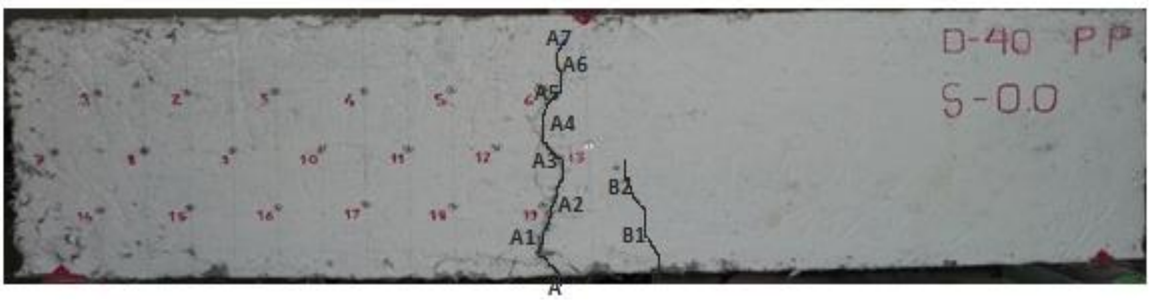


FIG. 6.18 D 40-S 0.0-PPFRC (FT)-1P

TABLE 6.19 D 50-S 0.0-PPFRC(FT)-1P

CRACK NAME	LOAD	ZONE	DISTANCE FROM		LENGTH	WIDTH	α	MAXIMUM WIDTH	TYPE OF FAILURE
			LHS	RHS					
	(T)		(mm)	(mm)	(mm)	(mm)		(mm)	
A1	10.8	Flexure		630	170	2.45	110°	2.78	
A2	11.8	Flexure	640		90	1.34	90°		
A3	14.5	Flexure	620		110	1.07	100°		
A4	14.9	Flexure	610		55	0.53	115°		
A5	18.1	Flexure	635		40	0.25	75°		
A	27.1					**2.78**			
B1	13.4	Shear		110	70	4.2	90°	**6.1**	**FS**
B2	14.4	Shear		160	85	3.46	75°		
B3	14.9	Shear		210	85	1.39	75°		
B4	27.1	Shear		250	130	0.45	70°		
B	**27.1**					**6.1**			
C1	18.1	Shear	110		80	0.26	95°	1.23	
C2	18.9	Shear	160		85	0.26	115°		
C	27.1					**1.23**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=2.4 a/D=1.2

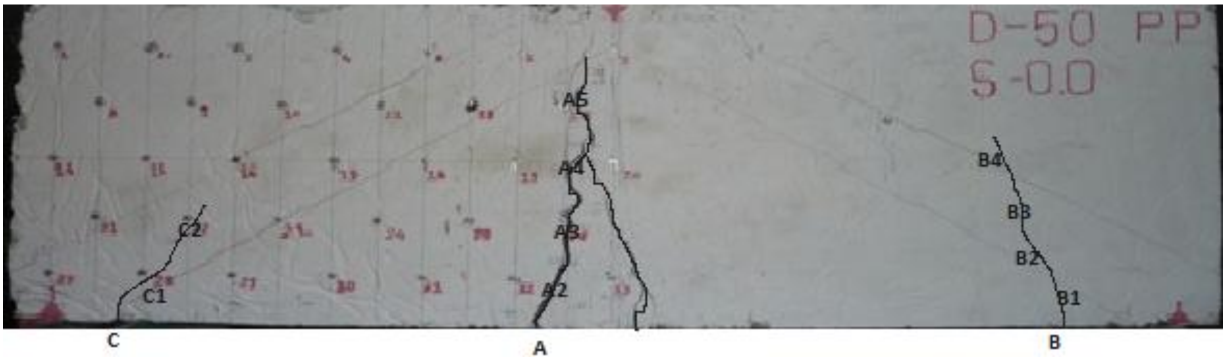


FIG. 6.19 D 50-S 0.0-PPFRC (FT)-1P

TABLE 6.20 D 60-S 0.0-PPFRC(FT)-1P

CRACK NAME	LOAD	ZONE	DISTANCE FROM		LENGTH	WIDTH	α	MAXIMUM WIDTH	TYPE OF FAILURE
			LHS	RHS					
	(T)		(mm)	(mm)	(mm)	(mm)		(mm)	
A1	22.6	Flexure	540		260	0.82	90°	1.08	
A2	32.1	Flexure	590		240	0.54	90°		
A	40.9					1.08			
B1	27.4	Shear		630	160	0.8	60°	1.24	
B2	27.9	Shear		620	110	0.76	65°		
B3	28.3	Shear		640	50	0.46	90°		
B4	31.8	Shear		650	40	0.19	60°		
B	40.9					**1.24**			
C1	27.4	Shear	300		240	5.65	120°	**7.21**	**FS**
C2	28.3	Shear	410		300	3.54	130°		
C	**40.9**					**7.21**			
D1	30	Flexure		100	210	0.18	50°	0.21	
D2	32.1	Flexure		450	120	0.13	60°		
D	40.9					**0.21**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=2 a/D=1

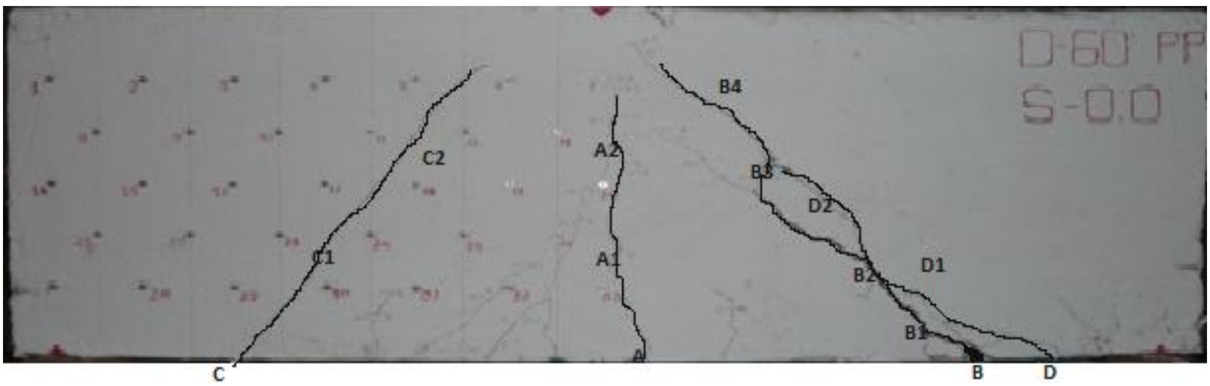


FIG. 6.20 D 60-S 0.0-PPFRC (FT)-1P

TABLE 6.21 D 30-S 5.0-PPFRC(FT)-1P

CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	4.8	Flexure	480		65	5.45	120°		
A2	6.4	Flexure	500		60	3.94	115°	**6.69**	**F**
A3	9	Flexure	530		110	0.56	140°		
A	**9**					**6.69**			
B1	6.7	Flexure		450	60	1.09	70°		
B2	8	Flexure		500	65	0.43	85°	1.25	
B	9					**1.25**			

α: Inclination with horizontal

F: crack is initiated in flexure zone and major cause of failure is flexure crack only.

L/D=4 a/D=2

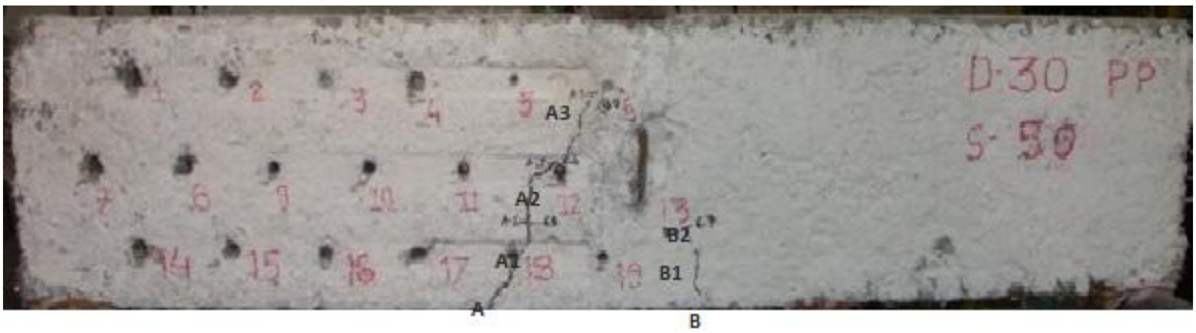


FIG. 6.21 D 30-S 5.0-PPFRC (FT)-1P

TABLE 6.22		**D 40-S 5.0-PPFRC(FT)-1P**							
CRACK NAME	LOAD	ZONE	DISTANCE FROM		LENGTH	WIDTH	α	MAXIMUM WIDTH	TYPE OF FAILURE
			LHS	RHS					
	(T)		(mm)	(mm)	(mm)	(mm)		(mm)	
A1	10.7	Shear	400		50	5.25	900°	7.1	**FS**
A2	11.8	Shear	520		80	4.34	170°		
A3	13.5	Shear	550		85	1.87	95°		
A4	16.20	Shear	610		90	0.43	110°		
A	**16.2**					**7.1**			
B1	10.8	Shear		480	105	1.2	75°	**1.36**	-
B2	12.9	Shear		510	65	0.66	60°		
B3	14	Shear		540	85	0.24	65°		
B	16.2					**1.36**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=3 a/D=1.5

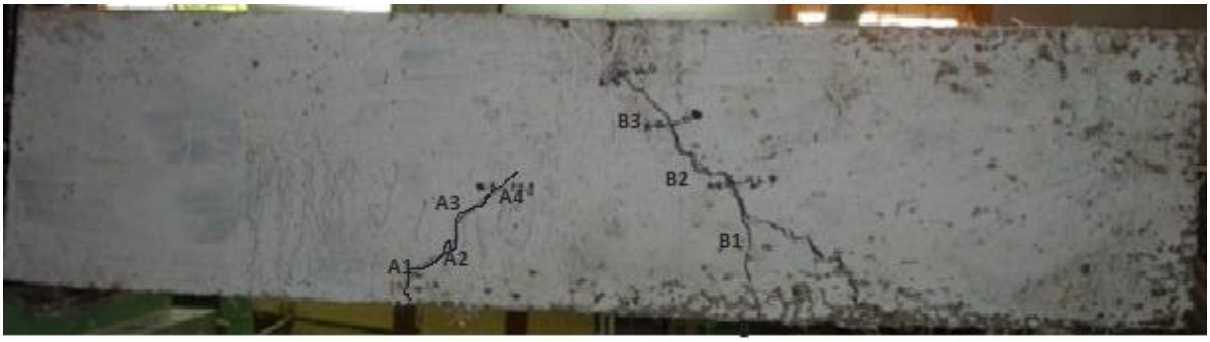


FIG. 6.22 D 40-S 5.0-PPFRC (FT)-1P

TABLE 6.23 D 50-S 5.0-PPFRC(FT)-1P

CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	12.1	Flexure		540	80	0.52	75°	0.73	
A2	16.2	Flexure		590	95	0.36	80°		
A	26.1					**0.73**			
B1	12.8	Flexure	110		105	0.81	115°	1.39	
B2	17.1	Flexure	170		80	0.65	115°		
B3	19.6	Flexure	250		85	0.52	120°		
B4	23.1	Flexure	340		87	0.48	125°		
B5	24	Flexure	452		90	0.39	130°		
B6	24.1	Flexure	470		110	0.16	160°		
B	26.1					**1.39**			
C1	14.6	Shear		180	55	0.25	65°	**6.33**	**FS**
C2	20.6	Shear		260	90	0.18	65°		
C	26.1	Shear				**6.33**			
D1	22.5	Shear	335		320	4.25	90°	5.2	
D2	26.1	Shear	450		130	1.86	110°		
D	**26.1**	shear				**5.2**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=2.4 a/D=1.2

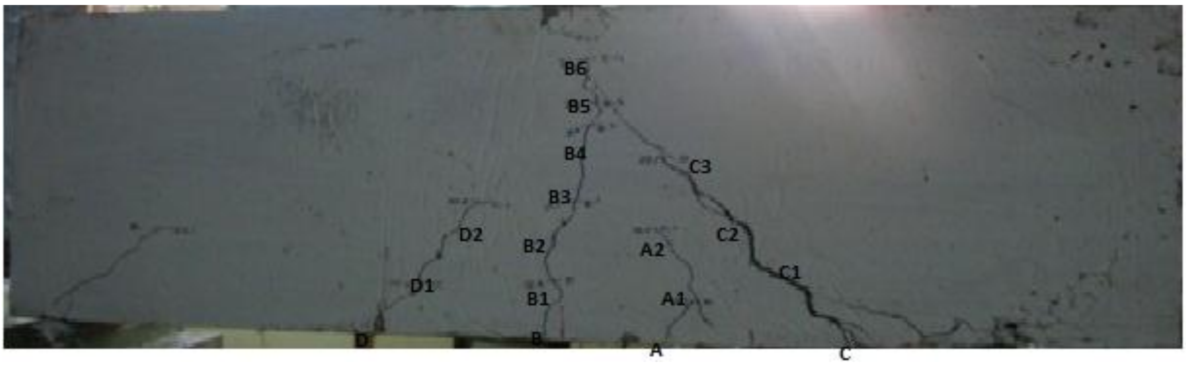


FIG. 6.23 D 50-S 5.0-PPFRC (FT)-1P

TABLE 6.24 D 60-S 5.0-PPFRC(FT)-1P

CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	19.7	Flexure		490	65	0.75	120°		
A2	25.7	Flexure		530	40	0.54	70°	1.08	
A	41.2					**1.08**			
B1	27.4	Shear	520		85	4.25	90°		
B2	27.9	Shear	510		65	1.94	80°		
B3	28.3	Shear	530		75	2.46	115°		
B4	29.6	Shear	540		70	1.59	100°	**6.87**	**S**
B5	31.8	Shear	545		45	0.74	100°		
B6	41.2	Shear	570		50	0.32	95°		
B	**41.2**					**6.87**			
C1	17.2	Shear		410	110	1.6	60°		
C2	25.4	Shear		540	95	0.9	60°	2.6	
C3	38.3	Shear		570	100	2.6	65°		
C	41.2								
D1	21.8	Flexure	420		85	1.4	130°		
D2	32.5	Flexure	490		95	0.5	120°	1.8	
D	41.2					**1.8**			

α: Inclination with horizontal

S: Crack is initiated in flexure zone but major cause of failure is inclined shear crack only.

L/D=2 a/D=1

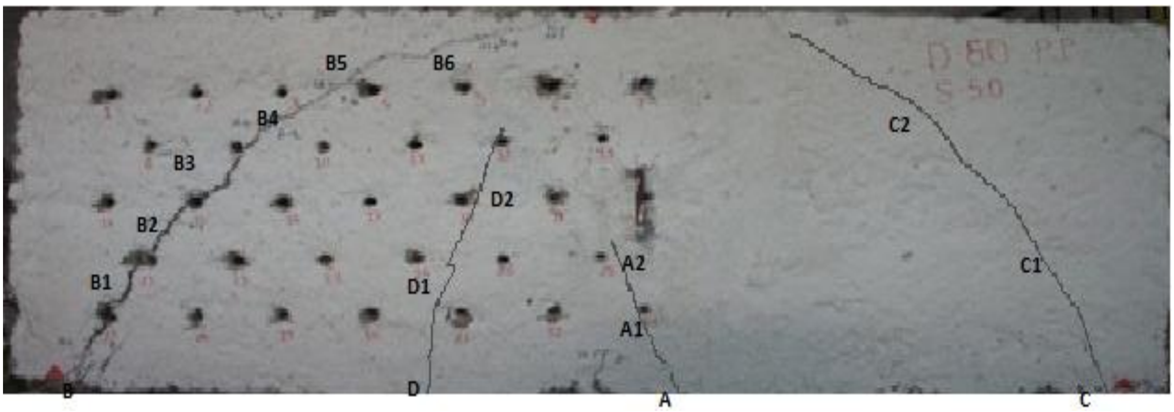


FIG. 6.24 D 60-S 5.0-PPFRC (FT)-1P

TABLE 6.25 D 30-S 7.5-PPFRC(FT)-1P

CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	3.7	Flexure	520		75	1.21	80°		
A2	4.5	Flexure	490		65	0.82	80°		
A3	5.9	Flexure	480		85	0.57	80°	1.25	
A4	6.2	Flexure	470		70	0.35	75°		
A	9.2	Flexure				**1.25**			
B1	5.7	Flexure	410		120	2.85	120°		
B2	5.8	Flexure	460		140	1.45	110°	**5.4**	**F**
B	**9.2**	Flexure				**5.4**			
C1	5.9	Flexure		440	95	0.32	90°		
C2	6	Flexure		460	85	0.18	85°	0.32	
C3	7.5	Flexure		470	110	0.18	85°		
C	9.2	Flexure				**0.32**			

α: Inclination with horizontal

F: crack is initiated in flexure zone and major cause of failure is flexure crack only.

L/D=4 a/D=2

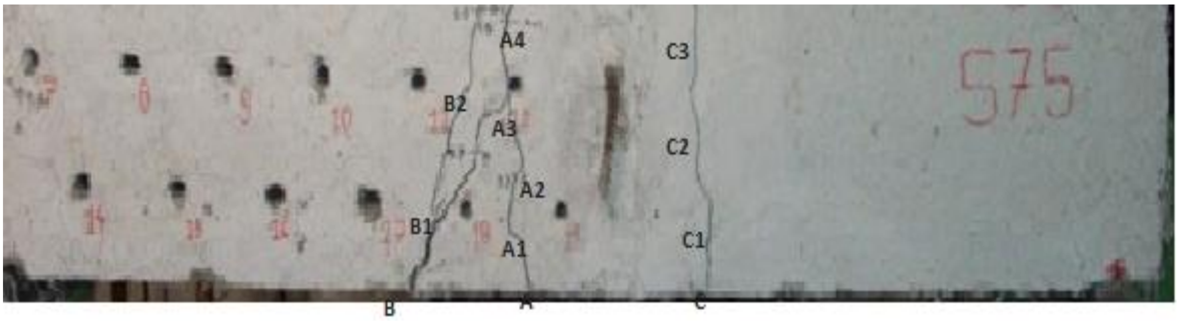


FIG. 6.25 D 30-S 7.5-PPFRC (FT)-1P

TABLE 6.26 D 40-S 7.5-PPFRC(FT)-1P

CRACK NAME	LOAD	ZONE	DISTANCE FROM		LENGTH	WIDTH	α	MAXIMUM WIDTH	TYPE OF FAILURE
			LHS	RHS					
	(T)		(mm)	(mm)	(mm)	(mm)		(mm)	
A1	8	Flexure		540	120	5.65	80°	**6.8**	**F**
A2	10	Flexure		555	140	4.34	75°		
A3	12	Flexure		564	60	2.87	80°		
A4	13.9	Flexure		605	45	0.83	75°		
A5	16.7	Flexure		625	65	0.27	80°		
A	**16.7**					**6.8**			
B1	10.6	Flexure	480		105	0.2	100°	1.58	
B2	16.2	Flexure	510		65	0.42	120°		
B	16.7					**1.58**			
C1	12.3	Flexure	560		65	0.45	85°	0.56	
C2	16.2	Flexure	610		25	0.18	100°		
C	16.7					**0.56**			

α: Inclination with horizontal

F: crack is initiated in flexure zone and major cause of failure is flexure crack only.

L/D=3 a/D=1.5

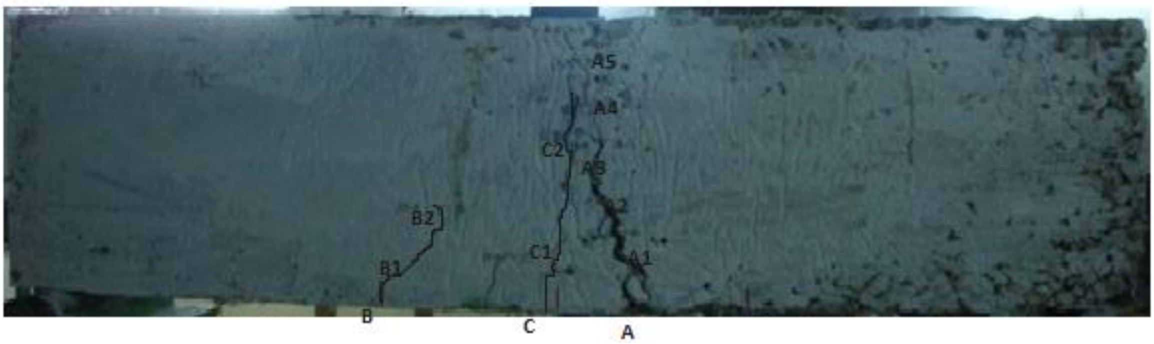


FIG. 6.26 D 40-S 7.5-PPFRC (FT)-1P

TABLE 6.27 D 50-S 7.5-PPFRC(FT)-1P

CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	9.5	Flexure		500	65	0.85	90°	0.97	
A2	12.5	Flexure		540	80	0.75	80°		
A3	15.5	Flexure		585	45	0.41	75°		
A4	22.1	Flexure		650	90	0.26	75°		
A	26.7					**0.97**			
B1	17.7	Flexure	410		70	0.42	105°	0.63	
B2	22.1	Flexure	450		85	0.15	120°		
B	26.7					**0.63**			
C1	18.1	Shear		400	170	5.82	60°	**6.2**	**FS**
C2	19.3	Shear		500	165	3.18	70°		
C3	26.7	Shear		600	120	1.89	80°		
C	**26.7**					**6.2**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=2.4 a/D=1.2

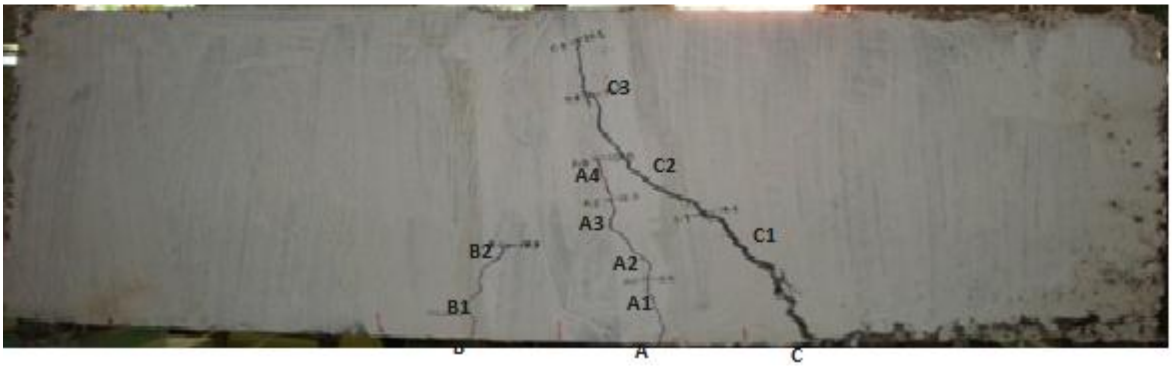


FIG. 6.27 D 50-S 7.5-PPFRC (FT)-1P

TABLE 6.28 D 60-S 7.5-PPFRC(FT)-1P

CRACK NAME	LOAD	ZONE	DISTANCE FROM		LENGTH	WIDTH	α	MAXIMUM WIDTH	TYPE OF FAILURE
			LHS	RHS					
	(T)		(mm)	(mm)	(mm)	(mm)		(mm)	
A1	21.4	Flexure	560		95	0.78	100°	1.54	
A2	25.8	Flexure	575		85	0.85	105°		
A3	26.7	Flexure	600		60	0.23	115°		
A4	28.5	Flexure	630		40	0.16	110°		
A	41.5					**1.54**			
B1	26.1	Flexure		500	100	4.25	70°	**6.63**	**Predominant support crushed**
B2	27.8	Flexure		520	110	2.35	75°		
B3	41.5	Flexure		525	95	1.41	70°		
B	**41.5**					**6.63**			

α: Inclination with horizontal

L/D=2 a/D=1

FIG. 6.28 D 60-S 7.5-PPFRC (FT)-1P

TABLE 6.29 D 30-S 0.0-PPFRC(FT)-2P 

CRACK NAME	LOAD	ZONE	DISTANCE FROM		LENGTH	WIDTH	α	MAXIMUM WIDTH	TYPE OF FAILURE
			LHS	RHS					
	(T)		(mm)	(mm)	(mm)	(mm)		(mm)	
A1	7.6	Flexure		540	110	1.73	90°	1.86	
A2	10	Flexure		520	150	0.73	115°		
A	11.9	Flexure				**1.86**			
B1	8.9	Flexure	510		110	0.82	90°	1.25	
B2	9.9	Flexure	535		150	0.98	125°		
B	11.9					**1.25**			
C1	8.5	Flexure		400	40	4.88	90°	**5.8**	**F**
C2	11.9	Flexure		410	170	2.62	98°		
C	**11.9**					**5.8**			
D1	8.5	Flexure	340		90	2.82	100°	3.25	
D2	11.9	Flexure	430		180	1.62	110°		
D	11.9	Flexure				**3.25**			
E1	8.5	Flexure	280		110	1.25	120°	1.65	
E2	11.9	Flexure	320		160	0.85	125°		
E	11.9					**1.65**			

α: Inclination with horizontal

F: crack is initiated in flexure zone and major cause of failure is flexure crack only.

L/D=4 a/D=1.33

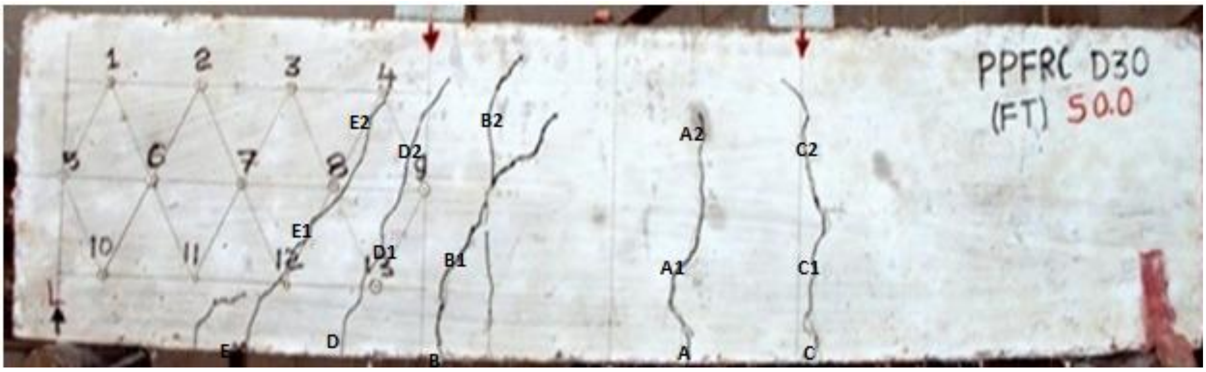


FIG. 6.29 D 30-S 0.0-PPFRC (FT)-2P

TABLE 6.30 D 40-S 0.0-PPFRC(FT)-2P

CRACK NAME	LOAD	ZONE	DISTANCE FROM		LENGTH	WIDTH	α	MAXIMUM WIDTH	TYPE OF FAILURE
			LHS	RHS					
	(T)		(mm)	(mm)	(mm)	(mm)		(mm)	
A1	12.8	Flexure	540		110	0.48	100°	0.48	
A	22.3	Flexure				**0.48**			
B1	16.7	shear		310	30	6.2	74°	**6.5**	**F**
B2	18	shear		370	50	4.5	54°		
B3	19.7	shear		410	60	2.55	85°		
B4	21.1	Shear		470	50	1.43	70°		
B5	22.3	Shear		490	35	0.8	65°		
B	**22.3**					**6.5**			
C1	18.8	Shear	40		75	0.83	125°	1.2	
C2	20.5	Shear	180		210	0.9	135°		
C	22.3	Shear				**1.2**			
D1	18.5	Shear		60	200	0.7	68°	1.1	
D	22.3	Shear				**1.1**			

α: Inclination with horizontal

F: crack is initiated in flexure zone and major cause of failure is flexure crack only.

L/D=3 a/D=1

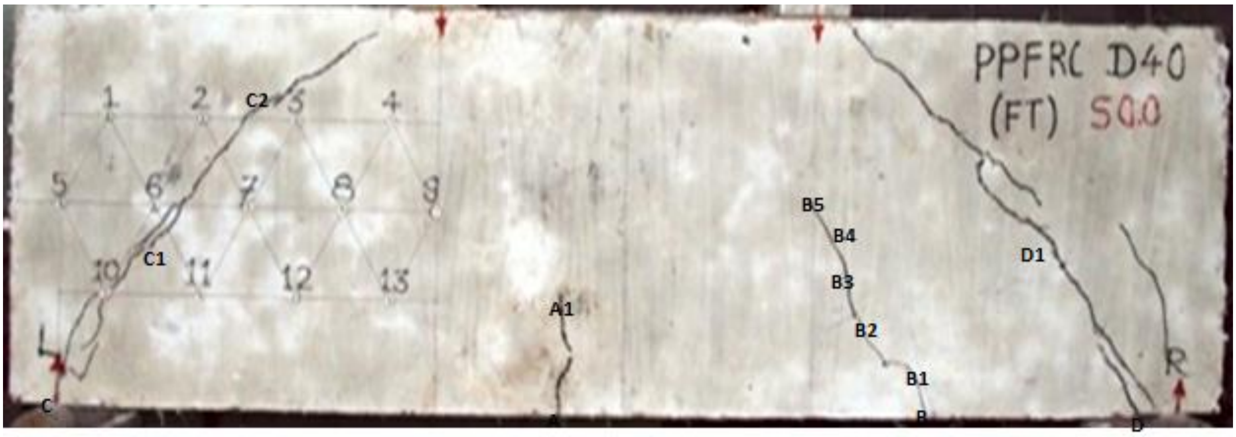


FIG. 6.30 D 40-S 0.0-PPFRC (FT)-2P

TABLE 6.31 D 50-S 0.0-PPFRC(FT)-2P

CRACK NAME	LOAD	ZONE	DISTANCE FROM		LENGTH	WIDTH	α	MAXIMUM WIDTH	TYPE OF FAILURE
			LHS	RHS					
	(T)		(mm)	(mm)	(mm)	(mm)		(mm)	
A1	16	Flexure	520		50	0.6	110°	0.8	
A2	18.5	Flexure	524		70	0.4	120°		
A3	19.7	Flexure	530		45	0.32	135°		
A	37.4					**0.8**			
B1	17.5	Flexure		430	60	0.45	90°	0.56	
B2	18.2	Flexure		435	80	0.3	80°		
B	37.4					**0.56**			
C1	19.7	shear		85	50	3.46	80°	**5.3**	**FS**
C2	21.2	shear		95	55	2.56	78°		
C3	24	shear		105	35	1.86	68°		
C4	25	shear		80	48	0.8	60°		
C5	37.4			125	68	0.51	76°		
C	**37.4**	shear				**5.3**			
D1	20	shear	50		54	3.21	100°	3.45	
D2	22.4	shear	120		90	2.41	110°		
D3	25.7	shear	162		120	1.48	120°		
D4	27.2	shear	260		210	1.19	125°		
D	37.4					**3.45**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=2.4 a/D=0.8

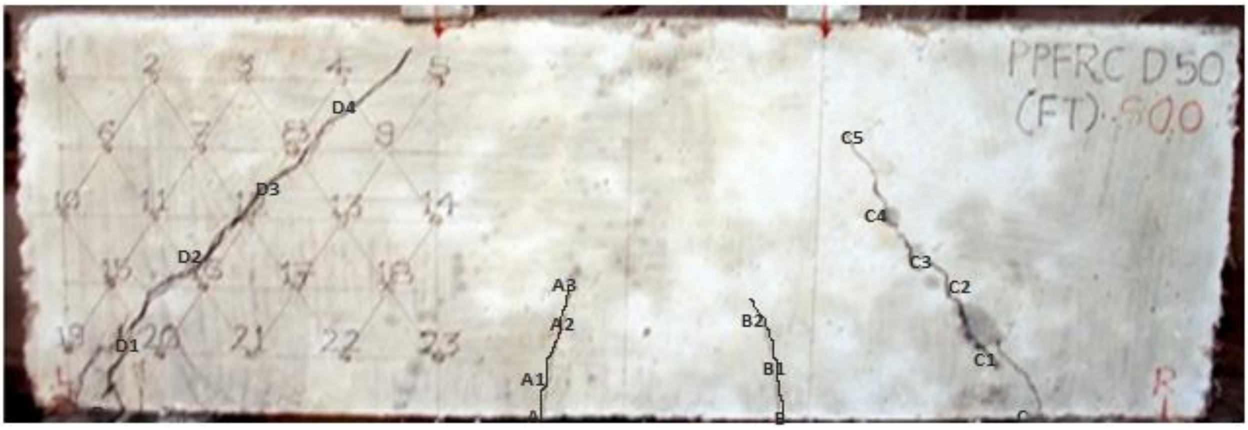


FIG. 6.31 D 50-S 0.0-PPFRC (FT)-2P

TABLE 6.32 D 60-S 0.0-PPFRC(FT)-2P

CRACK NAME	LOAD	ZONE	DISTANCE FROM		LENGTH	WIDTH	α	MAXIMUM WIDTH	TYPE OF FAILURE
			LHS	RHS					
	(T)		(mm)	(mm)	(mm)	(mm)		(mm)	
A1	19.4	Flexure		460	110	0.78	90°		
A2	26	Flexure		575	105	0.54	70°		
A3	31.8	Flexure		550	120	0.23	80°	1.54	
A4	39.2	Flexure		578	70	0.16	72°		
A	39.2					**1.54**			
B1	22.1	shear	100		260	1.04	100°	1.04	
B	22.1					**1.04**			
C1	20.1	Shear		150	155	4.25	70°		
C2	44.5	Shear		275	165	3.21	65°	**5.7**	**S**
C3	51.3	Shear		360	180	2.18	60°		
C	**51.3**					**5.7**			

α: Inclination with horizontal

S: Crack is initiated in flexure zone but major cause of failure is inclined shear crack only.

L/D=2 a/D=0.67

FIG. 6.32 D 60-S 0.0-PPFRC (FT)-2P

TABLE 6.33 D 30-S 0.0-SFRC(FCT)-2P

CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	7.40	Flexure		590	75	6.6	110°	**8.93**	**F**
A2	12.5	Flexure		530	110	3.2	105°		
A	**12.5**					**8.93**			
B1	8.9	Flexure	470		120	1.2	90°	2.2	
B2	10.8	Flexure	530		105	0.6	120°		
B	12.5					**2.2**			
C1	9.2	Flexure		320	92	2.5	90°	3.2	
C2	10.5	Flexure		350	95	1.2	95°		
C3	11.8	Flexure		410	80	0.8	90°		
C	12.5					**3.2**			
D1	8.2	Shear	310		120	1.3	120°	2.8	
D2	10.9	Shear	420		150	0.8	145°		
D	12.5					**2.8**			

α: Inclination with horizontal

F: crack is initiated in flexure zone and major cause of failure is flexure crack only.

L/D=4 a/D=1.33

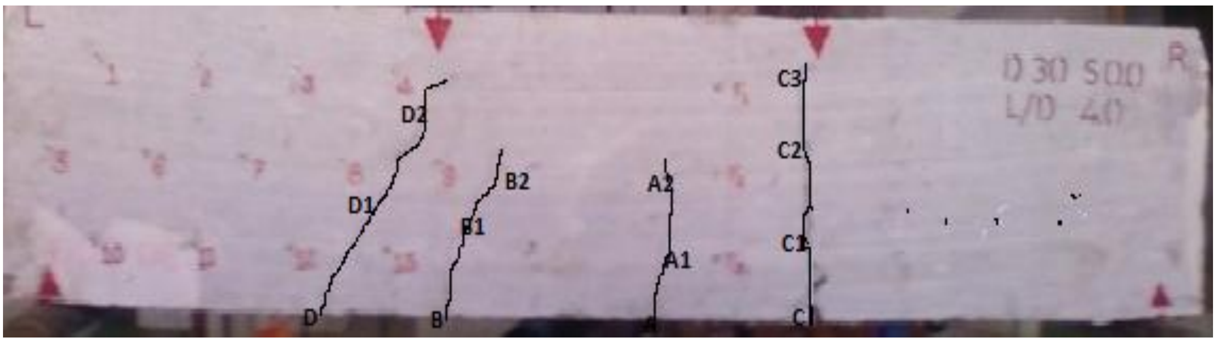


FIG. 6.33 D 30-S 0.0-SFRC (FCT)-2P

TABLE 6.34 D 40-S 0.0-SFRC(FCT)-2P

CRACK NAME	LOAD	ZONE	DISTANCE FROM		LENGTH	WIDTH	α	MAXIMUM WIDTH	TYPE OF FAILURE
			LHS	RHS					
	(T)		(mm)	(mm)	(mm)	(mm)		(mm)	
A1	11.5	Flexure	590		85	3.8	75°	**8.5**	**FS**
A2	15.8	Flexure	560		110	2.5	90°		
A3	16.6	Flexure	570		95	1.2	85°		
A4	23.5	Flexure	490		120	2	80°		
A	**23.5**					**8.5**			
B1	12.2	Flexure		410	75	1.6	85°	2.2	
B2	15.8	Flexure		425	105	0.8	80°		
B3	18.2	Flexure		450	115	0.6	75°		
B	23.5					**2.2**			
C1	17.2	shear	300		80	2.5	110°	3	
C2	20.2	shear	350		120	1.8	105°		
C3	21.5	shear	390		135	0.9	105°		
C	23.5					**3**			
D1	18.2	shear		250	55	0.8	75°	1.8	
D2	19.5	shear		310	105	0.6	70°		
D3	20.8	shear		370	110	0.4	70°		
D4	22	shear		410	120	0.2	75°		
D	23.5					**1.8**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=3 a/D=1

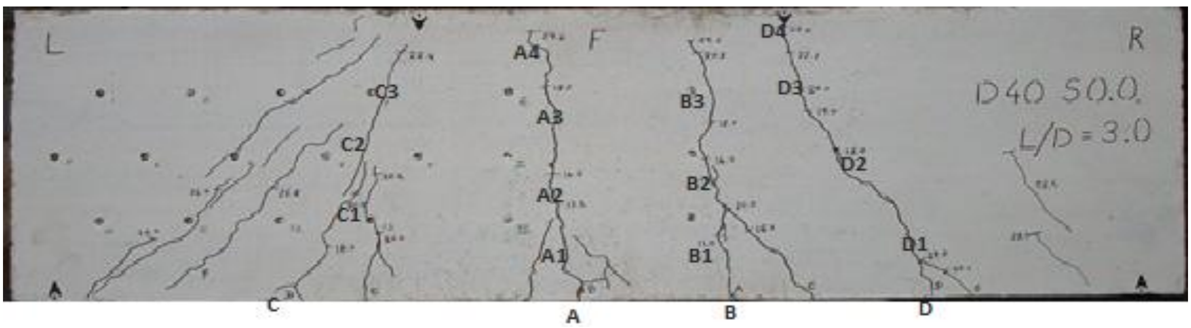


FIG. 6.34 D 40-S 0.0-SFRC (FCT)-2P

TABLE 6.35 D 50-S 0.0-SFRC(FCT)-2P

CRACK NAME	LOAD	ZONE	DISTANCE FROM		LENGTH	WIDTH	α	MAXIMUM WIDTH	TYPE OF FAILURE
			LHS	RHS					
	(T)		(mm)	(mm)	(mm)	(mm)		(mm)	
A1	20.3	Flexure		480	85	1.2	120°	2.8	
A2	28.6	Flexure		510	110	0.9	90°		
A3	36.5	Flexure		520	120	0.6	80°		
A	39.75					**2.8**			
B1	15	shear	220		95	4.8	140°	**8.6**	**FS**
B2	22.4	shear	310		125	3.5	160°		
B3	39.75	shear	490		240	2.5	130°		
B	**39.75**					**8.6**			
C1	16.4	shear		80	75	0.6	75°	1.8	
C2	22.6	shear		120	120	1.2	70°		
C3	32.2	shear		140	140	0.4	68°		
C4	36	shear		210	210	0.8	70°		
C	39.75					**1.8**			
D1	28.5	shear	75		100	1.4	125°	1.4	
D	39.75					**1.4**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=2.4 a/D=0.8

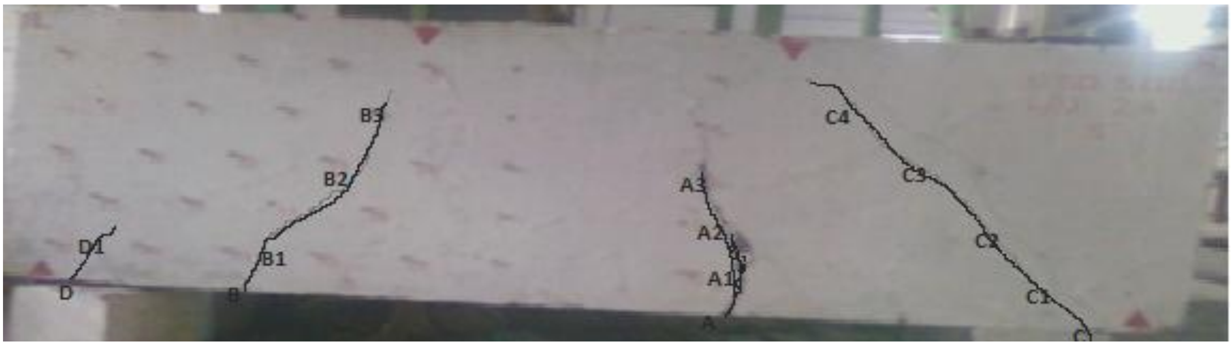


FIG. 6.35 D 50-S 0.0-SFRC (FCT)-2P

TABLE 6.36 D 60-S 0.0-SFRC(FCT)-2P

CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	18	Flexure	430		80	1.2	95°	1.8	
A2	30	Flexure	480		110	0.9	85°		
A3	32.5	Flexure	460		130	0.6	80°		
A	53.9					**1.8**			
B1	24.2	shear	50		75	2.2	140°	2.8	
B2	28.2	shear	180		210	1.6	120°		
B3	35.8	shear	340		350	1.8	145°		
B	53.9					**2.8**			
C1	22.2	Flexure		410	82	2.6	80°	3.2	
C2	29.5	Flexure		480	180	2.4	70°		
C3	38.8	Flexure		490	210	1.2	110°		
C	53.9					**3.2**			
D1	17.6	shear		70	110	5.8	75°	**9.2**	**S**
D2	28.2	shear		95	105	2.8	70°		
D3	40.5	shear		110	95	5	65°		
D4	53.9	shear		180	210	2.2	60°		
D	**53.9**					**9.2**			

α: Inclination with horizontal

S: Crack is initiated in flexure zone but major cause of failure is inclined shear crack only.

L/D=2 a/D=0.67

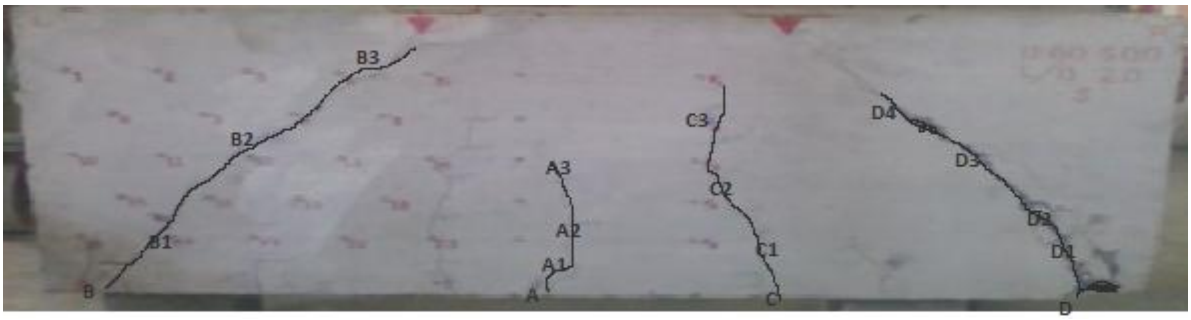


FIG. 6.36 D 60-S 0.0-SFRC (FCT)-2P

TABLE 6.37 D 30-S 5.0-SFRC(FCT)-2P

CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	7.6	Flexure	560		88	8.5	90°	**9.3**	**F**
A2	8.2	Flexure	570		105	6.2	80°		
A3	12.45	Flexure	560		110	4.2	90°		
A	**12.45**					**9.3**			
B1	8.2	Flexure		450	95	4.2	110°	6.2	
B2	10.2	Flexure		420	85	2.8	90°		
B	12.45					**6.2**			
C1	10.5	Flexure		370	110	8.9	115°	8.9	
C	12.45					**8.9**			

α: Inclination with horizontal

F: crack is initiated in flexure zone and major cause of failure is flexure crack only.

L/D=4 a/D=1.33

FIG. 6.37 D 30-S 5.0-SFRC (FCT)-2P

TABLE 6.38 D 40-S 5.0-SFRC(FCT)-2P 

CRACK NAME	LOAD	ZONE	DISTANCE FROM		LENGTH	WIDTH	α	MAXIMUM WIDTH	TYPE OF FAILURE
			LHS	RHS					
	(T)		(mm)	(mm)	(mm)	(mm)		(mm)	
A1	11.7	Flexure		480	90	9.8	89°		
A2	17.8	Flexure		460	110	8.6	90°		
A3	21.5	Flexure		450	130	6.4	85°	**10.1**	**F**
A4	23.3	Flexure		450	85	4.2	80°		
A	**23.3**					**10.1**			
B1	18.2	Flexure	480		90	2.6	92°		
B2	22.5	Flexure	490		110	1.6	100°	2.8	
B	23.3					**2.8**			
C1	18.2	Flexure		380	100	1.2	110°		
C2	18.9	Flexure		340	190	0.8	120°	1.8	
C3	20.5	Flexure		300	150	0.6	120°		
C	23.3					**1.8**			

α: Inclination with horizontal

F: crack is initiated in flexure zone and major cause of failure is flexure crack only.

L/D=3 a/D=1

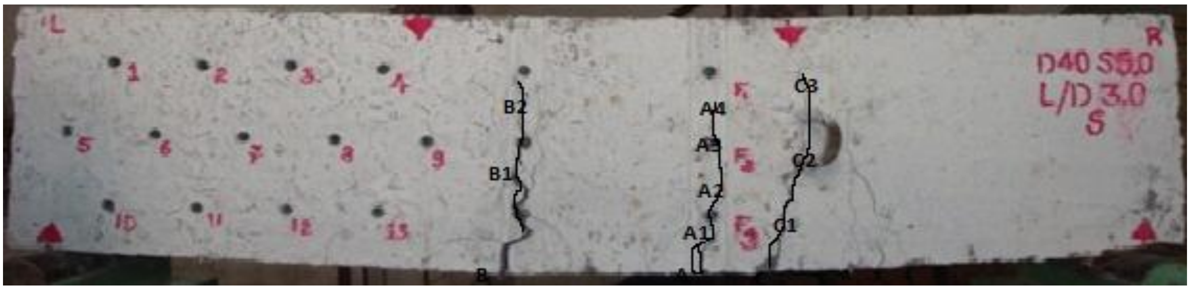


FIG. 6.38 D 40-S 5.0-SFRC (FCT)-2P

TABLE 6.39 D 50-S 5.0-SFRC(FCT)-2P

CRACK NAME	LOAD	ZONE	DISTANCE FROM		LENGTH	WIDTH	α	MAXIMUM WIDTH	TYPE OF FAILURE
			LHS	RHS					
	(T)		(mm)	(mm)	(mm)	(mm)		(mm)	
A1	19.9	Flexure	580		190	1.2	75°		
A2	25.2	Flexure	520		80	0.8	85°	1.8	
A3	30.8	Flexure	510		210	0.6	80°		
A	39.1					**1.8**			
B1	28.4	Flexure		470	180	1.2	90°		
B2	39.2	Flexure		480	215	0.9	80°	1.5	
B	39.1					**1.5**			
C1	19.9	Shear	80		120	6.8	130°		
C2	22.6	Shear	110		135	4.2	140°		
C3	36.6	Shear	230		140	3.2	150°	**9.22**	**FS**
C4	39.1	Shear	320		145	1.8	160°		
C	**39.1**					**9.22**			
D1	22.8	Shear		85	125	1.8	70°		
D2	28.4	Shear		110	135	1.6	62°		
D3	32.6	Shear		220	150	1.2	55°	2.8	
D4	38.8	Shear		380	160	0.8	45°		
D	39.1					**2.8**			
E1	28.2	Flexure	360		85	1.6	90°		
E2	35.2	Flexure	380		90	0.8	100°	2.2	
E	39.1					**2.2**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=2.4 a/D=0.8

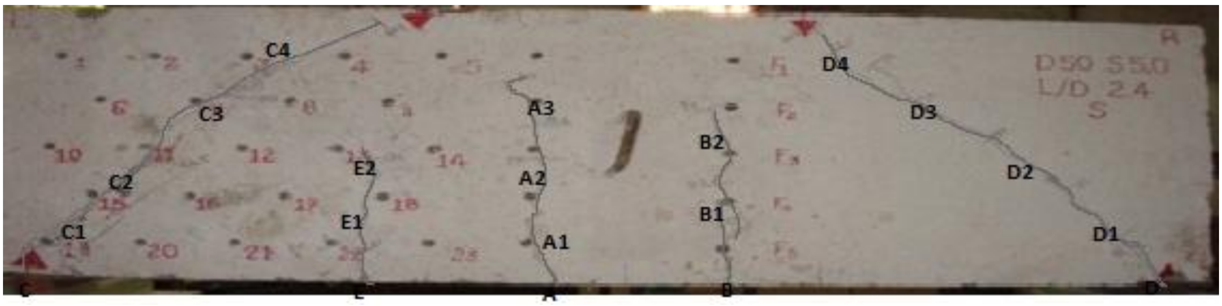


FIG. 6.39 D 50-S 5.0-SFRC (FCT)-2P

TABLE 6.40 D 60-S 5.0-SFRC(FCT)-2P

CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	20.7	Flexure	590		130	1	60°	1.2	
A2	42.5	Flexure	510		150	0.8	95°		
A3	48.3	Flexure	480		180	0.6	80°		
A	53.15					**1.2**			
B1	38.4	Flexure		480	190	1.2	110°	1.4	
B2	45.5	Flexure		430	120	0.9	90°		
B	53.15					**1.4**			
C1	30.8	Shear	40		140	3.2	125°	4.6	
C2	36.6	Shear	110		145	2.2	120°		
C3	42.8	Shear	230		155	1.4	115°		
C4	53.15	Shear	420		95	1.2	145°		
C	53.15					**4.6**			
D1	32.8	Shear		40	100	4.6	75°	**8.6**	**S**
D2	42	Shear		180	110	2.2	70°		
D3	53.15	Shear		230	120	0.9	60°		
D	**53.15**					**8.6**			

α: Inclination with horizontal

S: Crack is initiated in flexure zone but major cause of failure is inclined shear crack only.

L/D=2 a/D=0.67

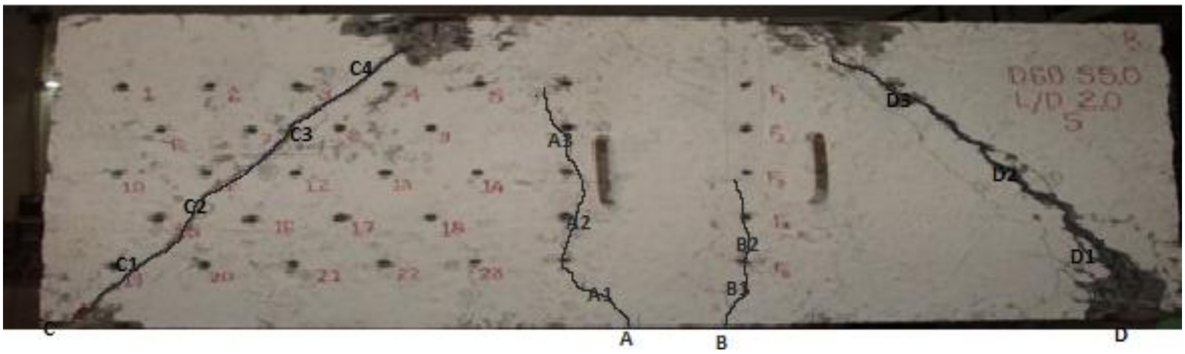


FIG. 6.40 D 60-S 5.0-SFRC (FCT)-2P

TABLE 6.41 D 30-S 7.5-SFRC(FCT)-2P

CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	6.2	Flexure		570	75	2.2	90°	2.65	
A2	11.4	Flexure		575	110	1.8	100°		
A	12.4					**2.65**			
B1	9.2	Flexure	520		80	7.4	90°	**8.4**	**F**
B2	10.8	Flexure	540		150	5.2	120°		
B3	12.4	Flexure	550		110	3	110°		
B	**12.4**					**8.4**			
C1	9.8	Flexure		410	85	1.8	85°	2.5	
C	12.4					**2.5**			
D1	9.2	Flexure		310	90	2.6	90°	3.2	
D2	10.5	Flexure		330	105	1.8	85°		
D	12.4					**3.2**			

α: Inclination with horizontal

F: crack is initiated in flexure zone and major cause of failure is flexure crack only.

L/D=4 a/D=1.33

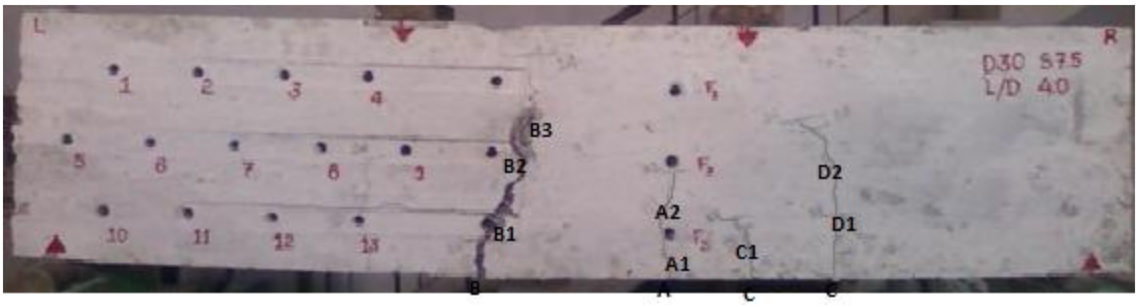


FIG. 6.41 D 30-S 7.5-SFRC (FCT)-2P

TABLE 6.42 D 40-S 7.5-SFRC(FCT)-2P

CRACK NAME	LOAD	ZONE	DISTANCE FROM		LENGTH	WIDTH	α	MAXIMUM WIDTH	TYPE OF FAILURE
			LHS	RHS					
	(T)		(mm)	(mm)	(mm)	(mm)		(mm)	
A1	12.4	Flexure		550	85	1.2	100°	1.8	
A2	16.2	Flexure		540	95	1	90°		
A3	18.8	Flexure		530	110	0.9	110°		
A4	20.2	Flexure		550	85	0.7	70°		
A	23.1					**1.8**			
B1	14.5	Flexure	460		110	1.6	120°	2.5	
B2	22	Flexure	475		130	1.2	120°		
B	23.1	Flexure				**2.5**			
C1	12.4			450	150	8.2	100°	**10.2**	**F**
C2	18.2	Flexure		460	105	6.8	110°		
C3	23.1	Flexure		450	115	4.2	90°		
C	**23.1**					**10.2**			

α: Inclination with horizontal

F: crack is initiated in flexure zone and major cause of failure is flexure crack only.

L/D=3 a/D=1

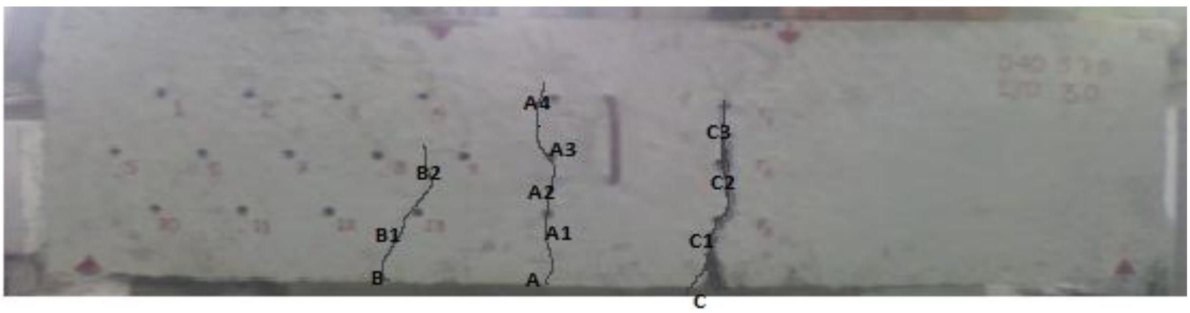


FIG. 6.42 D 40-S 7.5-SFRC (FCT)-2P

TABLE 6.43 D 50-S 7.5-SFRC(FCT)-2P

CRACK NAME	LOAD	ZONE	DISTANCE FROM		LENGTH	WIDTH	α	MAXIMUM WIDTH	TYPE OF FAILURE
			LHS	RHS					
	(T)		(mm)	(mm)	(mm)	(mm)		(mm)	
A1	14.8	Flexure	560		100	6.2	70°	**8.9**	**FS**
A2	26.2	Flexure	560		110	4.8	120°		
A3	38.85	Flexure	590		120	2.2	110°		
A	**38.85**					**8.9**			
B1	16.2	shear	50		105	1.2	140°	1.8	
B2	25.6	shear	110		125	0.9	130°		
B3	38.4	shear	190		135	0.85	125°		
B	38.85					**1.8**			
C1	15.2	shear		150	110	1.35	80°	1.95	
C2	22.4	shear		185	120	0.85	80°		
C3	35.8	shear		190	130	0.75	75°		
C	38.85					**1.95**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=2.4 a/D=0.8

FIG. 6.43 D 50-S 7.5-SFRC (FCT)-2P

TABLE 6.44 D 60-S 7.5-SFRC(FCT)-2P

CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	21.8	Flexure	580		180	0.9	110°		
A2	48.4	Flexure	520		210	0.6	80°	1.2	
A	52.95					**1.2**			
B1	22.8	Flexure		410	110	2.8	75°		
B2	38.2	Flexure		430	130	1.9	85°	3.2	
B	52.95					**3.2**			
C1	25.4	shear	150		120	2.8	110°		
C2	32.8	shear	280		180	1.6	120°	4.2	
C3	46.6	shear	300		240	0.9	145°		
C	52.95					**4.2**			
D1	21.8	shear		110	180	4.52	60°		
D2	32.5	shear		210	160	2.8	65°	**7.8**	**FS**
D3	52.95	shear		420	170	1.2	60°		
D	**52.95**					**7.8**			
E1	27.4	Flexure		240	110	1.6	70°		
E2	42.2	Flexure		310	95	0.8	65°	2.5	
E	52.95					**2.5**			
F1	28.4	shear	420		100	0.8	85°		
F2	48.2	shear	380		180	0.6	75°	1	
F	52.95					**1**			
G1	35.8	shear	220		110	1.2	115°	1.2	
G	52.95					**1.2**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=2 a/D=0.67

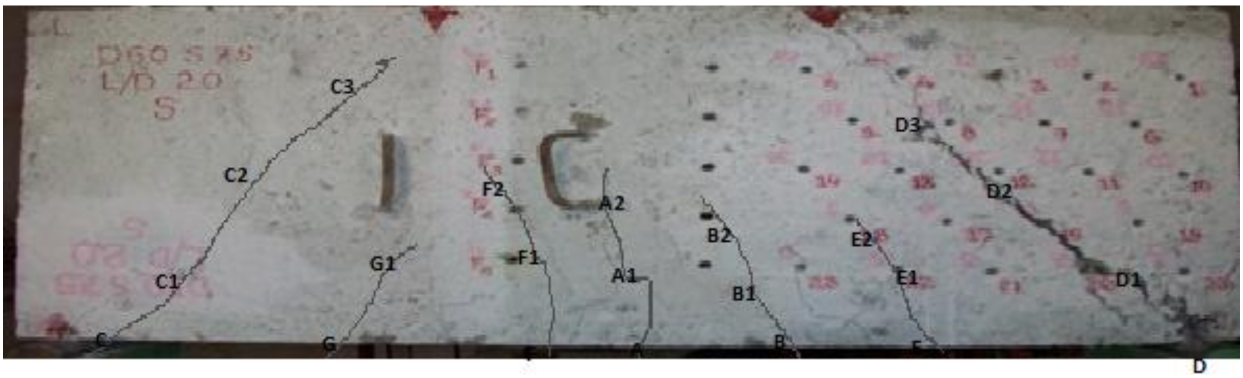


FIG. 6.44 D 60-S 7.5-SFRC (FCT)-2P

TABLE 6.45 D 30-S 0.0-SFRC(CCT)-1P 

CRACK NAME	LOAD	ZONE	DISTANCE FROM		LENGTH	WIDTH	α	MAXIMUM WIDTH	TYPE OF FAILURE
			LHS	RHS					
	(T)		(mm)	(mm)	(mm)	(mm)		(mm)	
A1	5	Flexure	590		75	3.2	70°	**7.5**	**F**
A2	8	Flexure	560		85	2.2	60°		
A3	8.9	Flexure	520		95	1.2	65°		
A	**8.9**					**7.5**			
B2	6.4	Flexure	520		95	1.6	85°	2.4	
B3	7.8	Flexure	510		85	0.9	90°		
B4	8.2	Flexure	490		80	0.7	80°		
B	8.9					**2.4**			
C1	5.8	Flexure	410		75	0.9	75°	1.3	
C2	8.2	Flexure	400		80	0.6	80°		
C	8.9					**1.3**			
D1	6.4	Flexure		510	80	0.85	90°	1.4	
D2	7.8	Flexure		550	85	0.62	80°		
D3	8.5	Flexure		560	90	1.2	70°		
D	8.9					**1.4**			

α: Inclination with horizontal

F: crack is initiated in flexure zone and major cause of failure is flexure crack only.

L/D=4 a/D=2

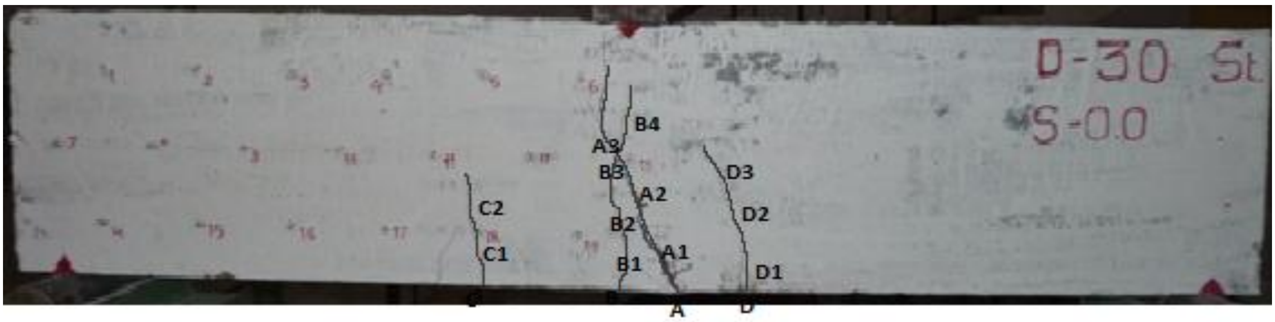


FIG. 6.45 D 30-S 0.0-SFRC (CCT)-1P

TABLE 6.46 D 40-S 0.0-SFRC (CCT)-1P

CRACK NAME	LOAD	ZONE	DISTANCE FROM		LENGTH	WIDTH	α	MAXIMUM WIDTH	TYPE OF FAILURE
			LHS	RHS					
	(T)		(mm)	(mm)	(mm)	(mm)		(mm)	
A1	8.5	Flexure	420		60	3.8	90°	**7.1**	**F**
A2	9.4	Flexure	440		65	3.2	89°		
A3	10.8	Flexure	460		75	2.6	110°		
A4	12.4	Flexure	490		80	1.4	120°		
A5	16.7	Flexure	530		85	0.9	130°		
A	**16.7**					**7.1**			
B1	8.9	Flexure		580	35	0.8	80°	1.8	
B2	12.2	Flexure		590	45	0.6	78°		
B	16.9					**1.8**			
C1	9.2	Shear	80		40	0.6	75°	0.8	
C2	12.8	Shear	65		45	0.4	80°		
C	16.7					**0.8**			

α: Inclination with horizontal

F: crack is initiated in flexure zone and major cause of failure is flexure crack only.

L/D=3 a/D=1.5

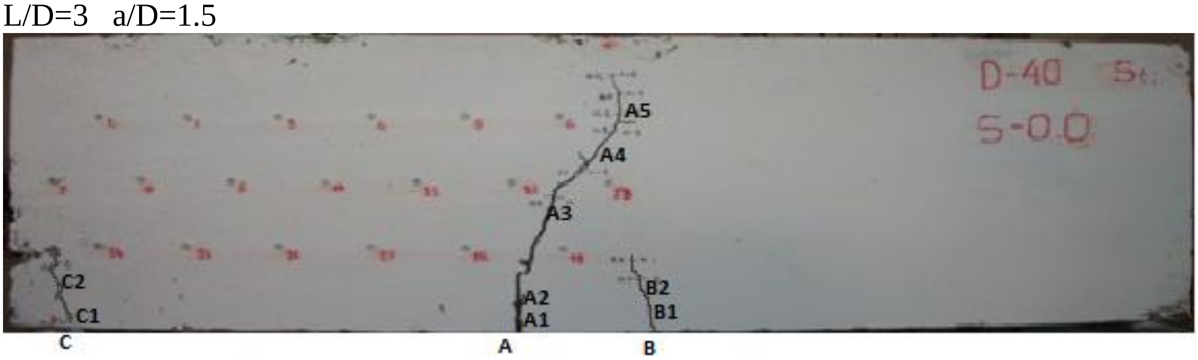


FIG. 6.46 D 40-S 0.0-SFRC (CCT)-1P

TABLE 6.47	**D 50-S 0.0-SFRC (CCT)-1P**								
CRACK NAME	LOAD	ZONE	DISTANCE FROM		LENGTH	WIDTH	α	MAXIMUM WIDTH	TYPE OF FAILURE
			LHS	RHS					
	(T)		(mm)	(mm)	(mm)	(mm)		(mm)	
A1	9.2	Flexure		550	85	0.8	70°	0.9	
A2	11.7	Flexure		560	95	0.62	90°		
A3	14.2	Flexure		570	110	0.45	75°		
A4	18.6	Flexure		580	105	0.4	110°		
A5	22.2	Flexure		590	85	0.3	65°		
A	27.3					**0.9**			
B1	10.2	Flexure	410		90	0.46	90°	0.8	
B2	18.8	Flexure	450		85	0.28	120°		
B	27.3					**0.8**			
C1	10.8	Shear		400	80	0.9	85°	1.2	
C2	14.2	Shear		420	85	0.75	75°		
C3	19.5	Shear		450	90	0.48	70°		
C	27.3					**1.2**			
D1	8.9	Shear	60		95	2.8	110°	**6.2**	**FS**
D2	11.8	Shear	120		120	2	105°		
D3	14.6	Shear	210		110	1.25	120°		
D4	27.3	Shear	390		130	0.85	130°		
D	**27.3**					**6.2**			
E1	12	Shear		200	210	0.84	65°	1.2	
E2	14	Shear		290	220	0.65	70°		
E3	16	Shear		385	280	0.42	70°		
E	27.3					**1.2**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=2.4 a/D=1.2

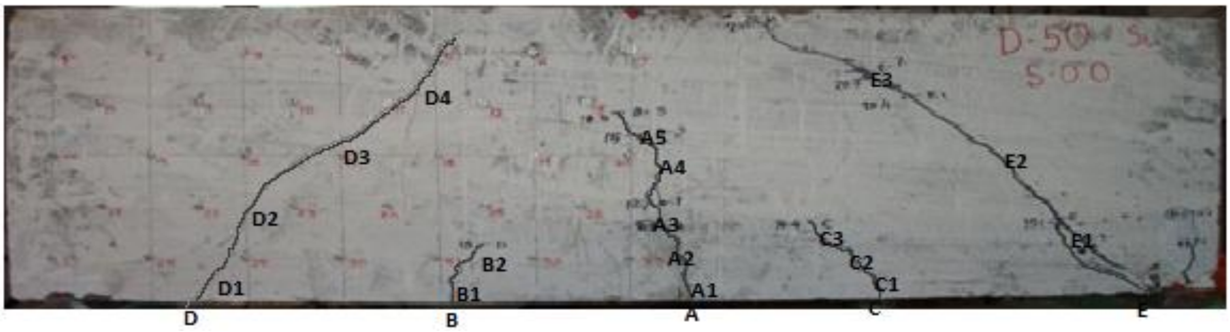


FIG. 6.47 D 50-S 0.0-SFRC (CCT)-1P

TABLE 6.48			**D 60-S 0.0-SFRC (CCT)-1P**						
CRACK NAME	LOAD	ZONE	DISTANCE FROM		LENGTH	WIDTH	α	MAXIMUM WIDTH	TYPE OF FAILURE
			LHS	RHS					
	(T)		(mm)	(mm)	(mm)	(mm)		(mm)	
A1	20.5	Flexure	355		85	1.45	100°	1.8	
A2	25.4	Flexure	410		110	0.72	120°		
A3	28.8	Flexure	490		120	0.58	130°		
A4	29.4	Flexure	510		180	0.42	140°		
A5	32.6	Flexure	520		170	0.4	145°		
A	43.7					**1.8**			
B1	22.4	Flexure		580	85	1.28	115°	1.5	
B2	28.6	Flexure		590	210	0.89	105°		
B3	35.2	Flexure		570	220	0.67	80°		
B	43.7					**1.5**			
C1	20.5	Shear	75		180	3.26	90°	**5.65**	**FS**
C2	28.2	Shear	120		190	1.85	120°		
C3	43.7	Shear	240		210	0.73	130°		
C	**43.7**					**5.65**			
D1	21.8	Shear		80	110	4.8	85°	5.2	
D2	25.6	Shear		110	120	4.2	70°		
D3	29.2	Shear		220	130	3.2	60°		
D4	32.8	Shear		310	140	2	50°		
D	43.7					**5.2**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=2 a/D=1

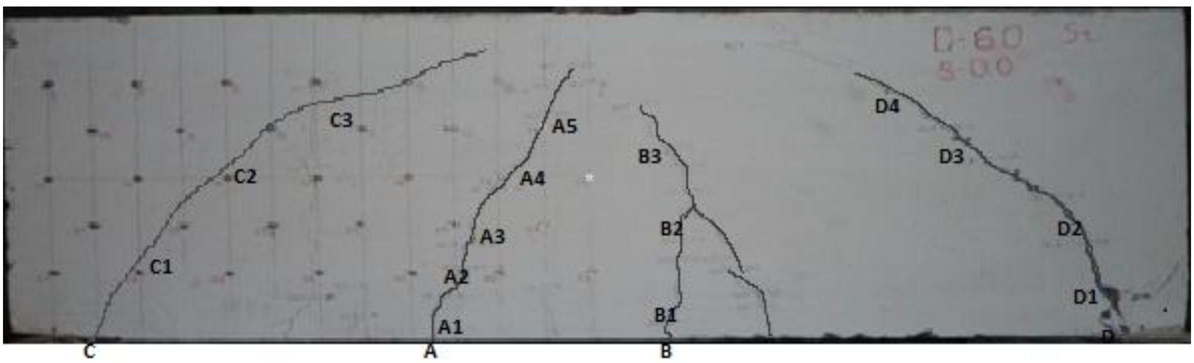
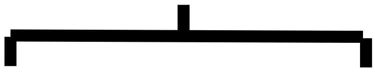


FIG. 6.48 D 60-S 0.0-SFRC (CCT)-1P

TABLE 6.49 D 30-S 5.0-SFRC (CCT)-1P 

CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	5.4	Flexure	480		70	4.86	120°		
A2	10.5	Flexure	490		80	3.25	130°	**5.8**	**F**
A	**10.5**					**5.8**			
B1	6.2	Flexure	310		75	0.9	65°	0.9	
B	10.5					0.9			
C1	8.4	Flexure		420	65	**0.9**	110°		
C2	9.8	Flexure		490	80	0.6	70°	1.3	
C	10.5					**1.3**			

α: Inclination with horizontal

F: crack is initiated in flexure zone and major cause of failure is flexure crack only.

L/D=4 a/D=2

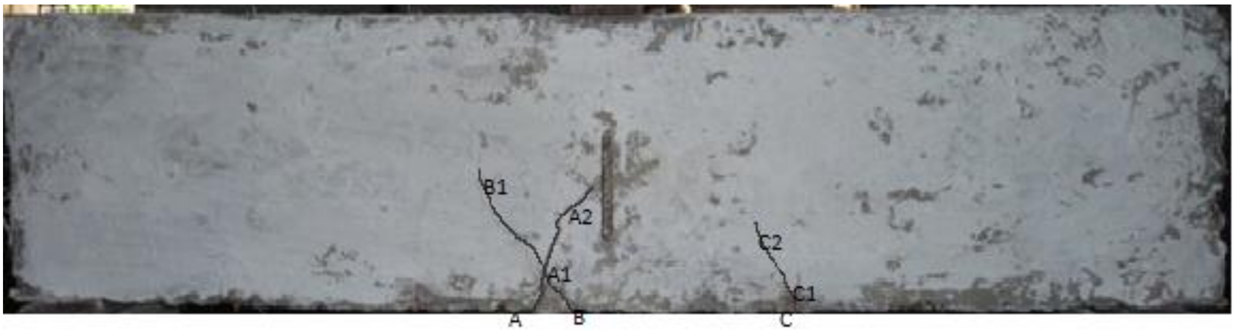
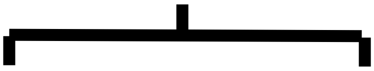


FIG. 6.49 D 30-S 5.0-SFRC (CCT)-1P

TABLE 6.50 D 40-S 5.0-SFRC(CCT)-1P



CRACK NAME	LOAD	ZONE	DISTANCE FROM		LENGTH	WIDTH	α	MAXIMUM WIDTH	TYPE OF FAILURE
			LHS	RHS					
	(T)		(mm)	(mm)	(mm)	(mm)		(mm)	
A1	10.3	Flexure	480		85	5.2	70°		
A2	11.6	Flexure	510		95	4.6	80°		
A3	12.8	Flexure	530		110	2.85	110°	**5.97**	**F**
A4	16.7	Flexure	540		120	1.36	105°		
A	**16.7**					**5.97**			
B1	12.2	Flexure	410		90	3.2	110°		
B2	13.8	Flexure	420		110	2.4	70°	4.2	
B	16.7					**4.2**			

α: Inclination with horizontal

F: crack is initiated in flexure zone and major cause of failure is flexure crack only.

L/D=3 a/D=1.5

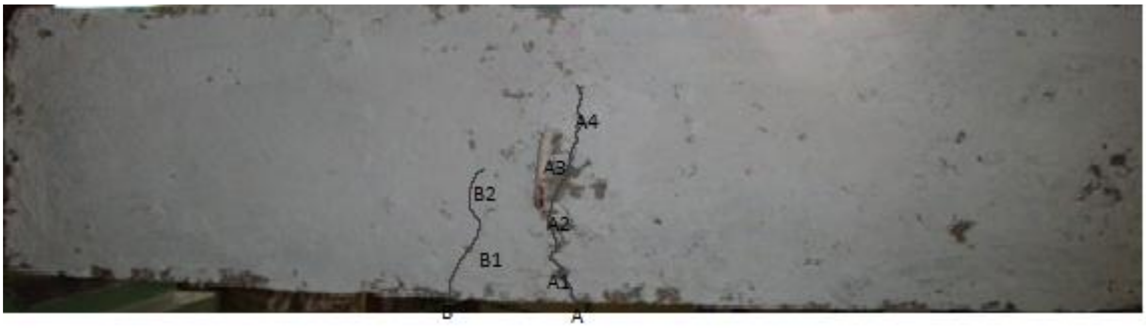


FIG. 6.50 D 40-S 5.0-SFRC (CCT)-1P

TABLE 6.51 D 50-S 5.0-SFRC(CCT)-1P

CRACK NAME	LOAD	ZONE	DISTANCE FROM		LENGTH	WIDTH	α	MAXIMUM WIDTH	TYPE OF FAILURE
			LHS	RHS					
	(T)		(mm)	(mm)	(mm)	(mm)		(mm)	
A1	12.1	Flexure	580		105	2.8	75°	3.2	
A2	13.8	Flexure	540		115	2	95°		
A3	15.4	Flexure	550		120	1.67	90°		
A4	22.8	Flexure	560		130	1.25	110°		
A	26.9					**3.2**			
B1	8.2	Shear		210	110	4.89	95°	**5.95**	**FS**
B2	10.8	Shear		250	120	2.75	80°		
B3	18.2	Shear		300	180	2.18	75°		
B4	26.9	Shear		380	210	1.25	55°		
B	**26.9**					**5.95**			
C1	9.5	Shear	100		110	1.8	120°	2.2	
C2	18.2	Shear	190		120	1.2	110°		
C3	24.5	Shear	280		130	0.8	130°		
C	26.9					**2.2**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=2.4 a/D=1.2

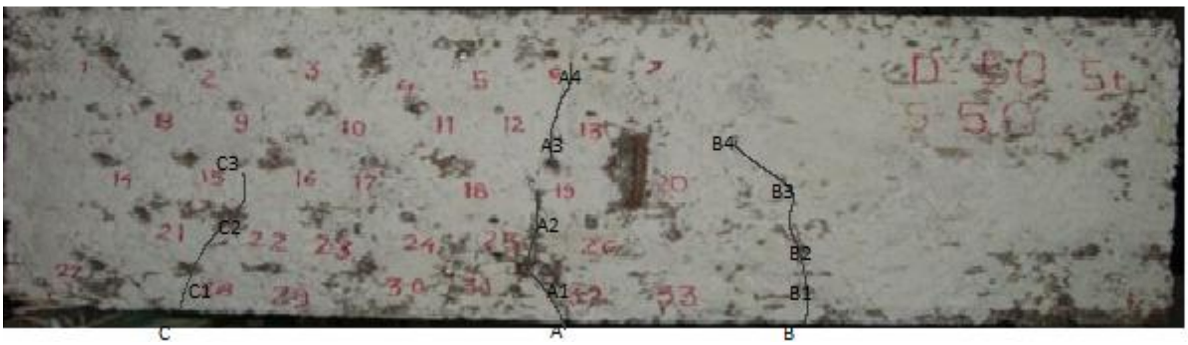


FIG. 6.51 D 50-S 5.0-SFRC (CCT)-1P

TABLE 6.52 D 60-S 5.0-SFRC (CCT)-1P									
CRACK NAME	LOAD	ZONE	DISTANCE FROM		LENGTH	WIDTH	α	MAXIMUM WIDTH	TYPE OF FAILURE
			LHS	RHS					
	(T)		(mm)	(mm)	(mm)	(mm)		(mm)	
A1	19.7	Flexure	475		95	1.76	75°	2.2	
A2	29.8	Flexure	420		105	1.25	110°		
A3	38.6	Flexure	440		190	0.86	90°		
A	43.7					**2.2**			
B1	26.2	Flexure		420	120	1.2	75°	1.75	
B2	32.4	Flexure		580	130	0.9	60°		
B	43.7					**1.75**			
C1	22.5	Shear	105		120	5.38	145°	**6.3**	**FS**
C2	34.8	Shear	170		140	4.2	135°		
C3	43.7	Shear	240		280	2.62	140°		
C	**43.7**					**6.3**			
D1	23.7	Shear		80	130	1.62	70°	2.4	
D2	26.8	Shear		230	180	1.35	75°		
D3	30.8	Shear		310	220	0.87	60°		
D	43.7					**2.4**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=2 a/D=1

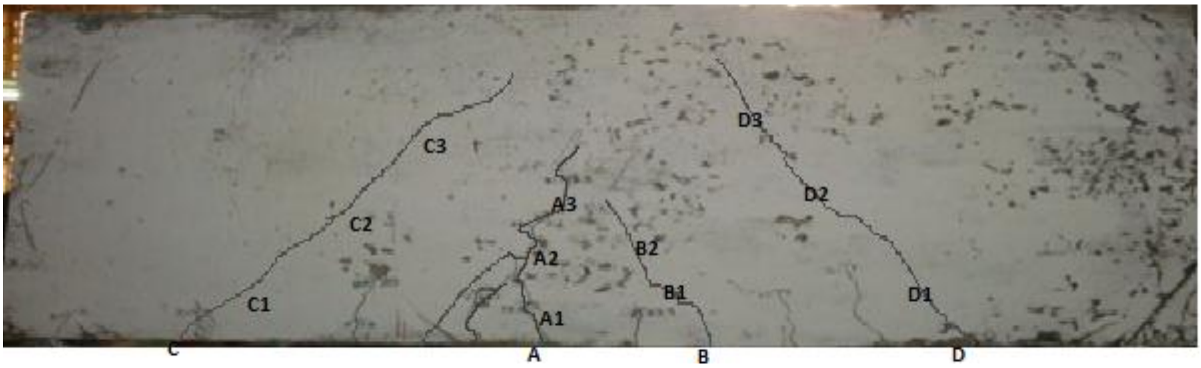


FIG. 6.52 D 60-S 5.0-SFRC (CCT)-1P

TABLE 6.53 D 30-S 7.5-SFRC(CCT)-1P

CRACK NAME	LOAD	ZONE	DISTANCE FROM		LENGTH	WIDTH	α	MAXIMUM WIDTH	TYPE OF FAILURE
			LHS	RHS					
	(T)		(mm)	(mm)	(mm)	(mm)		(mm)	
A1	5.8	Flexure	590		70	5.82	85°	**7.05**	**F**
A2	8.9	Flexure	580		75	4.35	70°		
A3	10.2	Flexure	560		80	3.28	100°		
A	**10.2**					**7.05**			
B1	6	Flexure	480		60	1.8	120°	2.4	
B2	8.6	Flexure	490		75	1.2	90°		
B3	9.2	Flexure	510		80	1	90°		
B4	10	Flexure	520		85	0.9	120°		
B	10.2					**2.4**			
C1	6.2	Flexure	310		60	1.6	140°	1.8	
C2	8.8	Flexure	330		85	1.2	135°		
C	10.2					**1.8**			
D1	6.2	Flexure		480	80	1.6	105°	2.2	
D2	7.5	Flexure		490	95	1.42	80°		
D3	8.6	Flexure		500	110	0.8	75°		
D	10.2					**2.2**			
E1	7.6	Flexure		310	105	1.4	110°	1.8	
E2	9.4	Flexure		340	110	0.9	80°		
E	10.2					**1.8**			

α: Inclination with horizontal

F: crack is initiated in flexure zone and major cause of failure is flexure crack only.

L/D=4 a/D=2

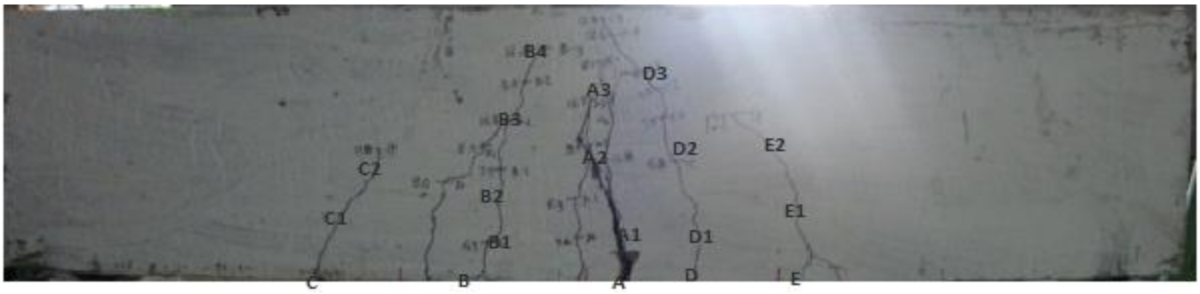


FIG. 6.53 D 30-S 7.5-SFRC (CCT)-1P

TABLE 6.54 D 40-S 7.5-SFRC(CCT)-1P

CRACK NAME	LOAD (t)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	8.7	Flexure		540	80	4.82	85°		
A2	11.5	Flexure		560	85	3.64	80°		
A3	12.4	Flexure		580	105	2.28	85°	**5.96**	**F**
A4	14.8	Flexure		590	100	1.56	170°		
A5	16.1	Flexure		595	85	0.98	115°		
A	**16.1**					**5.96**			
B1	12	Flexure	530		80	1.2	90°		
B2	14.8	Flexure	510		90	0.92	110°	1.32	
B	16.1					**1.32**			

α: Inclination with horizontal

F: crack is initiated in flexure zone and major cause of failure is flexure crack only.

L/D=3 a/D=1.5

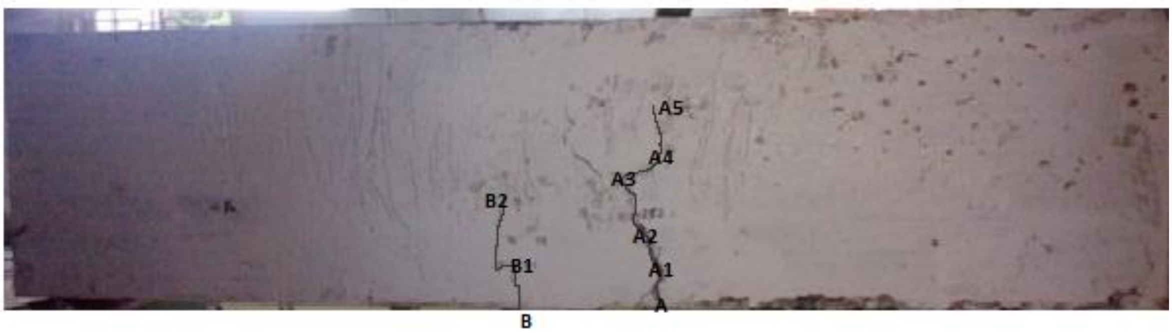


FIG. 6.54 D 40-S 7.5-SFRC (CCT)-1P

TABLE 6.55 D 50-S 7.5-SFRC(CCT)-1P

CRACKNAME	LOAD (T)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	13.7	Flexure		480	105	0.6	85°		
A2	19.5	Flexure		510	110	0.5	70°		
A3	21.6	Flexure		580	120	0.42	75°	1.8	
A4	22.8	Flexure		590	125	0.38	70°		
A	26.85					**1.8**			
B1	18.5	Flexure	410		110	1.89	100°		
B2	24.2	Flexure	490		130	1.2	110°	2.2	
B	26.85					**2.2**			
C1	13.7	Shear	80		80	4.87	90°		
C2	15.2	Shear	120		110	2.82	145°		
C3	21.8	Shear	210		120	1.25	140°	**6.8**	**FS**
C4	26.85	Shear	280		140	1	130°		
C	**26.85**					**6.8**			
D1	16.5	Shear		90	90	1.8	70°		
D2	20.2	Shear		120	105	1.2	75°	2.3	
D3	21.5	Shear		180	120	0.9	75°		
D	26.85					**2.3**			
E1	17.2	Shear	260		120	0.8	110°		
E2	24.2	Shear	310		110	0.62	110°	0.9	
E	26.85					**0.9**			
F1	22.5	Shear		600	140	1.2	90°	1.2	
F	26.85					**1.2**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=2.4 a/D=1.2

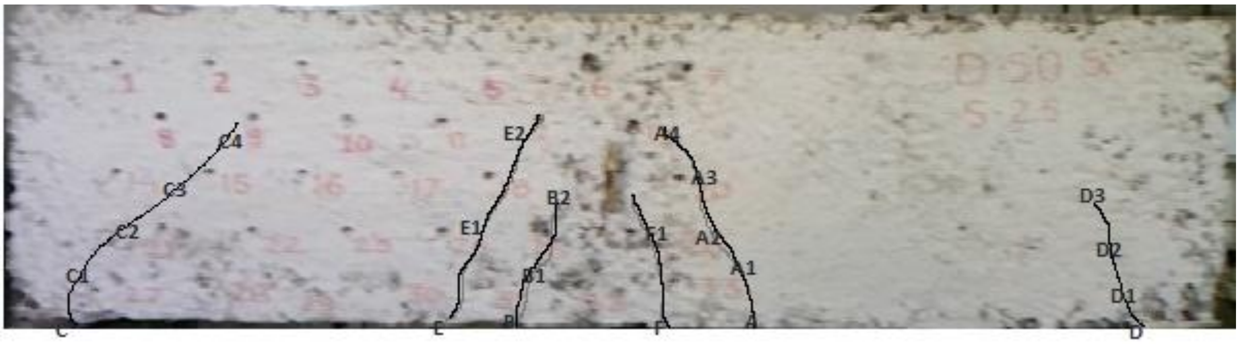


FIG. 6.55 D 50-S 7.5-SFRC (CCT)-1P

TABLE 6.56 D 60-S 7.5-SFRC (CCT)-1P

CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	23.7	Flexure	570		80	0.86	110°	1.2	
A2	24.8	Flexure	560		110	0.72	75°		
A3	25.6	Flexure	570		120	0.64	115°		
A4	32.2	Flexure	580		130	0.56	75°		
A5	40	Flexure	590		140	0.43	105°		
A	42.6					**1.2**			
B1	28.5	Flexure	320		170	1.8	120°	1.8	
B	42.6					**1.8**			
C1	29.6	Shear	85		200	2.2	120°	2.8	
C2	38.5	Shear	190		310	1.8	145°		
C	42.6					**2.8**			
D1	23.7	Shear		100	110	3.2	70°	**6.2**	**FS**
D2	26.3	Shear		180	170	2.7	75°		
D3	32.8	Shear		250	185	2.2	70°		
D4	42.6	Shear		300	110	1.2	99°		
D	**42.6**					**6.2**			
E1	28.9	Shear	320		110	0.6	130°	0.9	
E2	40	Shear	410		120	0.4	135°		
E	42.6					**0.9**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=2 a/D=1

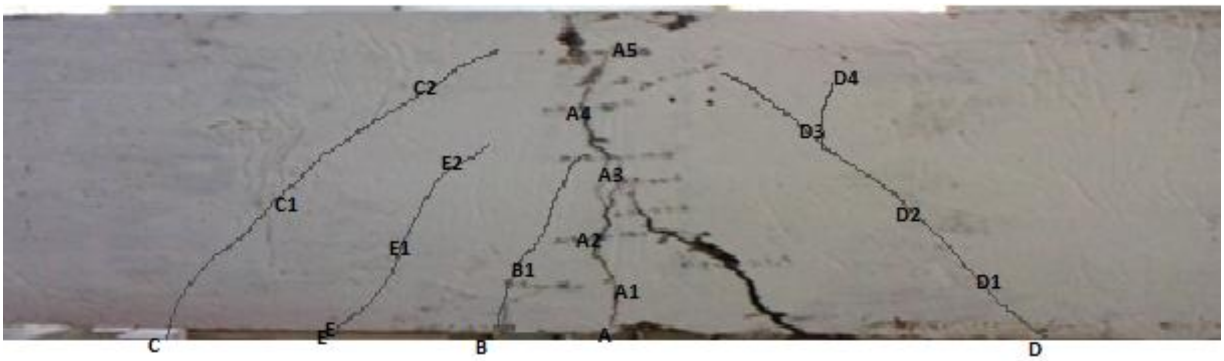


FIG. 6.56 D 60-S 7.5-SFRC (CCT)-1P

TABLE 6.57 D 30-S 0.0-HFRC(MT+CCT)-1P

CRACK NAME	LOAD	ZONE	DISTANCE FROM		LENGTH	WIDTH	α	MAXIMUM WIDTH	TYPE OF FAILURE
			LHS	RHS					
	(T)		(mm)	(mm)	(mm)	(mm)		(mm)	
A1	5.8	Flexure		600	110	6.25	115°	**7.5**	**F**
A2	6.5	Flexure		595	190	4.55	100°		
A3	7.8	Flexure		530	210	2.36	90°		
A4	10.7	Flexure		552	230	1.15	95°		
A	**10.7**					**7.5**			
B1	6.5	Flexure	420		50	0.22	95°	0.25	
B2	7.3	Flexure	470		110	0.16	90°		
B	10.7					**0.25**			
C1	6.5	Flexure		410	130	0.32	88°	0.4	
C	10.7	Flexure				**0.4**			

α: Inclination with horizontal

F: crack is initiated in flexure zone and major cause of failure is flexure crack only.

L/D=4 a/D=2

FIG. 6.57 D 30-S 0.0-HFRC (MT+CCT)-1P

TABLE 6.58 D 40-S 0.0-HFRC(MT+CCT)-1P

CRACK NAME	LOAD	ZONE	DISTANCE FROM		LENGTH	WIDTH	α	MAXIMUM WIDTH	TYPE OF FAILURE
			LHS	RHS					
	(T)		(mm)	(mm)	(mm)	(mm)		(mm)	
A1	7.2	Flexure		490	90	7	110°	**7.2**	**FS**
A2	12	Flexure		510	110	6.84	85°		
A3	13.08	Flexure		515	105	3.45	90°		
A	**13.08**					**7.2**			
B1	7.2	Flexure	350		70	0.65	105°	0.8	
B2	10.2	Flexure	400		110	0.5	110°		
B	13.08					**0.8**			
C1	8.1	Shear		300	110	0.54	75°	0.6	
C2	9.6	Shear		380	200	0.45	70°		
C3	12	Shear		490	230	0.39	70°		
C	13.08					**0.6**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=3 a/D=1.5

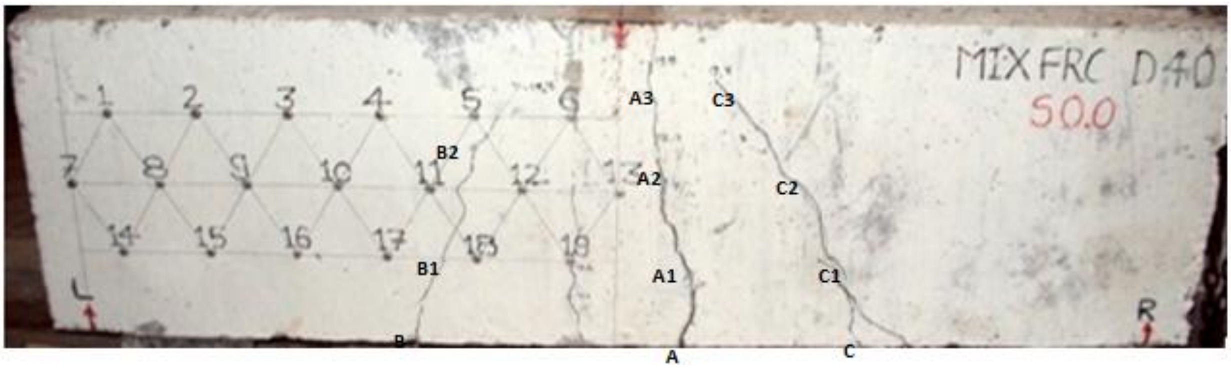


FIG. 6.58 D 40-S 0.0-HFRC (MT+CCT)-1P

TABLE 6.59 D 50-S 0.0-HFRC(MT+CCT)-1P

CRACK NAME	LOAD	ZONE	DISTANCE FROM		LENGTH	WIDTH	α	MAXIMUM WIDTH	TYPE OF FAILURE
			LHS	RHS					
	(T)		(mm)	(mm)	(mm)	(mm)		(mm)	
A1	16.3	Flexure		540	150	0.3	80°	0.6	
A2	17.3	Flexure		570	180	0.22	85°		
A3	19	Flexure		580	140	0.15	60°		
A	27.6					**0.6**			
B1	19.5	Flexure		450	190	0.33	83°	0.33	
B	27.6					**0.33**			
C1	17.5	shear	390		80	5.22	105°	**6.22**	**FS**
C2	18.3	shear	420		100	4.77	90°		
C3	18.7	shear	435		100	3.48	100°		
C4	19.8	shear	450		90	2.68	110°		
C5	27.6	shear	540		100	1.34	105°		
C	**27.6**					**6.22**			
D1	17.5	shear		120	160	0.5	60°	0.8	
D2	18.3	shear		200	180	0.4	60°		
D3	18.7	shear		390	220	0.3	75°		
D	27.6					**0.8**			
E1	17.5	shear		70	80	0.9	160°	1.5	
E2	18.3	shear		230	290	0.7	140°		
E3	18.7	shear		380	200	0.6	135°		
E	27.6					**1.5**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=2.4 a/D=1.2

FIG. 6.59 D 50-S 0.0-HFRC (MT+CCT)-1P

TABLE 6.60 D 60-S 0.0-HFRC(MT+CCT)-1P

CRACK NAME	LOAD	ZONE	DISTANCE FROM		LENGTH	WIDTH	α	MAXIMUM WIDTH	TYPE OF FAILURE
			LHS	RHS					
	(T)		(mm)	(mm)	(mm)	(mm)		(mm)	
A1	19.1	Flexure	70		160	0.58	71°		
A2	33.2	Flexure	140		220	0.63	72°	0.6	
A	43.8					**0.6**			
B1	34.5	shear	450		122	0.22	60°	0.22	
B	43.8					**0.22**			
C1	34.8	shear	70		120	4.24	75°		
C2	35.3	shear	160		190	3.8	48°		
C3	43.8	shear	240		250	6.3	48°	**6.3**	**S**
C	**43.8**					**6.3**			
D1	30.2	shear		400	160	1.1	105°		
D2	35.8	shear		380	210	0.8	60°	1.3	
D	43.8					**1.3**			

α: Inclination with horizontal

S: Crack is initiated in flexure zone but major cause of failure is inclined shear crack only.

L/D=2 a/D=1

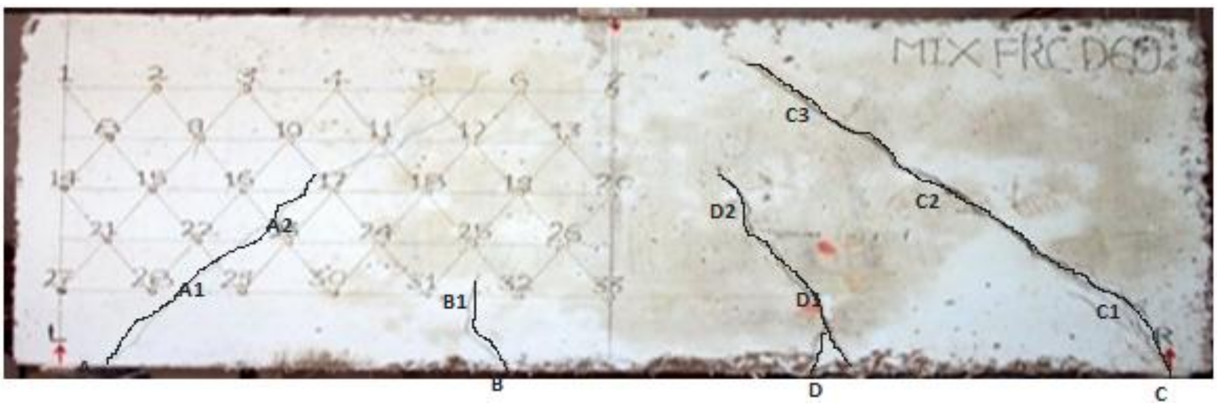


FIG. 6.60 D 60-S 0.0-HFRC (MT+CCT)-1P

TABLE 6.61 D 30-S 0.0-HFRC(MT+CCT)-2P

CRACK NAME	LOAD	ZONE	DISTANCE FROM		LENGTH	WIDTH	α	MAXIMUM WIDTH	TYPE OF FAILURE
			LHS	RHS					
	(T)		(mm)	(mm)	(mm)	(mm)		(mm)	
A1	5.9	Flexure		600	50	5.01	90°	**6.01**	**FS**
A2	7.2	Flexure		570	60	4.67	115°		
A3	12.05	Flexure		580	110	2.52	78°		
A	**12.05**					**6.01**			
B1	7	Flexure		400	45	0.82	85°	0.95	
B2	8	Flexure		421	95	0.6	80°		
B3	9.1	Flexure		440	125	0.25	70°		
B	12.05					**0.95**			
C1	10.2	Shear	262		50	0.9	65°	1.01	
C2	11.2	Shear	292		110	0.82	115°		
C3	11.4	Shear	330		150	0.44	110°		
C	12.05					**1.01**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=4 a/D=1.33

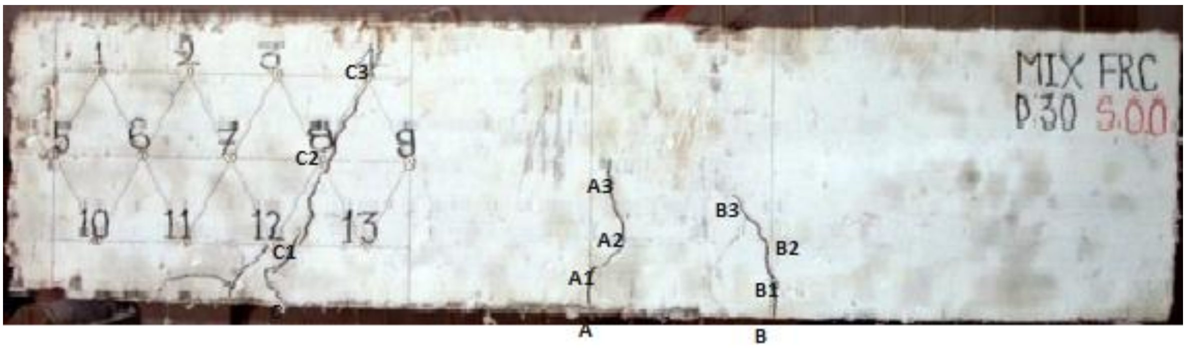


FIG. 6.61 D 30-S 0.0-HFRC (MT+CCT)-2P

TABLE 6.62 D 40-S 0.0-HFRC(MT+CCT)-2P

CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	14.2	Flexure		530	80	0.65	65°		
A2	16	Flexure		547	105	0.54	110°		
A3	20	Flexure		560	150	0.34	60°	0.84	
A4	21.5	Flexure		600	180	0.22	60°		
A	23.9					**0.84**			
B1	18.4	Flexure	447		120	0.3	90°		
B2	20.2	Flexure	422		210	0.25	90°	0.37	
B	23.9					0.37			
C1	18	shear	130		60	0.65	115°		
C2	19.2	shear	250		120	0.58	120°	0.81	
C3	25.2	shear	326		260	0.3	120°		
C	23.9					**0.81**			
D1	16	shear		110	110	8.02	60°		
D2	18.6	shear		220	170	1.05	70°		
D3	23.9	shear		310	150	0.85	80°	**8.96**	**FS**
D	**23.9**					**8.96**			
E1	17	shear		85	100	2.35	45°		
E2	20.3	shear		180	110	1.25	55°	2.6	
E3	21.2	shear		230	120	0.8	55°		
E	23.9					**2.6**			
F1	20.8	shear	220		125	1.5	115°	1.5	
F	23.9					**1.5**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=3 a/D=1

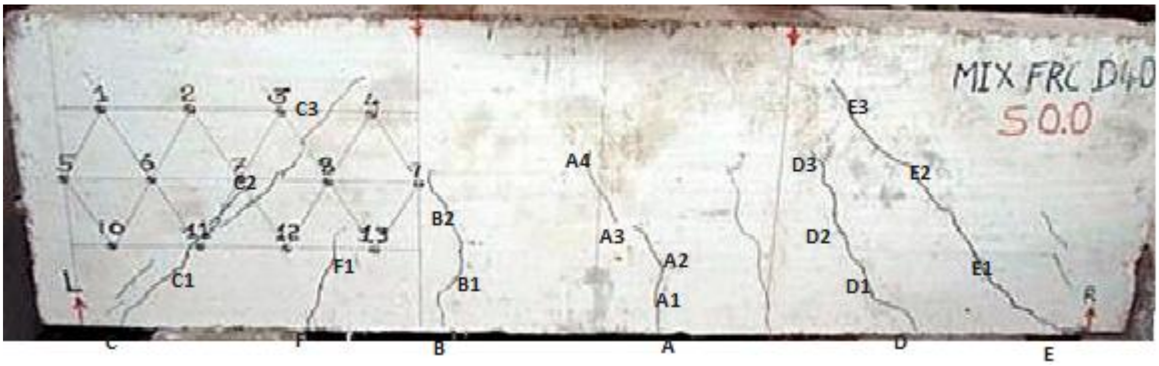


FIG. 6.62 D 40-S 0.0-HFRC (MT+CCT)-2P

TABLE 6.63 D 50-S 0.0-HFRC(MT+CCT)-2P

CRACK NAME	LOAD	ZONE	DISTANCE FROM		LENGTH	WIDTH	α	MAXIMUM WIDTH	TYPE OF FAILURE
			LHS	RHS					
	(T)		(mm)	(mm)	(mm)	(mm)		(mm)	
A1	23.8	Flexure		510	200	0.53	70°	0.53	
A	39.8					0.53			
B1	29.2	Flexure		420	70	0.33	110°	0.52	
B2	35	Flexure		425	90	0.43	105°		
B3	36	Flexure		410	110	0.25	100°		
B4	38	Flexure		405	120	0.29	70°		
B	39.8					**0.52**			
C1	32.7	shear		210	170	0.3	58°	0.6	
C2	33.4	shear		280	220	0.25	60°		
C	39.8					**0.6**			
D1	30	shear		90	120	7.52	46°	**9.66**	**FS**
D2	32.7	shear		120	150	5.06	50°		
D3	39.8	shear		210	170	2.97	55°		
D	**39.8**					**9.66**			
E1	29	shear	90		130	1	135°	1.2	
E2	33	shear	190		140	0.85	140°		
E3	37.6	shear	280		150	0.7	130°		
E	39.8					**1.2**			
F1	30	shear	310		170	0.8	140°	0.9	
F2	38	shear	380		180	0.65	140°		
F	39.8	shear				**0.9**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=2.4 a/D=0.8

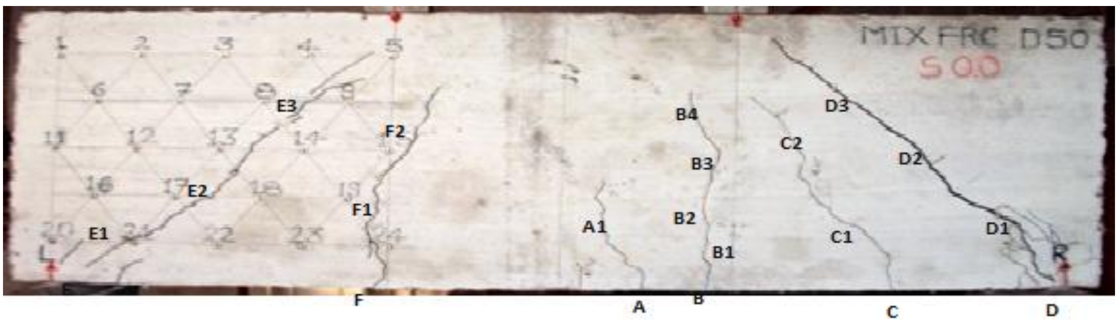


FIG. 6.63 D 50-S 0.0-HFRC (MT+CCT)-2P

TABLE 6.64 D 60-S 0.0-HFRC(MT+CCT)-2P

CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	27.7	Flexure	540		130	0.26	85°		
A2	32.3	Flexure	542		230	0.19	90°	0.35	
A	50.9					**0.35**			
B1	35.3	Flexure	300		110	0.15	705°	0.6	
B	50.9					**0.6**			
C1	41.8	shear		190	160	5.85	60°		
C2	50.9	shear		232	180	3.53	66°	**6.47**	**S**
C	**50.9**					**6.47**			
D1	42.7	shear	50		180	0.45	90°		
D2	42.9	shear	168		305	0.4	130°	0.52	
D	50.9					**0.52**			

α: Inclination with horizontal

S: Crack is initiated in flexure zone but major cause of failure is inclined shear crack only.

L/D=2 a/D=0.67

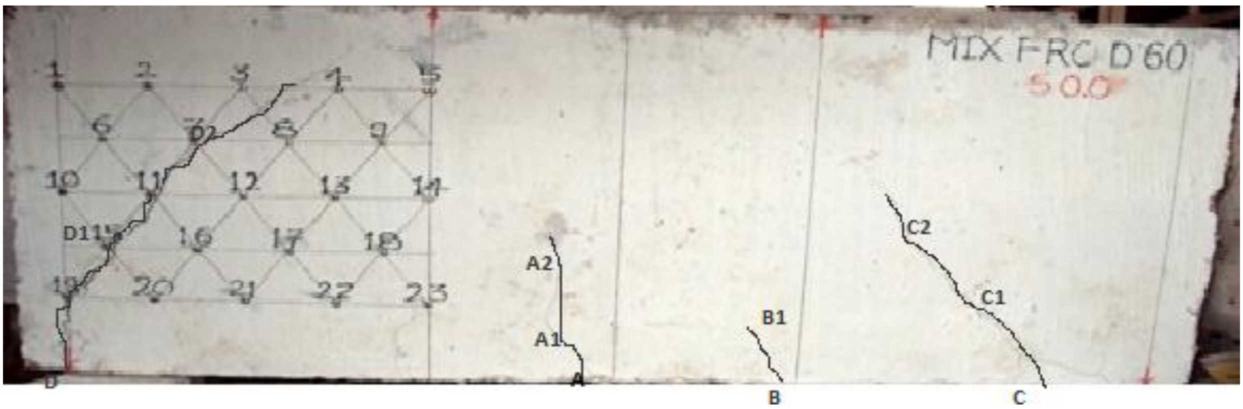


FIG. 6.64 D 60-S 0.0-HFRC (MT+CCT)-2P

TABLE 6.65 D 30-S 0.0-RCC(W/S)-1P

CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM		LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
			LHS (mm)	RHS (mm)					
A1	4.7	Flexure	650		200	0.37	85°	**1.25**	**F**
A2	5.1	Flexure	630		175	0.45	89°		
A3	5.3	Flexure	640		135	0.85	80°		
A	**11.5**					**1.25**			
B1	6.1	Flexure		550	94	0.35	90°	0.85	
B2	6.5	Flexure		560	43	0.7	78°		
B	11.5					**0.85**			
C1	5	Flexure	500		128	0.75	86°	1.05	
C2	5.6	Flexure	490		78	0.72	85°		
C	11.5					**1.05**			
D1	5.7	Flexure		440	220	0.29	90°	1.2	
D2	6.2	Flexure		450	140	1.01	60°		
D	11.5					**1.2**			

α: Inclination with horizontal

F: crack is initiated in flexure zone and major cause of failure is flexure crack only.

L/D=4 a/D=2

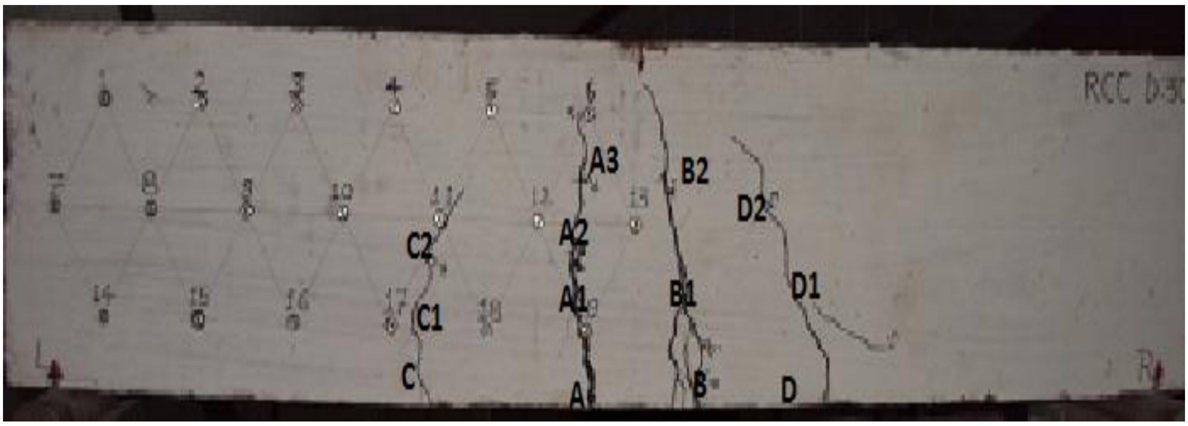
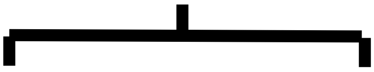


FIG. 6.65 D 30-S 0.0-RCC (WITH STIRRUPS)-1P

TABLE 6.66 D 40-S 0.0-RCC(W/S)-1P



CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	8.40	Flexure	600		60	0.43	92°	**0.55**	**FS**
A2	10.2	Flexure	650		75	0.6	60°		
A3	17.2	Flexure	620		80	0.55	90°		
A	**17.2**					**0.55**			
B1	10.5	Flexure	410		75	0.57	110°	1.5	
B2	12	Flexure	450		110	0.87	70°		
B	17.2					**1.5**			
C1	9.5	Shear		500	75	0.38	80°	1.2	
C2	10.5	Shear		550	85	0.45	80°		
C3	17.2	Shear		570	120	0.75	80°		
C	17.2					**1.2**			
D1	9.5	Flexure		450	56	0.58	90°	0.95	
D2	12.6	Flexure		410	120	0.48	65°		
D	17.2					**0.95**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=3 a/D=1.5

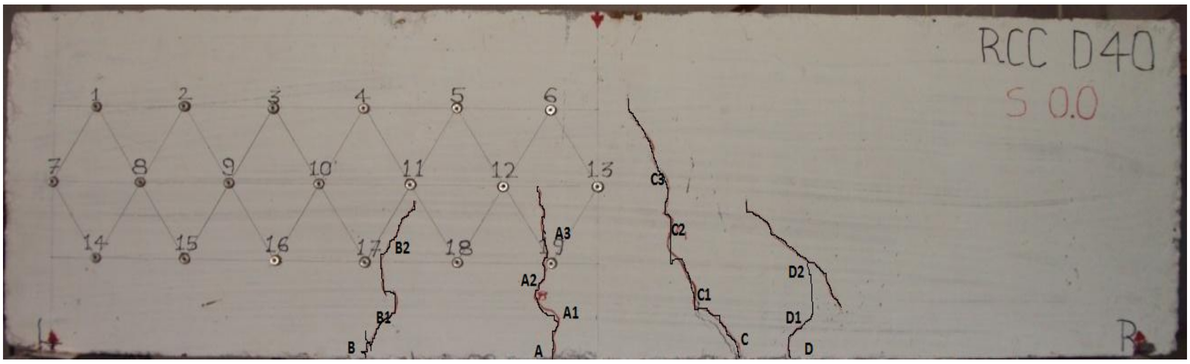


FIG. 6.66 D 40-S 0.0-RCC (WITH STIRRUPS)-1P

TABLE 6.67 D50-S 0.0-RCC(W/S)-1P

<table>
<tr><th rowspan="2">CRACK NAME</th><th rowspan="2">LOAD (T)</th><th rowspan="2">ZONE</th><th colspan="2">DISTANCE FROM</th><th rowspan="2">LENGTH (mm)</th><th rowspan="2">WIDTH (mm)</th><th rowspan="2">α</th><th rowspan="2">MAXIMUM WIDTH (mm)</th><th rowspan="2">TYPE OF FAILURE</th></tr>
<tr><th>LHS (mm)</th><th>RHS (mm)</th></tr>
<tr><td>A1</td><td>12.2</td><td>Flexure</td><td>500</td><td></td><td>56</td><td>0.28</td><td>90°</td><td rowspan="3">1.03</td><td rowspan="3">F</td></tr>
<tr><td>A2</td><td>10.3</td><td>Flexure</td><td>450</td><td></td><td>85</td><td>0.2</td><td>105°</td></tr>
<tr><td>A</td><td>27.3</td><td></td><td></td><td></td><td></td><td>1.03</td><td></td></tr>
<tr><td>B1</td><td>17</td><td>Flexure</td><td></td><td>650</td><td>56</td><td>0.41</td><td>80°</td><td rowspan="4">0.85</td><td rowspan="4"></td></tr>
<tr><td>B2</td><td>21</td><td>Flexure</td><td></td><td>600</td><td>85</td><td>0.5</td><td>80°</td></tr>
<tr><td>B3</td><td>27.3</td><td>Flexure</td><td></td><td>620</td><td>100</td><td>0.56</td><td>80°</td></tr>
<tr><td>B</td><td>27.3</td><td></td><td></td><td></td><td></td><td>0.85</td><td></td></tr>
</table>

α: Inclination with horizontal

F: crack is initiated in flexure zone and major cause of failure is flexure crack only.

L/D=2.4 a/D=1.2

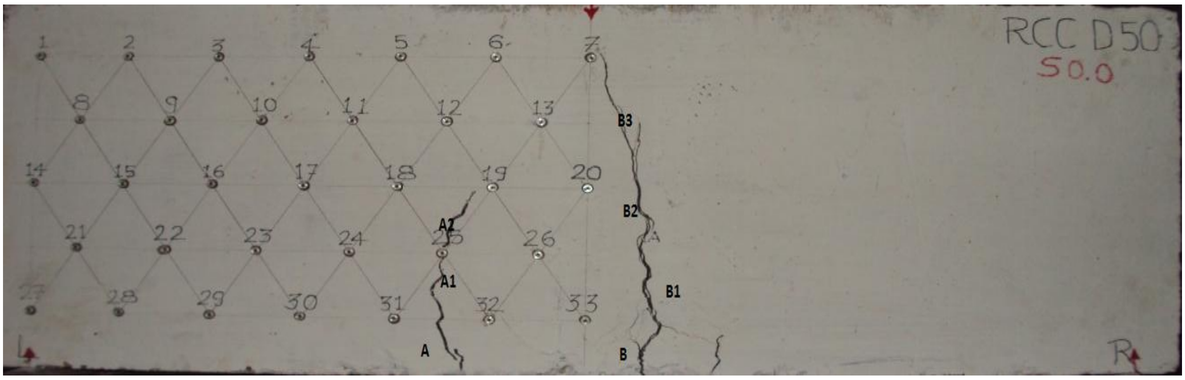


FIG. 6.67 D50-S 0.0-RCC (WITH STIRRUPS)-1P

TABLE 6.68 D 60-S 0.0-RCC(W/S)-1P

CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	21.3	Flexure		400	155	0.78	70°	**2.22**	**FS**
A	**45.5**					**2.22**			
B1	26.1	Flexure		500	120	1.04	80°	1.2	
B2	27.8	Flexure		52	140	0.71	85°		
B3	35.5	Flexure		510	210	0.41	80°		
B	45.5					**1.2**			
C1	25.8	Flexure	500		70	0.58	120°	1.2	
C2	36	Flexure	600		85	0.85	90°		
C	45.5					**1.2**			
D1	20.1	Shear	300		52	1.25	110°	1.5	
D	45.5					**1.5**			
E1	26	Shear	400		60	0.35	120°	1.0	
E2	27.5	Shear	450		100	0.85	132°		
E3	38	Shear	500		90	0.98	135°		
E	45.5					**1.0**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=2 a/D=1

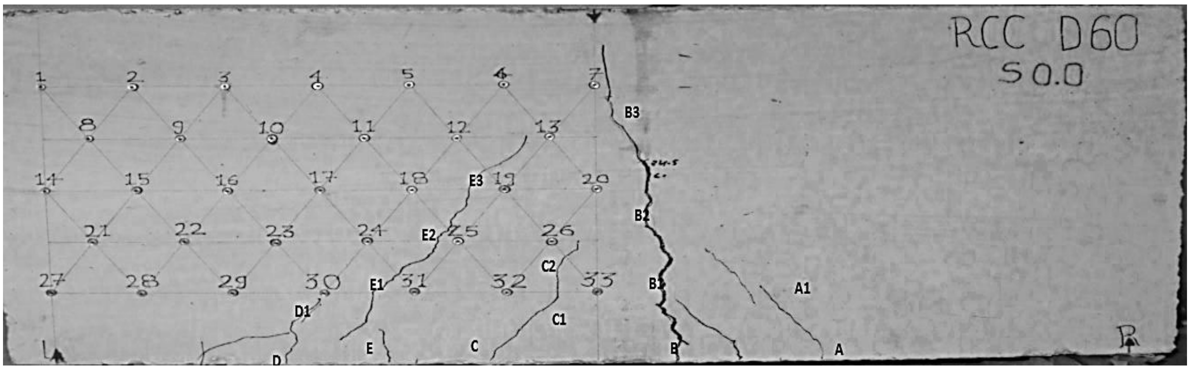


FIG. 6.68 D 60-S 0.0-RCC (WITH STIRRUPS)-1P

TABLE 6.69 D 30-S 0.0-RCC(W/S)-2P

CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM		LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
			LHS (mm)	RHS (mm)					
A1	6	Flexure	500		100	0.35	90°		
A2	8	Flexure	510		80	0.48	89°	**0.55**	**F**
A3	12.5	Flexure	500		70	0.54	90°		
A	**13.4**					**0.55**			
B1	7.5	Flexure		400	100	0.41	90°		
B2	10	Flexure		410	120	0.42	85°	0.48	
B	13.4					0.48			
C1	7.2	Flexure		510	110	0.39	90°		
C2	10.8	Flexure		490	140	0.45	85°	0.53	
C	13.4					0.53			
D1	11	Shear	300		170	0.5	110°		
D2	13	Shear	350		110	0.46	115°	0.51	
D	13.4					0.51			
E1	13.4	Shear		310	195	0.42	75°	0.47	
E	13.4					0.47			

α: Inclination with horizontal

F: crack is initiated in flexure zone and major cause of failure is flexure crack only.

L/D=4 a/D=1.33

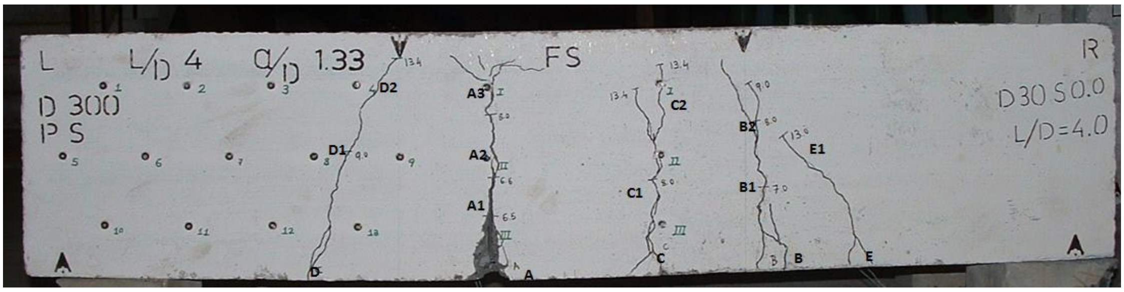


FIG. 6.69 D 30-S 0.0-RCC (WITH STIRRUPS)-2P

TABLE 6.70 D 40-S 0.0-RCC(W/S)-2P

CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	11.5	Flexure		500	100	0.41	90°	0.85	
A2	18.5	Flexure		500	120	0.39	90°		
A3	25.2	Flexure		520	110	0.52	70°		
A4	28	Flexure		500	70	0.64	105°		
A	29.5					**0.85**			
B1	11	Flexure	650		125	0.36	90°	**1.58**	**FS**
B2	12.5	Flexure	600		85	0.48	70°		
B3	18.5	Flexure	640		75	0.59	90°		
B4	29.5	Flexure	600		72	1.21	85°		
B	**29.5**					**1.58**			
C1	12.6	Shear		400	100	0.69	65°	1.25	
C2	15	Shear		450	75	0.87	65°		
C	29.5					**1.25**			
D1	15	Shear	300		110	0.39	120°	0.95	
D2	28	Shear	350		280	0.87	116°		
D	29.5					**0.95**			
E1	25.2	Shear		410	105	0.39	110°	0.86	
E2	28.5	Shear		450	89	0.57	75°		
E	29.5					**0.86**			
F1	22.8	Shear		300	100	0.3	75°	0.85	
F2	26.5	Shear		400	200	0.45	65°		
F3	28.5	Shear		420	120	0.54	68°		
F4	29.5	Shear		430	85	0.62	80°		
F	29.5					**0.85**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=3 a/D=1

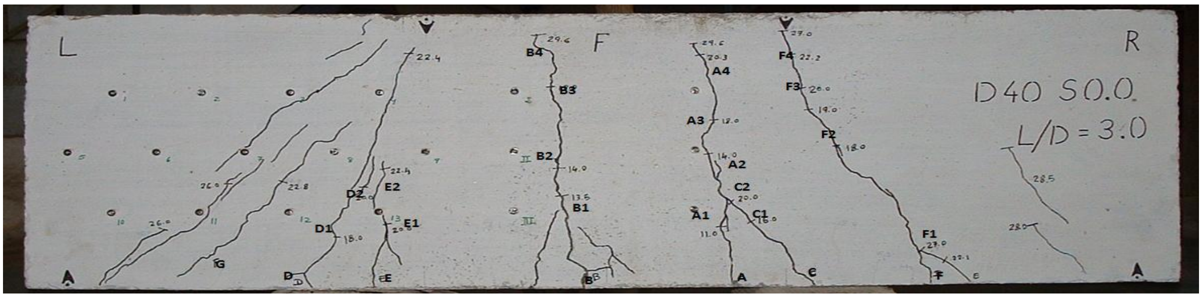


FIG. 6.70 D 40-S 0.0-RCC (WITH STIRRUPS)-2P

TABLE 6.71 D 50-S 0.0-RCC(W/S)-2P

CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	20.5	Flexure	600		180	0.84	105°	2.28	
A2	39.4	Flexure	620		120	1.1	90°		
A3	45	Flexure	630		170	1.35	108°		
A	46					**2.28**			
B1	37	Flexure		470	140	0.87	80°	3.15	
B2	39.5	Flexure		500	120	1.39	110°		
B3	42.5	Flexure		510	180	2.14	80°		
B	46					**3.15**			
C1	38.2	Shear		390	150	0.39	90°	1.29	
C2	42.5	Shear		410	85	0.82	65°		
C	46					**1.29**			
D1	36.2	Shear	400		110	0.85	90°	2.37	
D2	38	Shear	410		90	1.26	85°		
D3	40	Shear	450		150	2.2	120°		
D	46					**2.37**			
E1	36	Shear	150		95	0.35	130°	**4.28**	**FS**
E2	40	Shear	300		120	0.64	135°		
E3	42	Shear	400		175	1.58	130°		
E4	44	Shear	450		75	2.25	140°		
E5	46	Shear	480		86	3.21	120°		
E	**46**					**4.28**			
F1	45	Shear		100	210	0.34	75°	0.89	
F	46					0.38			
G1	40	Shear		80	180	0.47	82°	0.91	
G2	43.5	Shear		100	195	0.56	72°		
G3	44	Shear		200	192	0.85	70°		
G	46					**0.91**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=2.4 a/D=0.8

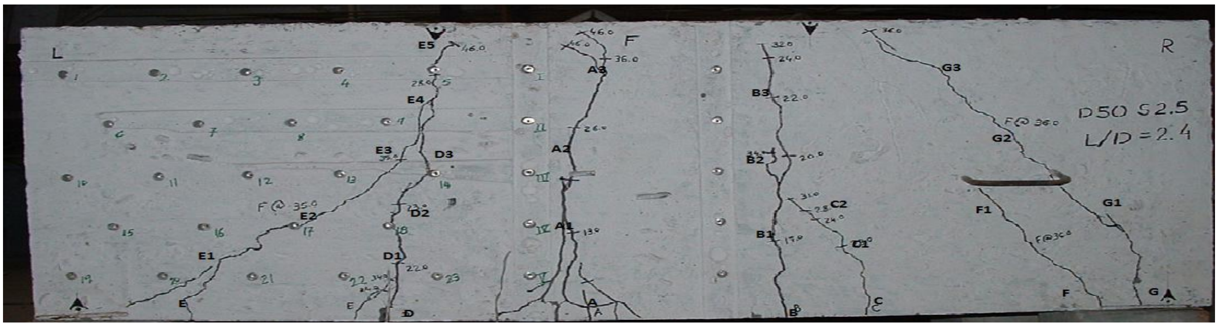


FIG. 6.71 D 50-S 0.0-RCC (WITH STIRRUPS)-2P

TABLE 6.72 D 60-S 0.0-RCC(W/S)-2P

CRACKNAME	LOAD (T)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	56	Shear	100		170	0.38	130°		
A2	60	Shear	200		140	0.81	125°	**1.22**	**S**
A3	63.8	Shear	300		210	0.96	124°		
A	**63.8**					**1.22**			
B1	58	Shear		85	140	0.43	74°		
B2	60.5	Shear		150	295	0.87	65°	0.93	
B	63.8					**0.93**			
C1	59.2	Shear	300		120	0.41	90°		
C2	60.5	Shear	450		195	0.43	120°	1.14	
C3	61.8	Shear	480		230	0.38	125		
C	63.8					**1.14**			
D1	57	Shear		200	145	0.39	64°		
D2	58.2	Shear		320	120	0.51	68°		
D3	59.6	Shear		400	100	0.63	80°	0.84	
D4	60.5	Shear			115	0.74	75°		
D	63.8					**0.84**			
E1	60	Flexure	480		100	0.38	90°		
E2	60.8	Flexure	520		130	0.68	115°	1.17	
E3	61.3	Flexure	570		158	0.98	90°		
E	63.8					**1.17**			
F1	25.3	Flexure		500	142	0.47	90°	0.83	
F	63.8					0.83			
G1	60	Shear		600	175	0.68	70°	0.74	
G	63.8					**0.74**			

α: Inclination with horizontal

S: Crack is initiated in flexure zone but major cause of failure is inclined shear crack only.

L/D=2 a/D=0.67

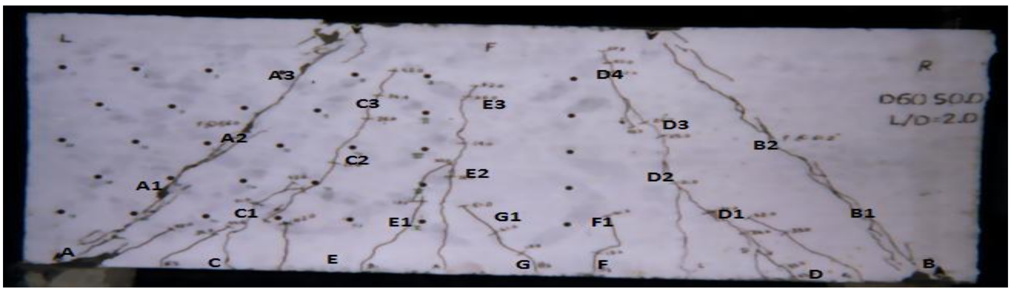


FIG. 6.72 D 60-S 0.0-RCC (WITH STIRRUPS)-2P

TABLE 6.73 D 30-S 5.0-RCC(W/S)-2P

CRACKNAME	LOAD (T)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	5.8	Flexure	600		150	0.31	70°		
A2	6.6	Flexure	550		70	0.25	90°	**0.35**	**F**
A3	13.5	Flexure	570		80	0.32	110°		
A	**15.7**					**0.35**			
B1	6	Flexure		500	150	0.12	75°		
B2	9.2	Flexure		500	75	0.25	80°	0.32	
B3	13.5	Flexure		520	60	0.31	110°		
B	15.7					**0.32**			
C1	5.8	Flexure	500		90	0.24	100°		
C2	9.3	Flexure	550		70	0.31	80°	0.34	
C	15.7					**0.34**			
D1	8.8	Flexure		400	170	0.25	170°		
D2	10.4	Flexure		420	70	0.23	75°	0.3	
D	15.7					**0.3**			
E1	10	Shear	300		70	0.3	80°		
E2	11.4	Shear	330		65	0.25	70°		
E3	11.5	Shear	350		60	0.24	60°	0.32	
E4	12.4	Shear	600		70	0.26	75°		
E	15.7					**0.32**			

α: Inclination with horizontal

F: crack is initiated in flexure zone and major cause of failure is flexure crack only.

L/D=4 a/D=1.33

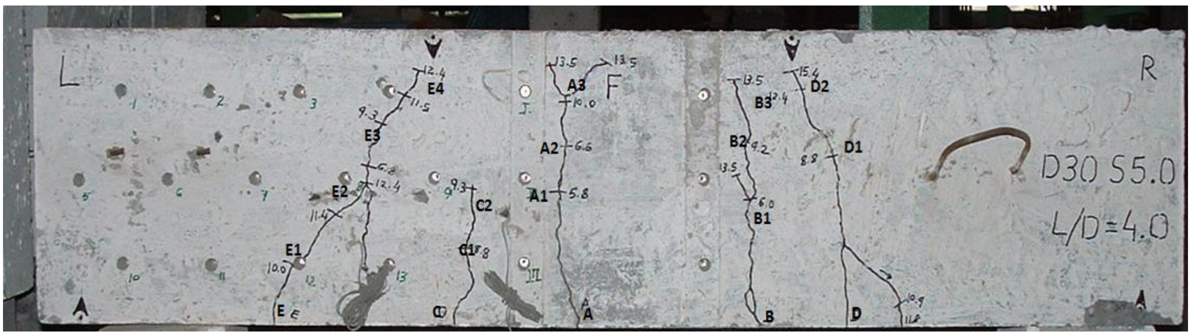


FIG. 6.73 D 30-S 5.0-RCC (WITH STIRRUPS)-2P

TABLE 6.74 D 40-S 5.0-RCC(W/S)-2P

CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	10.6	Flexure	600		85	0.36	80°	**1.2**	**FS**
A2	10.8	Flexure	580		80	0.35	78°		
A3	16.3	Flexure	570		70	0.43	75°		
A4	26.5	Flexure	550		60	0.59	80°		
A5	29	Flexure	550		65	0.87	78°		
A	**29**					**1.2**			
B1	10.9	Flexure	400		180	0.93	110°	1.1	
B2	12.1	Flexure	420		70	0.56	75°		
B3	15.4	Flexure	410		172	0.48	80°		
B	29					**1.1**			
C1	12	Flexure		370	100	0.57	90°	1.1	
C2	12.1	Flexure		300	150	0.68	90°		
C	31					**1.1**			
D1	13.4	Flexure	400		50	0.68	90°	0.68	
D	29					**0.68**			
E1	15.3	Shear		300	70	0.74	90°	0.98	
E2	16	Shear		260	90	0.64	85°		
E3	19.5	Shear		320	60	0.38	75°		
E4	23.8	Shear		400	30	0.56	75°		
E5	25.5	Shear		410	50	0.84	72°		
E	29					**0.98**			
F1	18	Shear	310		180	0.56	115°	0.89	
F	29					**0.89**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=3 a/D=1

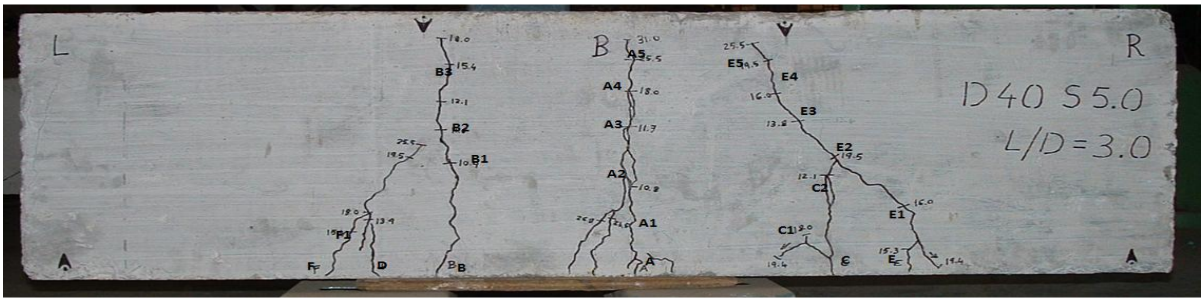


FIG. 6.74 D 40-S 5.0-RCC (WITH STIRRUPS)-2P

TABLE 6.75 D 50-S 5.0-RCC(W/S)-2P

CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	20.2	Flexure		600	170	0.54	90°	2.1	
A2	39.2	Flexure		610	120	0.89	90°		
A3	42	Flexure		620	98	1.36	90°		
A	45.5					**2.1**			
B1	35.2	Flexure	500		100	0.45	85°	**4.08**	**FS**
B2	36.5	Flexure	490		80	0.98	85°		
B3	38.2	Flexure	495		70	1.38	100°		
B4	39.8	Flexure	500		45	2.84	85°		
B5	42	Flexure	496		110	3.2	75°		
B	**45.5**					**4.08**			
C1	36.5	Flexure		400	50	0.73	90°	1.36	
C2	38	Flexure		420	60	0.5	110°		
C3	40	Flexure		430	200	0.46	80°		
C4	42.5	Flexure		440	75	0.83	79°		
C	45.5					**1.36**			
D1	40	Shear	420		40	0.72	90°	1.38	
D	45.5					**1.38**			
E1	37	Shear		100	120	0.68	70°	1.28	
E2	39.2	Shear		200	70	0.84	80°		
E3	41	Shear		300	130	1.21	68°		
E	45.5					**1.28**			
F1	36	Shear	100		140	0.81	120°	2.1	
F2	36.8	Shear	190		80	0.98	110°		
F3	38	Shear	289		85	1.51	130°		
F4	41	Shear	400		98	1.68	125°		
F	45.5					**2.1**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=2.4 a/D=0.8

FIG. 6.75 D 50-S 5.0-RCC (WITH STIRRUPS)-2P

TABLE 6.76 D 60-S 5.0-RCC(W/S)-2P

CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM		LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
			LHS (mm)	RHS (mm)					
A1	23.6	Shear	210		200	0.35	120°		
A2	52.2	Shear	300		240	0.65	125°	1.32	
A	52.2					**1.32**			
B1	41.2	Shear		100	210	0.45	65°		
B2	48	Shear		200	220	1.35	70°	**4.22**	**S**
B3	50	Shear		295	200	2.25	70°		
B	**52.2**					**4.22**			
C1	45	Shear		400	140	1.32	78°		
C2	48	Shear		450	132	2.3	80°	3.25	
C	52.2					**3.25**			
D1	50	Shear		300	170	0.74	74°	1.11	
D	52.2					**1.11**			
E1	48.5	Flexure	600		210	1.23	90°	1.97	
E	52.2					**1.97**			
F1	40.8	Shear	100		230	1.2	130°		
F2	48.3	Shear	150		150	2.1	125°	2.32	
F3	51.0	Shear	200		240	1.26	135°		
F	52.2					**2.32**			

α: Inclination with horizontal

S: Crack is initiated in flexure zone but major cause of failure is inclined shear crack only.

L/D=2 a/D=0.67

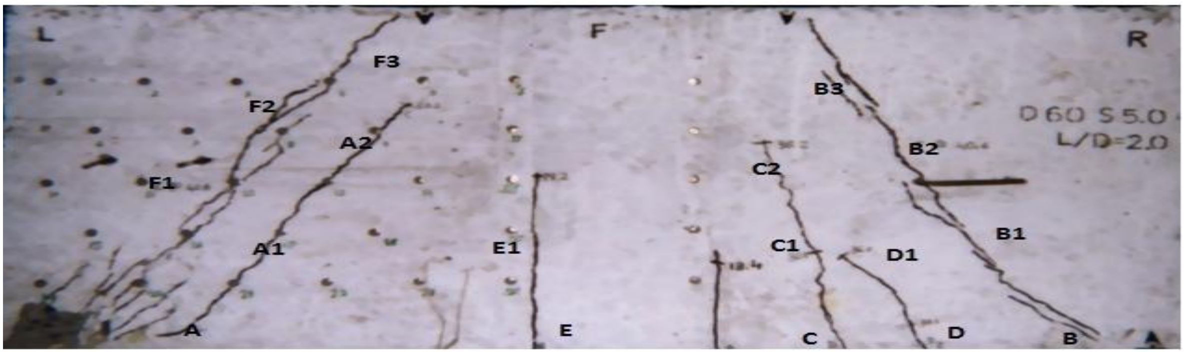


FIG. 6.76 D 60-S 5.0-RCC (WITH STIRRUPS)-2P

TABLE 6.77 D 30-S 7.5-RCC(W/S)-2P

CRACKNAME	LOAD (T)	ZONE	DISTANCE FROM		LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
			LHS (mm)	RHS (mm)					
A1	5	Flexure		420	110	0.87	90°	**2.55**	**F**
A2	16	Flexure		460	150	1.35	70°		
A	**16.1**					**2.55**			
B1	5.9	Flexure	520		100	0.35	70°	2.1	
B2	7.9	Flexure	430		90	0.82	65°		
B3	10.3	Flexure	400		150	1.32	80°		
B	16.1					**2.1**			
C1	6	Flexure	640		120	0.61	95°	1.45	
C2	9.7	Flexure	650		90	1.52	80°		
C3	11.2	Flexure	640		85	0.84	110°		
C	16.1					**1.45**			
D1	9.8	Flexure		360	95	0.65	80°	0.91	
D2	10.3	Flexure		375	130	0.72	85°		
D3	15	Flexure		400	70	0.85	75°		
D	16.1					**0.91**			
E1	9.2	Flexure	410		140	0.39	120°	0.87	
E2	11.2	Flexure	430		75	0.54	110°		
E3	16.1	Flexure	450		60	0.68	110°		
E	16.1					**0.87**			

α: Inclination with horizontal

F: crack is initiated in flexure zone and major cause of failure is flexure crack only.

L/D=4 a/D=1.33

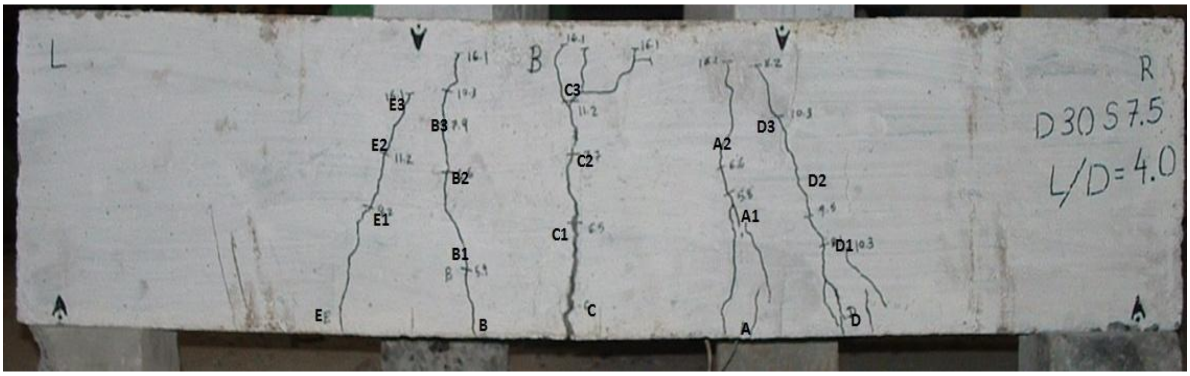


FIG. 6.77 D 30-S 7.5-RCC (WITH STIRRUPS)-2P

TABLE 6.78 D 40-S 7.5-RCC(W/S)-2P

CRACKNAME	LOAD (T)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	10.1	Flexure	510		140	0.39	75°	**1.53**	**FS**
A2	18.5	Flexure	505		120	0.78	80°		
A3	28	Flexure	500		15	1.38	110°		
A	**28.9**					**1.53**			
B1	11.7	Flexure		450	150	0.39	90°	1.21	
B2	14	Flexure		420	75	0.84	110°		
B3	26	Flexure		430	100	0.92	110°		
B	28.9					**1.21**			
C1	16	Flexure	430		95	0.72	110°	1.14	
C2	27	Flexure	480		70	0.95	120°		
C	28.9					**1.14**			
D1	16	Flexure		600	100	0.65	90°	1.35	
D2	18.5	Flexure		550	80	0.84	85°		
D3	24	Flexure		550	75	1.36	85°		
D4	27	Flexure		540	60	1.21	110°		
D	28.9					**1.35**			
E1	17.4	Shear		350	100	0.62	70°	0.85	
E2	24	Shear		400	85	0.79	68°		
E	28.9					**0.85**			
F1	20.8	Shear	300		110	0.38	120°	0.76	
F2	24	Shear	330		120	0.56	110°		
F	28.9					**0.76**			
G1	20	Shear	100		150	0.45	145°	0.69	
G2	24	Shear	200		270	0.54	140°		
G	28.9					**0.69**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=3 a/D=1

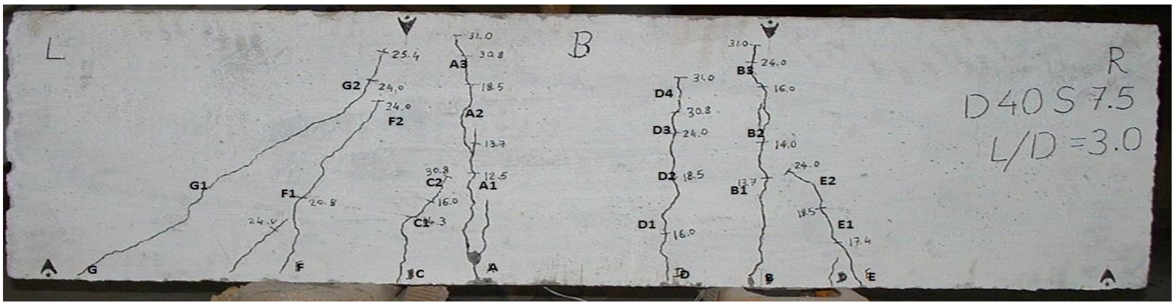


FIG. 6.78 D 40-S 7.5-RCC (WITH STIRRUPS)-2P

TABLE 6.79 D 50-S 7.5-RCC(W/S)-2P

CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM		LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
			LHS (mm)	RHS (mm)					
A1	19.6	Flexure		630	110	0.45	90°	**4.55**	**FS**
A2	29.3	Flexure		600	110	1.35	120°		
A3	44.9	Flexure		550	200	2.5	110°		
A	**44.9**					**4.55**			
B1	22.5	Flexure	480		80	0.45	70°	2.1	
B2	35	Flexure	450		95	0.53	90°		
B3	39	Flexure	460		92	0.65	90°		
B4	40	Flexure	470		92	0.85	110°		
B5	42	Flexure	472		85	1.56	110°		
B	44.9					**2.1**			
C1	20.5	Shear	300		150	0.58	110°	1.3	
C2	32.8	Shear	400		80	0.78	120°		
C3	42.5	Shear	450		100	0.82	115°		
C4	44.9	Shear	500		90	1.2	110°		
C	44.9					**1.3**			
D1	40	Shear	200		100	0.75	120°	0.84	
D	44.9					**0.84**			
E1	22.5	Flexure		460	100	0.44	90°	0.95	
E2	38.6	Flexure		500	85	0.58	45°		
E3	42.4	Flexure		550	250	0.84	45°		
E	44.9					**0.95**			
F1	28.5	Shear		230	150	0.39	65°	1.56	
F2	44	Shear		270	354	0.58	70°		
F	44.9					**1.56**			
G1	28.6	Shear	100		120	0.56	130°	1.38	
G2	38.2	Shear	200		156	0.85	130°		
G	44.9					**1.38**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=2.4 a/D=0.8

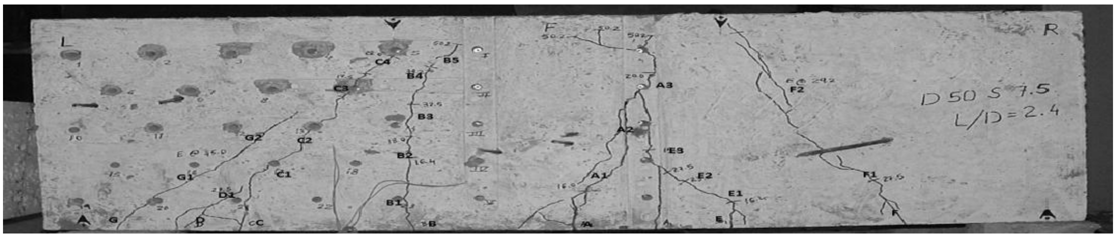


FIG. 6.79 D 50-S 7.5-RCC (WITH STIRRUPS)-2P

TABLE 6.80 D 60-S 7.5-RCC(W/S)-2P

CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM		LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
			LHS (mm)	RHS (mm)					
A1	21.6	Flexure		600	300	0.85	90°		
A2	38	Flexure		600	230	1.2	90°	3.1	
A	53.02					**3.1**			
B1	35	Shear	400		130	1.2	115°	2.5	
B	53.02					**2.5**			
C1	42	Shear		350	220	1.2	60°	1.5	
C	53.02					**1.5**			
D1	21.6	Shear	100		230	0.56	120°		
D2	46.5	Shear	200		400	2.8	130°	**4.2**	**S**
D	**53.02**					**4.2**			
E1	30	Shear		90	220	1.3	30°		
E2	48	Shear		250	340	2.2	60°	3.4	
E	53.02					**3.4**			

α: Inclination with horizontal

S: Crack is initiated in flexure zone but major cause of failure is inclined shear crack only.

L/D=2 a/D=0.67

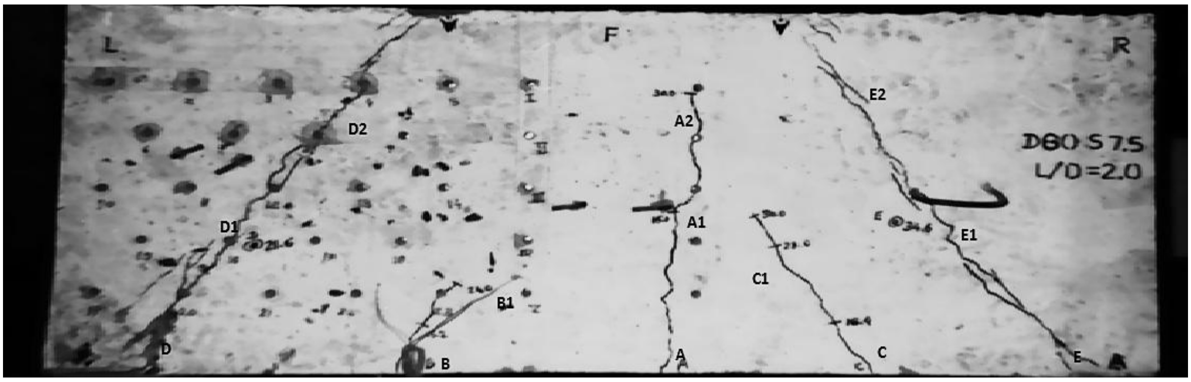


FIG. 6.80 D 60-S 7.5-RCC (WITH STIRRUPS)-2P

TABLE 6.81 D 30-S 0.0-RCC(W/O/S)-1P

CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	3	Flexure	560		120	0.42	115°		
A2	3.58	Flexure	540		110	0.34	85°	**0.42**	
A	6.2					**0.42**			
B1	3.5	Flexure		490	150	0.22	82°		
B2	4.23	Flexure		520	80	0.35	78°	**0.35**	
B	6.2					**0.35**			
C1	3.8	Flexure	400		140	0.4	75°		
C2	3.98	Flexure	480		95	2.1	120°		
C3	4.5	Flexure	540		80	0.5	148°	**2.1**	
C4	5.2	Flexure	540		75	2	125°		
C	6.2					**2.1**			
D1	4.8	Shear	410		100	3.85	124°		
D2	5.2	Shear	350		95	3.5	168°		
D3	6.2	Shear	200		120	6	172°	**6**	**FS**
D	**6.2**					**6**			
E1	5	Shear		295	150	0.6	78°	**0.6**	
E	6.2					**0.6**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=4 a/D=2

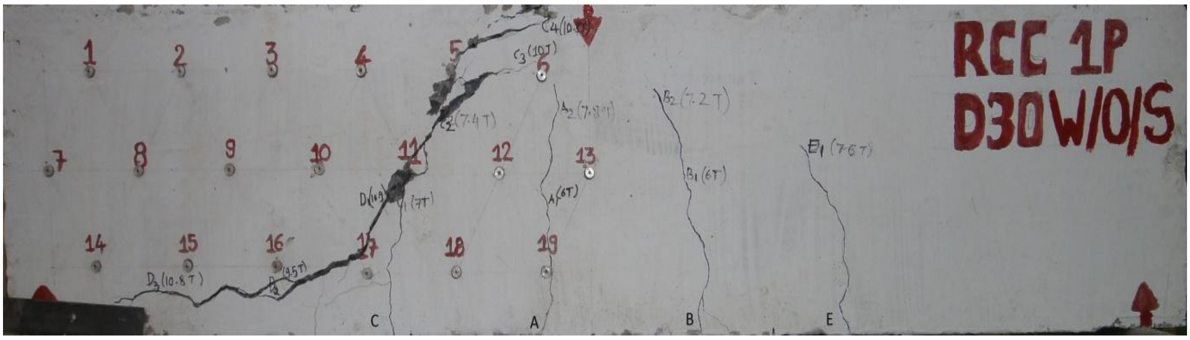


FIG. 6.81 D 30-S 0.0-RCC (WITHOUT STIRRUPS)-1P

TABLE 6.82 D 40-S 0.0-RCC(W/O/S)-1P

CRACKNAME	LOAD (t)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	4	Flexure	560		120	0.8	45°		
A2	6.8	Flexure	620		130	0.9	100°	0.9	
A	9.9					**0.9**			
B1	5.6	Flexure		500	200	0.2	85°		
B2	6.9	Flexure		560	120	0.4	90°	0.51	
B	9.9					**0.51**			
C1	5.32	Shear	200		140	2	110°		
C2	6.87	Shear	225		210	2.85	120°	**2.92**	**FS**
C3	9.9	Shear	400		120	2.2	145°		
C	**9.9**					**2.92**			
D1	7.2	Flexure	430		100	0.2	100°	0.2	
D	9.9					**0.2**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=3 a/D=1.5

FIG. 6.82 D 40-S 0.0-RCC (WITHOUT STIRRUPS)-1P

TABLE 6.83 D 50-S 0.0-RCC(W/O/S)-1P

CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	7.6	flexure		630	230	1.5	80°		
A2	8.3	flexure		635	70	5.2	78°		
A3	9.58	flexure		620	110	3.8	68°	7	
A4	10.2	flexure		635	50	1.1	58°		
A	14.0					**7**			
B1	10.48	flexure		520	190	8	60°		
B2	14.0	flexure		535	70	10	110°	**10**	**FS**
B	14.0					**10**			
C1	10.32	flexure	535		160	4.2	110°		
C2	11.65	flexure	605		70	1.5	160°	6	
C	14.0					**6**			
D1	10.3	flexure		420	100	3	48°	3	
D	14.0					**3**			
E1	12.6	flexure	460		80	0.6	148°	0.6	
E	14.0					**0.6**			
F1	7.95	shear	110		200	0.4	120°		
F2	8.21	shear	225		110	0.5	125°		
F3	9.31	shear	300		70	0.6	130°	1.4	
F4	10.3	shear	320		160	0.8	120°		
F5	11.5	shear	460		90	1.2	130°		
F	14.0					**1.4**			
G1	12	flexure		500	100	0.3	140°	0.8	
G	**14.0**					**0.8**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=2.4 a/D=1.2

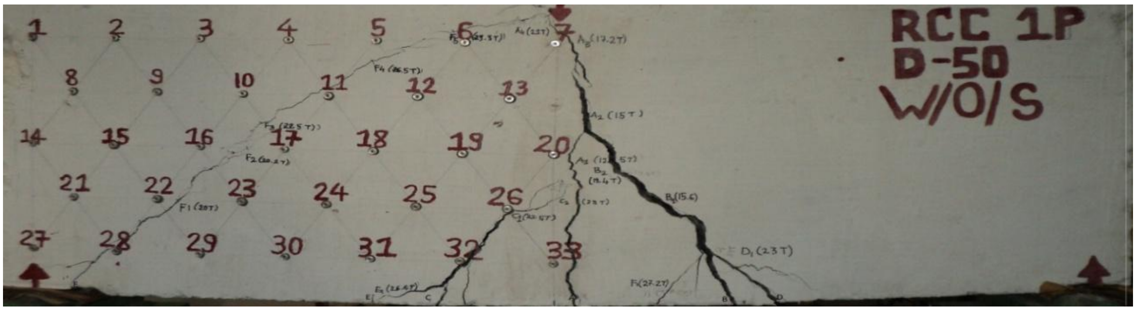


FIG. 6.83 D 50-S 0.0-RCC (WITHOUT STIRRUPS)-1P

TABLE 6.84 D60-S 0.0-RCC(W/O/S)-1P

CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	10.9	flexure	640		155	0.25	75°	6	
A2	12.8	flexure	640		200	0.31	90°		
A3	15.9	flexure	648		125	2.1	90°		
A4	18.5	flexure	680		75	4.1	100°		
A	24					**6**			
B1	12.54	flexure		550	100	0.24	75°	**12**	**FS**
B2	15.8	flexure		620	75	0.18	60°		
B3	16.87	flexure		645	40	4.25	62°		
B4	24	flexure		690	50	6	60°		
B	**24**					**12**			
C1	17.2	shear	500		220	0.17	110°	8	
C2	19.35	shear	565		165	0.36	120°		
C3	20.87	shear	630		75	2.5	120°		
C	24					**8**			
D1	21.2	shear	380		65	1.2	115°	2	
D	24					**2**			
E1	19	shear		680		2	100°	2	
E	24					**2**			
F1	20.5	shear	300		35	1.2	65°	1.2	
F	24					**1.2**			
G1	18.54	shear	150		210	0.5	170°	0.7	
G	24					**0.7**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack

L/D=2 a/D=1

FIG. 6.84 D 60-S 0.0-RCC (WITHOUT STIRRUPS)-1P

TABLE 6.85 D 30-S 0.0-RCC(W/O/S)-2P

CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	3.2	flexure	530		100	1.22	90°		
A2	4.51	flexure	540		80	2.1	110°	2.1	
A3	5.24	flexure	550		100	0.8	115°		
A	7					**2.1**			
B1	5.2	flexure		520	150	5.1	115°		
B2	5.8	flexure		500	50	2.2	110°		
B3	6.15	flexure		510	60	1.2	115°	5.1	
B4	6.8	flexure		520	30	0.12	20°		
B	7					**5.1**			
C1	4.2	flexure		460	150	4.1	90°		
C2	5.3	flexure		440	60	0.2	115°		
C3	5.9	flexure		450	30	0.1	35°	**4.1**	**F**
C4	6.45	flexure		480	80	2.2	45°		
C	7					**4.1**			
D1	5.28	flexure	430		60	2.1	95°		
D2	6.39	flexure	430		50	1.5	75°	2.2	
D	7					**2.2**			
E1	5.78	flexure	300		70	0.2	120°		
E2	6.28	flexure	330		30	0.3	120°	0.4	
E3	6.39	flexure	350		30	0.1	130°		
E	7					**0.4**			
F1	5.12	flexure	280		80	0.25	150°		
F2	6.25	flexure	340		150	0.15	165°	0.3	
F	7					**0.3**			
G1	6.4	flexure		570	120	1.8	145°	1.8	
G	7					**1.8**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack

L/D=4 a/D=1.33

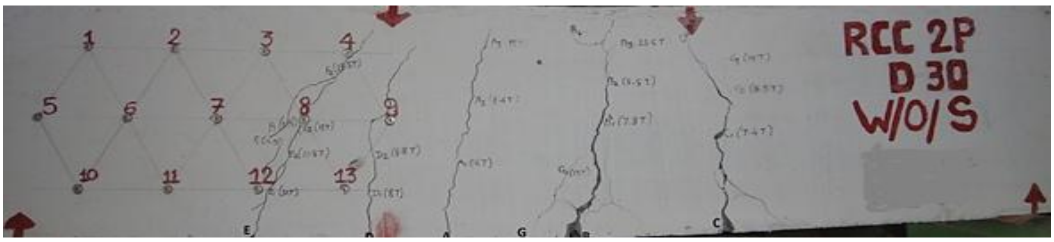


FIG. 6.85 D 30-S 0.0-RCC (WITHOUT STIRRUPS)-2P

TABLE 6.86 D40-S0.0-RCC(W/O/S)-2P

CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	6.1	flexure		590	120	0.4	90°		
A2	8.45	flexure		640	100	0.35	60°		
A3	10.2	flexure		595	40	0.42	120°	1.25	
A4	11.3	flexure		580	60	0.65	120°		
A	13.4					**1.25**			
B1	6.8	flexure	395		50	0.5	85°		
B2	8.25	flexure	440		120	0.4	130°		
B3	9.84	flexure	450		60	0.63	85°		
B4	10.87	flexure	470		80	0.92	120°	1.6	
B5	11	flexure	480		50	0.81	130°		
B	13.4					**1.6**			
C1	7.9	shear	380		60	0.4	90°		
C2	8.24	shear	450		170	0.82	60°		
C3	9.8	shear	490		80	0.63	75°	0.9	
C4	10.5	shear	480		40	0.81	89°		
C	13.4					**0.9**			
D1	8.2	shear	300		75	0.6	80°		
D2	10.8	shear	380		100	0.4	68°	0.7	
D3	11.5	shear	400		40	0.35	49°		
D	13.4					**0.7**			
E1	11	shear	350		35	3	45°		
E2	12.5	shear	390		45	2	120°	**4**	**FS**
E3	13.4	shear	420		80	1	100°		
E	**13.4**					**4**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=3 a/D=1

FIG. 6.86 D 40-S 0.0-RCC (WITHOUT STIRRUPS)-2P

TABLE 6.87 D50-S0.0-RCC(W/O/S)-2P

CRACK NAME	LOAD (T)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	10	Flexure	480		75	1.52	90°	**8**	**FS**
A2	12.3	Flexure	500		100	4.2	100°		
A3	16.9	Flexure	520		140	3.8	88°		
A4	20.4	Flexure	560		110	2.3	90°		
A	**20.4**					**8**			
B1	12.5	Flexure		620	85	1.2	110°	7.4	
B2	14.9	Flexure		600	95	5.8	88°		
B3	17.8	Flexure		570	110	4.2	108°		
B4	18	Flexure		540	80	3.2	120°		
B	20.4					**7.4**			
C1	12.6	Flexure		470	50	3.1	80°	3.8	
C2	14.9	Flexure		500	90	2.8	70°		
C3	15.8	Flexure		560	100	1.7	65°		
C	20.4					**3.8**			
D1	14.3	Shear	330		40	0.5	140°	0.8	
D2	18.7	shear	410		60	0.7	158°		
D	20.4					**0.8**			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=2.4 a/D=0.8

FIG. 6.87 D50-S 0.0-RCC (WITHOUT STIRRUPS)-2P

TABLE 6.88 D 60-S 0.0-RCC(W/O/S)-2P

CRACK NAME	LOAD (t)	ZONE	DISTANCE FROM LHS (mm)	DISTANCE FROM RHS (mm)	LENGTH (mm)	WIDTH (mm)	α	MAXIMUM WIDTH (mm)	TYPE OF FAILURE
A1	14.5	Flexure		680	130	0.58	110°	1.32	
A2	18.3	Flexure		682	75	0.89	90°		
A3	24.5	Flexure		670	100	1.21	75°		
A	30					1.32			
B1	15.8	Flexure		550	195	0.62	90°	0.98	
B2	19.3	Flexure		500	75	0.74	100°		
B3	22.4	Flexure		512	100	0.84	71°		
B	30					0.98			
C1	17.6	Flexure	520		95	0.81	95°	1.2	
C	30					1.2			
D1	14.8	Shear	350		120	0.58	94°	**2.4**	**FS**
D2	21.4	Shear	400		185	1	112°		
D3	24.7	Shear	500		195	1.36	100°		
D	**30**					2.4			
E1	22.8	Flexure		320	118	0.54	72°	1.56	
E	30					1.56			
F1	18.2	Shear		100	190	0.38	65°	1.2	
F2	22.1	Shear		210	212	0.92	68°		
F3	24.5	Shear		320	230	0.89	70°		
F	30					1.2			

α: Inclination with horizontal

FS: Crack is initiated in flexure zone but major cause of failure is combined effect of inclined shear crack and flexure crack.

L/D=2 a/D=0.67

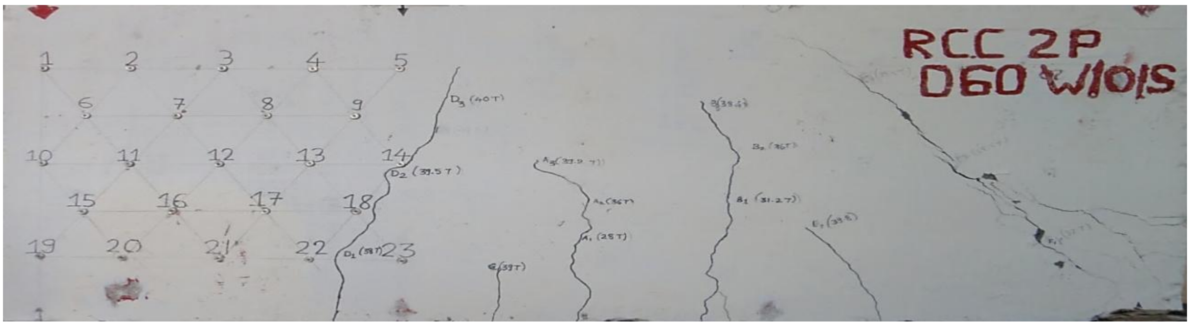


FIG. 6.88 D 60-S 0.0-RCC (WITHOUT STIRRUPS)-2P

6.2 COMPARISION OF EXPERIMENTAL RESULTS WITH THEORETICAL RESULTS

The experimental results of crack width are compared with theoretical results as shown in Table 6.89.

TABLE 6.89 CRACK WIDTHS (Experimental and Theoretical)

Sr. No.	TYPE	Ultimate Load (Tone)	Experimental Maximum Crack width (mm)	Theoretical Maximum Crack width (mm)	% Error
1	D30 S 0.0 PPFRC (MT) 1P	11.00	7.2	6.73	6.93
2	D40 S 0.0 PPFRC (MT) 1P	16.50	7.5	6.71	11.85
3	D50 S 0.0 PPFRC (MT) 1P	26.50	7	6.70	4.42
4	D60 S 0.0 PPFRC (MT) 1P	42.80	7.38	6.77	9.08
5	D30 S 0.0 PPFRC (MT) 2P	12.40	6.88	6.87	0.13
6	D40 S 0.0 PPFRC (MT) 2P	23.40	7.3	6.92	5.43
7	D50 S 0.0 PPFRC (MT) 2P	40.00	7.5	6.95	7.91
8	D60 S 0.0 PPFRC (MT) 2P	53.20	7.1	6.97	1.91
9	D30 S 5.0 PPFRC (MT) 2P	12.30	6.83	6.87	-0.55
10	D40 S 5.0 PPFRC (MT) 2P	24.20	6.9	6.94	-0.58
11	D50 S 5.0 PPFRC (MT) 2P	37.40	7.3	6.92	5.51
12	D60 S 5.0 PPFRC (MT) 2P	52.20	7	6.96	0.61
13	D30 S 7.5 PPFRC (MT) 2P	12.15	7.5	6.86	9.28
14	D40 S 7.5 PPFRC (MT) 2P	25.00	7.08	6.96	1.79
15	D50 S 7.5 PPFRC (MT) 2P	40.40	7.35	6.96	5.68
16	D60 S 7.5 PPFRC (MT) 2P	53.05	7.1	6.97	1.93
17	D30 S 0.0 PPFRC (FT) 1P	9.50	6.22	6.69	-7.08
18	D40 S 0.0 PPFRC (FT) 1P	15.50	6.1	6.69	-8.79
19	D50 S 0.0 PPFRC (FT) 1P	27.10	6.1	6.71	-9.04
20	D60 S 0.0 PPFRC (FT) 1P	40.90	7.21	6.75	6.83
21	D30 S 5.0 PPFRC (FT) 1P	9.00	6.69	6.68	0.13
22	D40 S 5.0 PPFRC (FT) 1P	16.20	7.1	6.70	6.00
23	D50 S 5.0 PPFRC (FT) 1P	26.10	6.33	6.70	-5.48
24	D60 S 5.0 PPFRC (FT) 1P	41.20	6.87	6.75	1.76
25	D30 S 7.5 PPFRC (FT) 1P	9.20	6.9	6.69	3.20
26	D40 S 7.5 PPFRC (FT) 1P	16.70	6.8	6.71	1.41
27	D50 S 7.5 PPFRC (FT) 1P	26.70	6.2	6.70	-7.50
28	D60 S 7.5 PPFRC (FT) 1P	41.50	6.63	6.75	-1.83
29	D30 S 0.0 PPFRC (FT) 2P	11.90	5.8	6.85	-15.33
30	D40 S 0.0 PPFRC (FT) 2P	22.30	6.5	6.90	-5.76
31	D50 S 0.0 PPFRC (FT) 2P	37.40	5.9	6.91	-14.66
32	D60 S 0.0 PPFRC (FT) 2P	51.30	6	6.94	-13.59

Sr.No	TYPE	Ultimate Load (Tone)	Maximum Crack width Measured (mm)	Maximum Crack width Calculated (mm)	% Error
33	D30 S 0.0 SFRC (FCT) 2P	12.50	9.3	10.82	-14.02
34	D40 S 0.0 SFRC (FCT) 2P	23.50	9.1	10.84	-16.01
35	D50 S 0.0 SFRC (FCT) 2P	39.75	9.7	10.84	-10.54
36	D60 S 0.0 SFRC (FCT) 2P	53.90	9.2	10.85	-15.23
37	D30 S 5.0 SFRC (FCT) 2P	12.45	9.3	10.82	-14.02
38	D40 S 5.0 SFRC (FCT) 2P	23.30	10.1	10.83	-6.77
39	D50 S 5.0 SFRC (FCT) 2P	39.10	9.22	10.84	-14.94
40	D60 S 5.0 SFRC (FCT) 2P	53.15	9.8	10.85	-9.68
41	D30 S 7.5 SFRC (FCT) 2P	12.40	9	10.82	-16.79
42	D40 S 7.5 SFRC (FCT) 2P	23.10	10.2	10.83	-5.84
43	D50 S 7.5 SFRC (FCT) 2P	38.85	8.9	10.84	-17.89
44	D60 S 7.5 SFRC (FCT) 2P	52.95	9.5	10.85	-12.43
45	D30 S 0.0 SFRC (CCT) 1P	10.90	7.5	6.61	13.51
46	D40 S 0.0 SFRC (CCT) 1P	16.90	7.1	6.42	10.57
47	D50 S 0.0 SFRC (CCT) 1P	27.30	6.2	6.42	-3.40
48	D60 S 0.0 SFRC (CCT) 1P	43.70	7.9	6.99	12.95
49	D30 S 5.0 SFRC (CCT) 1P	10.50	5.8	6.51	-10.96
50	D40 S 5.0 SFRC (CCT) 1P	16.70	5.97	6.39	-6.62
51	D50 S 5.0 SFRC (CCT) 1P	26.90	5.95	6.38	-6.79
52	D60 S 5.0 SFRC (CCT) 1P	42.75	6.3	6.93	-9.10
53	D30 S 7.5 SFRC (CCT) 1P	10.20	7.05	6.44	9.41
54	D40 S 7.5 SFRC (CCT) 1P	16.10	5.96	6.31	-5.54
55	D50 S 7.5 SFRC (CCT) 1P	26.85	6.8	6.38	6.60
56	D60 S 7.5 SFRC (CCT) 1P	42.60	6.2	6.92	-10.41
57	D30 S 0.0 HFRC (CCT+MT) 1P	9.20	7.5	6.67	12.43
58	D40 S 0.0 HFRC (CCT+MT) 1P	14.50	7.2	6.56	9.70
59	D50 S 0.0 HFRC (CCT+MT) 1P	22.40	6.22	6.56	-5.19
60	D60 S 0.0 HFRC (CCT+MT) 1P	28.80	6.3	6.88	-8.43
61	D30 S 0.0 HFRC (CCT+MT) 2P	11.40	7.9	8.84	-10.67
62	D40 S 0.0 HFRC (CCT+MT) 2P	25.20	8.96	8.88	0.91
63	D50 S 0.0 HFRC (CCT+MT) 2P	39.80	9.66	8.90	8.58
64	D60 S 0.0 HFRC (CCT+MT) 2P	45.90	8.1	8.91	-9.09

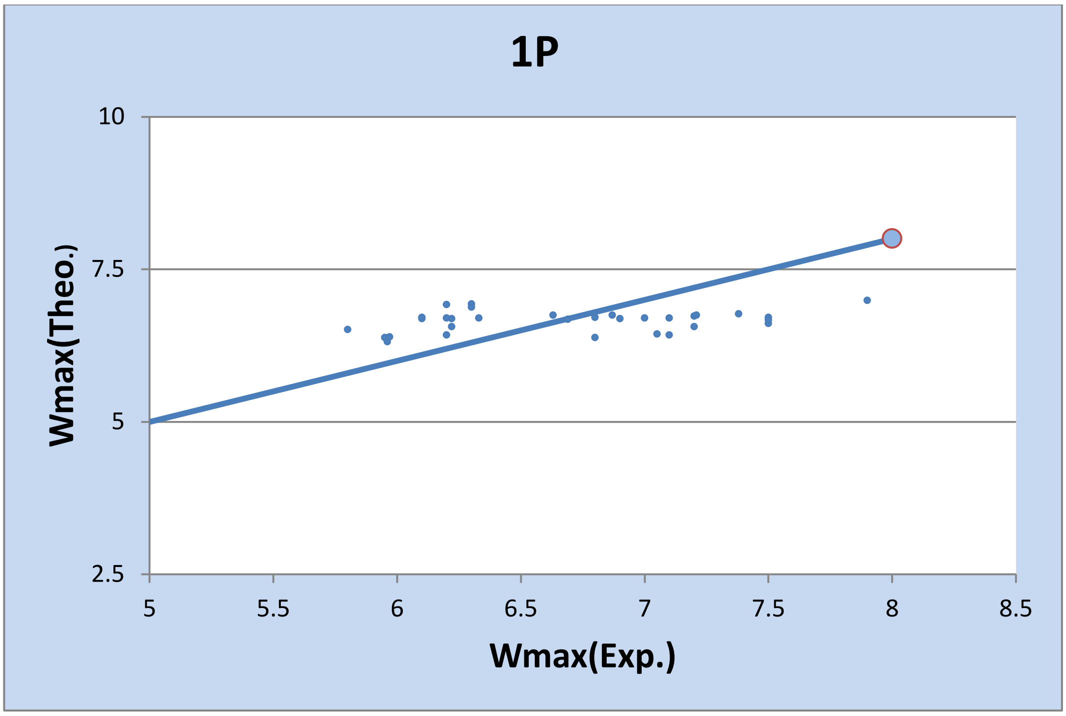


Fig. 6.89 Wmax$_{(Exp.)}$ Vs Wmax$_{(Theo.)}$ for 1P

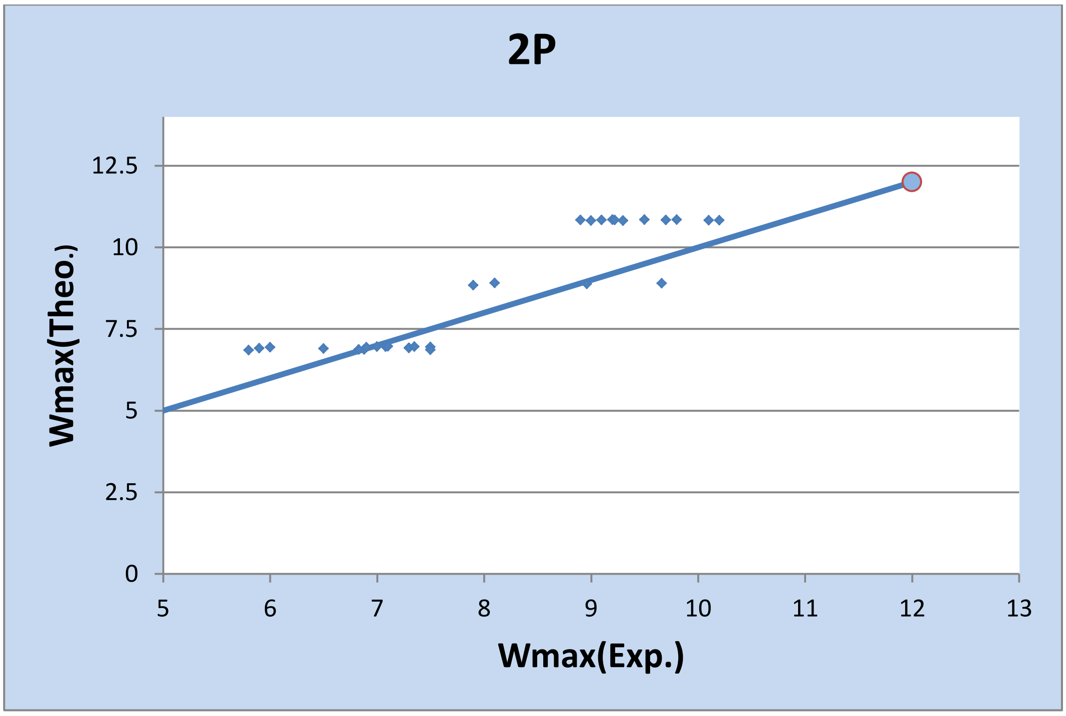


Fig. 6.90 Wmax$_{(Exp.)}$ Vs Wmax$_{(Theo.)}$ for 2P

CHAPTER-7
STRUT-AND-TIE MODEL FOR PREDICTION OF ULTIMATE SHEAR STRENGTH

7.1 FORMULAS FOR ULTIMATE SHEAR STRENGTH

The existing methods for analysis and design of deep beams consist of rational and semi- rational approaches as sectional approach or strut-and-tie Model (STM).

In parallel to the sectional approach, the strut- and-tie method is gaining rapid popularity for complex structures such as deep beams. Other researchers proposed some approaches applicable in D-regions. These approaches help in design of a complex structure. STM has been adopted in some American codes such as the Canadian Standard Association (CSA) and ACI which most recently has included STM approach in 2008 edition of the Building Code Requirements for Structural Concrete (ACI 318).

There are many parameters affecting on the shear strength of moderate deep and deep beams such as concrete compressive strength, shear span-depth ratio and the amount & arrangement of vertical and horizontal web reinforcements.

7.1.1 Strut-And-Tie Model Basis

FIG.7.1 shows a deep beam and its STM, this beam is loaded at center on top face by vertical point load and supported at the opposite face. The longitudinal main reinforcements are located at a distance d_{eff} from top. The shear strength is predicted by STM due to the diagonal struts and shear force flows along the strut from loaded point to the support.

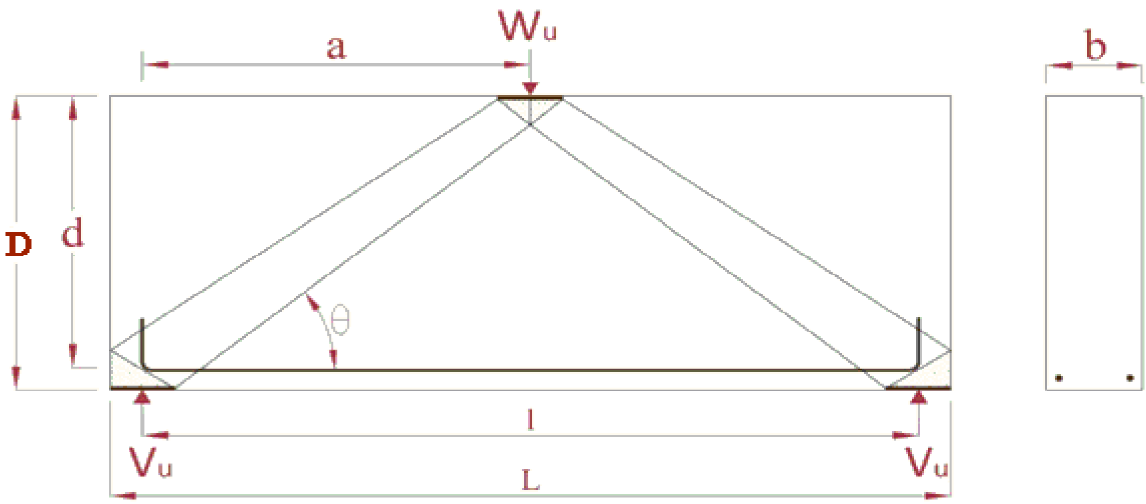


Fig. 7.1 Geometry Of Concrete Strut

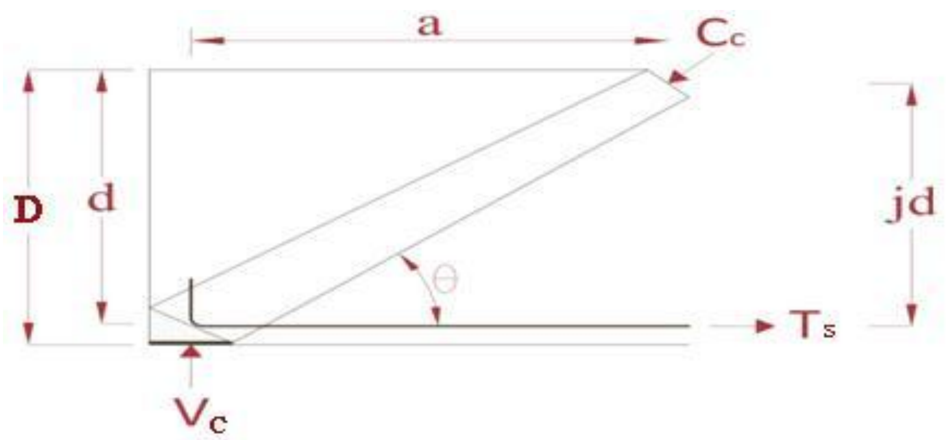


Fig. 7.2 Equilibrium of Strut In Absence Of Web Reinforcement

The equilibrium of the applied forces leads to the following expressions (Fig. 7.2).

.... (1)

.... (2)

Where,

C_c = Compression force in the diagonal strut

= Angle between strut and longitudinal reinforcements

(≥ 25 Degree, ACI 318 – 2008, A-2.5)

T_s = Tension force on longitudinal reinforcements (or ties)

V_c = Reaction at the support of deep beam.

The inclined angle of the diagonal strut is given by

.... (3)

Where,

a = Shear span measured center-to- center from load to support

jd = Distance of lever arm from the resultant compressive force to the center of the main tensile longitudinal reinforcements.

Using the assumption of Hwang et al, this term can be estimated as

.... (4)

Where,

kd = Depth of the compression zone or horizontal prismatic strut, where

.... (5)

Where,

n = modular ratio of elasticity,

E_s, E_c are the steel and concrete elasticity module

= Longitudinal reinforcement's ratio,

A_s= Area of main longitudinal reinforcements

b = width of beam.

d = Effective depth of beam

Although the diagonal strut is formed in bottle- shape, in the current study it is assumed that the strut has a prismatic form with a uniform width. The mean compressive stress in the strut can be computed as the force acting on the strut dividing by its cross-sectional area by following expression;

.... (6)

Where,

f' f'_{cu} = Maximum strength of the softened concrete strut (Effective compressive strength)

A_{cs} = Cross- sectional area of strut which can be calculated as

……. (7)

Where,

b = Width of beam

w_{cs} = Uniform width of strut which can be estimated as

……. (8)

Where,

w_t = Depth of bottom node, taken as twice the cover to the main reinforcement

l_p = Width of support bearing plate

w_s = depth of top node

l_b = Width of loading bearing plate

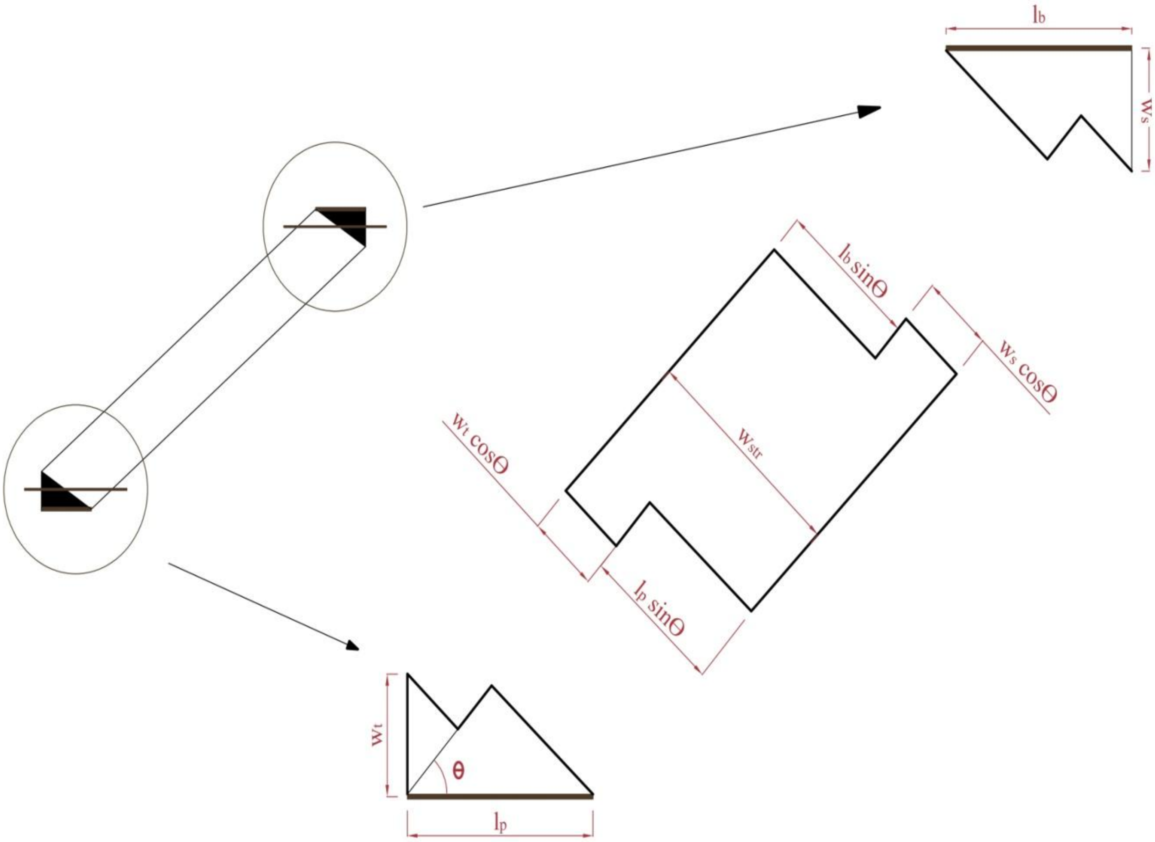


Fig. 7.3 Prismatic Strut Geometry

7.1.2 Compression Strength Of Softened Concrete

Cracked reinforced concrete can be treated as an orthotropic material with its principal axes corresponding to the directions of the principal average tensile and compressive strains. Cracked concrete subjected to high tensile strain in the direction normal to the compression is observed to be softer than concrete in a standard cylinder test. This phenomenon of strength and stiffness reduction is commonly referred to as compression softening. Applying this softening effect to the STM, it is recognized that the tensile straining perpendicular to the strut will reduce the capacity of the concrete strut to resist compressive stresses. Hence, f'_{cu} or softened concrete strength can be determined by

……. (9)

Where,

f'_c = Specified compressive strength of concrete based on cylinder tests

= Efficiency factor of concrete.

Now put equation (9) into equation (6)

……. (10)

Put equation (10) into equation (2)

……. (11)

Where,

= Efficiency factor of concrete.

f'_c = Cylindrical compressive strength of concrete

A_{cs} = Cross- sectional area of strut

= Angle between strut and longitudinal reinforcements

For beam without web reinforcement

……. (12)

For beam with web reinforcement

……. (13)

Where,

V_u= Ultimate shear strength

V_c= Shear strength provided by STM due to the diagonal conc. comp. strut.

V_w= Shear strength resulted by resisting mechanism of web reinforcement ……. (14)

Where,

f'_s= Yield strength of web reinforcement.

A'_s= Cross – sectional area of web reinforcement.

7.1.3 Formulas For Strut Strength Given By Different Sources Such As ACI 318-08[95], Schlaich et al. (1987)[94], Nielsen (1984)[92].

Table 7.1 Strut Strength For Each Design Specification

Specification	Strut compressive capacity without longitudinal reinforcement	Strut compressive capacity with longitudinal reinforcement
ACI 318-08 & NZS 3101	$f'_{cu}A_{cs}$ (Where $f'_{cu} = f'_c = 0.85\beta_s f'_c$) Prismatic: β_s= 1.0 Bottle-Shaped w/reinf. satisfying crack control: β_s= 0.75 Bottle-Shaped not satisfying crack control: β_s = 0.60λ λ =1.0 for normal weight concrete λ =0.85 for sand-lightweight concrete λ =0.75 for all lightweight concrete Strut in tension members: β_s= 0.40 All other cases: β_s= 0.60	$f'_{cu}A_{cs}+f'_sA'_s$
Schlaich et al. (1987)	$f'_{cu}A_{cs}$ (Where $f'_{cu} = f'_c$) For f'_{cu} $0.85f'_c$ "for an undisturbed and uniaxial state of compressive stress" (prismatic) $0.68f'_c$ "if tensile strains in the cross direction or transverse tensile reinforcement may cause cracking parallel to the strut with normal crack width" $0.51f'_c$ "as above for skew cracking or skew reinforcement" $0.34f'_c$ "for skew cracks with extraordinary crack width. Such cracks must be expected, if modeling of the struts departs significantly from the theory of elasticity's flow of internal forces"	$f'_{cu}A_{cs}+f'_sA'_s$
Nielsen (1984)	$f'_{cu}A_{cs}$ (Where $f'_{cu} = f'_c$) ——	$f'_{cu}A_{cs}+f'_sA'_s$

Table 7.2 Definitions For Variables Referenced In TABLE 7.1 For Each Design Specification

Specification	Definitions
ACI 318-08 & NZS 3101	A'_s = area of compression steel (in^2) A_c = area of concrete in the strut (in^2) A_{cs} = area of concrete in the strut (in^2) A_{si} = total area of surface reinforcement at spacing si (in^2) f'_c = concrete compressive strength (ksi) f'_{cu} = effective concrete compressive strength (ksi) α_i= the angle between the reinforcement and the axis of the strut (DEG.)

7.2 THE COMPARISON OF EXPERIMENT RESULTS WITH RESULTS USING STRUT-AND-TIE METHOD BASED ON VARIOUS CODES/RESEARCHERS

Experimental results are compared with theoretical results. Theoretical results are calculated from formula of STM which are given by various sources such as ACI 318-08 [95], Schlaich et al. (1987)[91], Nielsen (1984)[93].

First, the experimental test results of 12 RCC beams with stirrups with two point loads are compared with theoretical results calculated by ACI 318-08[95], Schlaich et al. (1987)[91], Nielsen (1984)[93]. [TABLE 7.3.1]

As per present investigation, we found that the variation in results is more than 25% for D30 & D40 specimen, i.e. L/D ≥ 3. D30 and D40 specimen fails due to flexure mode of failure. It is observed from test results that the variation in results is in close range for D50 & D60 specimen, i.e. L/D < 3. Theory of strut-and-tie is more appropriate to beam failing in shear (i.e. D50 and D60 series of beam). The theory of strut-and-tie may not be appropriate to apply for the beam failing in flexure (i.e. D30 and D40 series of beam). Therefore we have calculated ultimate shear strength by strut-and-tie method for D50 & D60 specimens only.

Table 7.3 Comparisons of Ultimate Shear Strength And Percentage Difference By Different Formulas Of STRUT-AND-TIE METHOD for RCC, PPFRC (MT), SFRC (FCT), PPFRC (FT), SFRC (CCT)

Table 7.3.1 Comparison of $V_{u\,(exp)}$ and $V_{u\,(th)}$ and % difference for **RCC** under two point load

Table 7.3.1.1 Comparison of $V_{u\,(exp)}$ and $V_{u(th)}$ for **RCC**

		a/D	L/D	Experimental Result (Tons)	ACI 318-08 (Tons)	Nielsen (1984) (Tons)	Schlaich et al. (1987) (Tons)	Mode of Failure
D30	**S0.0**	1.33	4	6.700	16.873	17.223	17.465	Flexure
	S5.0	1.33	4	7.850	16.998	17.324	17.598	Flexure
	S7.5	1.33	4	8.050	16.985	17.314	17.585	Flexure
D40	**S0.0**	1	3	14.750	24.496	25.055	25.466	Flexure-Shear
	S5.0	1	3	14.500	24.638	25.170	25.617	Flexure-Shear
	S7.5	1	3	14.450	24.597	25.137	25.574	Flexure-Shear
D50	**S0.0**	0.80	2.4	23.000	28.065	28.750	29.348	Flexure-Shear
	S5.0	0.80	2.4	22.750	27.827	28.557	29.094	Flexure-Shear
	S7.5	0.80	2.4	22.450	27.827	28.557	29.094	Flexure-Shear
D60	**S0.0**	0.66	2	31.870	33.241	34.137	34.782	Shear
	S5.0	0.66	2	26.100	33.241	34.137	34.782	Shear
	S7.5	0.66	2	26.520	33.369	34.241	34.919	Shear

Table 7.3.1.2 % difference of $V_{u(exp)}$ and $V_{u(th)}$ for **RCC**

		a/D	L/D	ACI 318-08	Nielsen (1984)	Schlaich et al. (1987)
D30	**S0.0**	1.33	4	60.29	61.10	61.64
	S5.0	1.33	4	53.82	54.69	55.39
	S7.5	1.33	4	52.61	53.51	54.22
D40	**S0.0**	1	3	39.79	41.13	42.08
	S5.0	1	3	41.15	42.39	43.40
	S7.5	1	3	41.25	42.52	43.50
D50	**S0.0**	0.80	2.4	18.05	20.00	21.63
	S5.0	0.80	2.4	18.25	20.34	21.80
	S7.5	0.80	2.4	19.32	21.39	22.84
D60	**S0.0**	0.66	2	4.13	6.64	8.37
	S5.0	0.66	2	21.48	23.54	24.96
	S7.5	0.66	2	20.53	22.55	24.05

Table 7.3.2 Comparison of $V_{u\ (exp)}$ and $V_{u\ (th)}$ and % difference for **PPFRC (MT)** under two point load

Table 7.3.2.1 Comparison of $V_{u\ (exp)}$ and $V_{u\ (th)}$ for **PPFRC (MT)**

		a/D	L/D	Experimental Result (Tons)	ACI 318-08 (Tons)	Nielsen (1984) (Tons)	Schlaich et al. (1987) (Tons)	Mode of Failure
D50	**S0.0**	0.80	2.4	20.000	20.320	20.783	21.675	Flexure
	S5.0	0.80	2.4	18.700	20.055	20.575	21.392	Flexure
	S7.5	0.80	2.4	20.200	20.585	20.989	21.958	Flexure
D60	**S0.0**	0.66	2	26.600	25.167	25.637	26.845	Flexure-Shear
	S5.0	0.66	2	26.100	24.910	25.438	26.571	Flexure-Shear
	S7.5	0.66	2	26.520	24.750	25.312	26.400	Flexure-Shear

Table 7.3.2.2 % difference of $V_{u\ (exp)}$ and $V_{u\ (th)}$ for **PPFRC (MT)**

		a/D	L/D	ACI 318-08	Nielsen (1984)	Schlaich et al. (1987)
D50	**S0.0**	0.80	2.4	1.58	3.77	7.73
	S5.0	0.80	2.4	6.76	9.11	12.59
	S7.5	0.80	2.4	1.87	3.76	8.00
D60	**S0.0**	0.66	2	5.69	3.76	0.91
	S5.0	0.66	2	4.78	2.60	1.77
	S7.5	0.66	2	7.15	4.77	0.46

Table 7.3.3 Comparison of $\mathbf{V_{u\ (exp)}}$ and $\mathbf{V_{u\ (th)}}$ and % difference for **SFRC (FCT)** under two point load

Table 7.3.3.1 Comparison of $V_{u\ (exp)}$ and $V_{u\ (th)}$ for **SFRC (FCT)**

		a/D	L/D	Experimental Result (Tons)	ACI 318-08 (Tons)	Nielsen (1984) (Tons)	Schlaich et al. (1987) (Tons)	Mode of Failure
D50	**S0.0**	0.80	2.4	19.880	20.400	20.845	21.760	Flexure
	S5.0	0.80	2.4	19.550	19.923	20.470	21.251	Flexure
	S7.5	0.80	2.4	19.430	20.267	20.741	21.619	Flexure
D60	**S0.0**	0.66	2	26.950	24.717	25.287	26.365	Flexure-Shear
	S5.0	0.66	2	26.580	24.750	25.312	26.400	Flexure-Shear
	S7.5	0.66	2	26.480	24.428	25.061	26.057	Flexure-Shear

Table 7.3.3.2 % difference of $V_{u\ (exp)}$ and $V_{u\ (th)}$ for **SFRC (FCT)**

		a/D	L/D	ACI 318-08	Nielsen (1984)	Schlaich et al. (1987)
D50	**S0.0**	0.80	2.4	2.55	4.63	8.64
	S5.0	0.80	2.4	1.87	4.49	8.00
	S7.5	0.80	2.4	4.13	6.32	10.12
D60	**S0.0**	0.66	2	9.03	6.57	2.22
	S5.0	0.66	2	7.40	5.01	0.68
	S7.5	0.66	2	8.40	5.66	1.62

Table 7.3.4 Comparison of $V_{u\ (exp)}$ and $V_{u\ (th)}$ and % difference for **PPFRC (FT)** under two point load

Table 7.3.4.1 Comparison of $V_{u\ (exp)}$ and $V_{u\ (th)}$ for **PPFRC (FT)**

		a/D	L/D	Experimental Result (Tons)	ACI 318-08 (Tons)	Nielsen (1984) (Tons)	Schlaich et al. (1987) (Tons)	Mode of Failure
D50	**S0.0**	0.80	2.4	18.700	19.896	20.449	21.223	Flexure
D60	**S0.0**	0.66	2	25.650	24.750	25.312	26.400	Flexure-Shear

Table 7.3.4.2 % difference of $V_{u\ (exp)}$ and $V_{u\ (th)}$ for **PPFRC (FT)**

		a/D	L/D	ACI 318-08	Nielsen (1984)	Schlaich et al. (1987)
D50	**S0.0**	0.80	2.4	6.01	8.55	11.89
D60	**S0.0**	0.66	2	3.64	1.33	2.84

Table 7.3.5 Comparison of $V_{u\ (exp)}$ and $V_{u\ (th)}$ and % difference for **HFRC** under two point load

Table 7.3.5.1 Comparison of $V_{u\ (exp)}$ and $V_{u\ (th)}$ for **HFRC**

		a/D	L/D	Experimental Result (Tons)	ACI 318-08 (Tons)	Nielsen (1984) (Tons)	Schlaich et al. (1987) (Tons)	Mode of Failure
D50	**S0.0**	0.80	2.4	19.900	19.896	20.449	21.223	Flexure
D60	**S0.0**	0.66	2	25.450	24.717	25.287	26.365	Flexure-Shear

Table 7.3.5.2 % difference of $V_{u\,(exp)}$ and $V_{u\,(th)}$ for **HFRC**

		a/D	L/D	ACI 318-08	Nielsen (1984)	Schlaich et al. (1987)
D50	**S0.0**	0.80	2.4	0.02	2.68	6.23
D60	**S0.0**	0.66	2	2.96	0.64	3.47

Table 7.3.6 Comparison of $V_{u\,(exp)}$ and $V_{u\,(th)}$ and % difference for **RCC** under one point load

Table 7.3.6.1 Comparison of $V_{u\,(exp)}$ and $V_{u\,(th)}$ for **RCC**

		a/D	L/D	Experimental Result (Tons)	ACI 318-08 (Tons)	Nielsen (1984) (Tons)	Schlaich et al. (1987) (Tons)	Mode of Failure
D50	**S0.0**	1.2	2.4	18.900	23.199	23.688	24.041	Flexure
D60	**S0.0**	1	2	22.700	29.377	30.049	30.497	Flexure-Shear

Table 7.3.6.2 % difference of $V_{u\,(exp)}$ and $V_{u\,(th)}$ for **RCC**

		a/D	L/D	ACI 318-08	Nielsen (1984)	Schlaich et al. (1987)
D50	**S0.0**	1.2	2.4	18.53	20.21	21.38
D60	**S0.0**	1	2	22.73	24.46	25.57

Table 7.3.7 Comparison of $V_{u\,(exp)}$ and $V_{u\,(th)}$ and % difference for **PPFRC (FT)** under one point load

Table 7.3.7.1 Comparison of $V_{u\,(exp)}$ and $V_{u\,(th)}$ for **PPFRC (FT)**

		a/D	L/D	Experimental Result (Tons)	ACI 318-08 (Tons)	Nielsen (1984) (Tons)	Schlaich et al. (1987) (Tons)	Mode of Failure
D50	**S0.0**	1.2	2.4	13.550	13.543	13.843	14.446	Flexure
	S5.0	1.2	2.4	13.050	13.560	13.856	14.464	Flexure
	S7.5	1.2	2.4	13.350	13.335	13.680	14.224	Flexure
D60	**S0.0**	1	2	20.450	18.106	18.506	19.313	Flexure-Shear
	S5.0	1	2	20.600	18.014	18.435	19.214	Flexure-Shear
	S7.5	1	2	20.750	18.060	18.470	19.264	Flexure-Shear

Table 7.3.7.2 % difference of $V_{u\ (exp)}$ and $V_{u\ (th)}$ for **PPFRC (FT)**

		a/D	L/D	ACI 318-08	Nielsen (1984)	Schlaich et al. (1987)
D50	**S0.0**	1.2	2.4	0.05	2.11	6.20
	S5.0	1.2	2.4	3.76	5.82	9.78
	S7.5	1.2	2.4	0.11	2.41	6.15
D60	**S0.0**	1	2	12.95	10.50	5.89
	S5.0	1	2	14.36	11.75	7.21
	S7.5	1	2	14.90	12.34	7.72

Table 7.3.8 Comparison of $V_{u\ (exp)}$ and $V_{u\ (th)}$ and % difference for **SFRC (CCT)** under one point load

Table 7.3.8.1 Comparison of $V_{u\ (exp)}$ and $V_{u\ (th)}$ for **SFRC (CCT)**

		a/D	L/D	Experimental Result (Tons)	ACI 318-08 (Tons)	Nielsen (1984) (Tons)	Schlaich et al. (1987) (Tons)	Mode of Failure
D50	**S0.0**	1.2	2.4	13.650	13.595	13.883	14.501	Flexure
	S5.0	1.2	2.4	13.450	13.439	13.762	14.335	Flexure
	S7.5	1.2	2.4	13.430	13.491	13.802	14.391	Flexure
D60	**S0.0**	1	2	21.850	18.014	18.435	19.214	Flexure-Shear
	S5.0	1	2	21.380	18.060	18.470	19.264	Flexure-Shear
	S7.5	1	2	21.300	18.129	18.524	19.337	Flexure-Shear

Table 7.3.8.2 % difference of $V_{u\ (exp)}$ and $V_{u\ (th)}$ for **SFRC (CCT)**

		a/D	L/D	ACI 318-08	Nielsen (1984)	Schlaich et al. (1987)
D50	**S0.0**	1.2	2.4	0.40	1.68	5.87
	S5.0	1.2	2.4	0.08	2.27	6.17
	S7.5	1.2	2.4	0.45	2.70	6.67
D60	**S0.0**	1	2	21.30	18.53	13.72
	S5.0	1	2	18.39	15.75	10.99
	S7.5	1	2	17.49	14.98	10.15

Table 7.3.9 Comparison of $V_{u\,(exp)}$ and $V_{u\,(th)}$ and % difference for **PPFRC (MT)** under one point load

Table 7.3.9.1 Comparison of $V_{u\,(exp)}$ and $V_{u\,(th)}$ for **PPFRC (MT)**

		a/D	L/D	Experimental Result (Tons)	ACI 318-08 (Tons)	Nielsen (1984) (Tons)	Schlaich et al. (1987) (Tons)	Mode of Failure
D50	**S0.0**	1.2	2.4	13.250	13.474	13.789	14.372	Flexure
D60	**S0.0**	1	2	21.400	17.991	18.417	19.190	Flexure-Shear

Table 7.3.9.2 % difference of $V_{u\,(exp)}$ and $V_{u\,(th)}$ for **PPFRC (MT)**

		a/D	L/D	ACI 318-08	Nielsen (1984)	Schlaich et al. (1987)
D50	**S0.0**	1.2	2.4	1.66	3.91	7.81
D60	**S0.0**	1	2	18.95	16.20	11.52

Table 7.3.10 Comparison of $V_{u\,(exp)}$ and $V_{u\,(th)}$ and % difference for **HFRC** under one point load

Table 7.3.10.1 Comparison of $V_{u\,(exp)}$ and $V_{u\,(th)}$ for **HFRC**

		a/D	L/D	Experimental Result (Tons)	ACI 318-08 (Tons)	Nielsen (1984) (Tons)	Schlaich et al. (1987) (Tons)	Mode of Failure
D50	**S0.0**	1.2	2.4	13.580	13.456	13.775	14.354	Flexure
D60	**S0.0**	1	2	21.900	18.106	18.506	19.313	Flexure-Shear

Table 7.3.10.2 % difference of $V_{u\,(exp)}$ and $V_{u\,(th)}$ for **HFRC**

		a/D	L/D	ACI 318-08	Nielsen (1984)	Schlaich et al. (1987)
D50	**S0.0**	1.2	2.4	0.92	1.42	5.39
D60	**S0.0**	1	2	20.96	18.34	13.40

Table 7.4 Comparison Of Ultimate Shear Strength And Percentage Difference Of RCC With PPFRC (MT), SFRC (FCT), PPFRC (FT), SFRC (CCT), and HFRC For Same Depth Of Beams

Table 7.4.1 Comparison of $V_{u\,(exp)}$ and $V_{u\,(th)}$ and % difference for D50 beams.

Table 7.4.1.1 Comparison of $V_{u\,(exp)}$ and $V_{u\,(th)}$for D50 beams

D50			a/D	L/D	Experimental Result (Tons)	ACI 318-08 (Tons)	Nielsen (1984) (Tons)	Schlaich et al. (1987) (Tons)
Two Point Load	**RCC**	**S0.0**	1.33	4	23.000	28.065	28.750	29.348
		S5.0	1.33	4	22.750	27.827	28.557	29.094
		S7.5	1.33	4	22.450	27.827	28.557	29.094
	PPFRC (MT)	**S0.0**	1.33	4	20.000	20.320	20.783	21.675
		S5.0	1.33	4	18.700	20.055	20.575	21.392
		S7.5	1.33	4	20.200	20.585	20.989	21.958
	SFRC (FCT)	**S0.0**	1.33	4	19.880	20.400	20.845	21.760
		S5.0	1.33	4	19.550	19.923	20.470	21.251
		S7.5	1.33	4	19.430	20.267	20.741	21.619
	PPFRC (FT)	**S0.0**	1.33	4	18.700	19.896	20.449	21.223
	HFRC (MT + CCT)	**S0.0**	1.33	4	19.900	19.896	20.449	21.223
One Point Load	**RCC**	**S0.0**	2	4	18.900	23.199	23.688	24.041
	PPFRC (FT)	**S0.0**	2	4	13.550	13.543	13.843	14.446
		S5.0	2	4	13.050	13.560	13.856	14.464
		S7.5	2	4	13.350	13.335	13.680	14.224
	SFRC (CCT)	**S0.0**	2	4	13.650	13.595	13.883	14.501
		S5.0	2	4	13.450	13.439	13.762	14.335
		S7.5	2	4	13.430	13.491	13.802	14.391
	PPFRC (MT)	**S0.0**	2	4	13.250	13.474	13.789	14.372
	HFRC (MT + CCT)	**S0.0**	1.33	4	13.580	13.456	13.775	14.354

Table 7.4.1.2 % difference of $V_{u\ (exp)}$ and $V_{u\ (th)}$ for D50 beams

<table>
<tr><th colspan="3">D50</th><th>a/D</th><th>L/D</th><th>ACI 318-08 (Tons)</th><th>Nielsen (1984) (Tons)</th><th>Schlaich et al. (1987) (Tons)</th></tr>
<tr><td rowspan="11">Two Point Load</td><td rowspan="3">RCC</td><td>S0.0</td><td>1.33</td><td>4</td><td>18.05</td><td>20.00</td><td>21.63</td></tr>
<tr><td>S5.0</td><td>1.33</td><td>4</td><td>18.25</td><td>20.34</td><td>21.80</td></tr>
<tr><td>S7.5</td><td>1.33</td><td>4</td><td>19.32</td><td>21.39</td><td>22.84</td></tr>
<tr><td rowspan="3">PPFRC (MT)</td><td>S0.0</td><td>1.33</td><td>4</td><td>1.58</td><td>3.77</td><td>7.73</td></tr>
<tr><td>S5.0</td><td>1.33</td><td>4</td><td>6.76</td><td>9.11</td><td>12.59</td></tr>
<tr><td>S7.5</td><td>1.33</td><td>4</td><td>1.87</td><td>3.76</td><td>8.00</td></tr>
<tr><td rowspan="3">SFRC (FCT)</td><td>S0.0</td><td>1.33</td><td>4</td><td>2.55</td><td>4.63</td><td>8.64</td></tr>
<tr><td>S5.0</td><td>1.33</td><td>4</td><td>1.87</td><td>4.49</td><td>8.00</td></tr>
<tr><td>S7.5</td><td>1.33</td><td>4</td><td>4.13</td><td>6.32</td><td>10.12</td></tr>
<tr><td>PPFRC (FT)</td><td>S0.0</td><td>1.33</td><td>4</td><td>6.01</td><td>8.55</td><td>11.89</td></tr>
<tr><td>HFRC (MT + CCT)</td><td>S0.0</td><td>1.33</td><td>4</td><td>0.02</td><td>2.68</td><td>6.23</td></tr>
<tr><td rowspan="10">One Point Load</td><td>RCC</td><td>S0.0</td><td>2</td><td>4</td><td>18.53</td><td>20.21</td><td>21.38</td></tr>
<tr><td rowspan="3">PPFRC (FT)</td><td>S0.0</td><td>2</td><td>4</td><td>0.05</td><td>2.11</td><td>6.20</td></tr>
<tr><td>S5.0</td><td>2</td><td>4</td><td>3.76</td><td>5.82</td><td>9.78</td></tr>
<tr><td>S7.5</td><td>2</td><td>4</td><td>0.11</td><td>2.41</td><td>6.15</td></tr>
<tr><td rowspan="3">SFRC (CCT)</td><td>S0.0</td><td>2</td><td>4</td><td>0.40</td><td>1.68</td><td>5.87</td></tr>
<tr><td>S5.0</td><td>2</td><td>4</td><td>0.08</td><td>2.27</td><td>6.17</td></tr>
<tr><td>S7.5</td><td>2</td><td>4</td><td>0.45</td><td>2.70</td><td>6.67</td></tr>
<tr><td>PPFRC (MT)</td><td>S0.0</td><td>2</td><td>4</td><td>1.66</td><td>3.91</td><td>7.81</td></tr>
<tr><td>HFRC (MT + CCT)</td><td>S0.0</td><td>1.33</td><td>4</td><td>0.92</td><td>1.42</td><td>5.39</td></tr>
</table>

Table 7.4.2 Comparison of $V_{u\ (exp)}$ and $V_{u\ (th)}$ and % difference for D60 beams.

Table 7.4.2.1 Comparison of $V_{u\ (exp)}$ and $V_{u\ (th)}$ for D60 beams

D60			a/D	L/D	Experimental Result (Tons)	ACI 318-08 (Tons)	Nielsen (1984) (Tons)	Schlaich et al. (1987) (Tons)
Two Point Load	**RCC**	**S0.0**	1.33	4	31.870	33.241	34.137	34.782
		S5.0	1.33	4	26.100	33.241	34.137	34.782
		S7.5	1.33	4	26.520	33.369	34.241	34.919
	PPFRC (MT)	**S0.0**	1.33	4	26.600	25.167	25.637	26.845
		S5.0	1.33	4	26.100	24.910	25.438	26.571
		S7.5	1.33	4	26.520	24.750	25.312	26.400
	SFRC (FCT)	**S0.0**	1.33	4	26.950	24.717	25.287	26.365
		S5.0	1.33	4	26.580	24.750	25.312	26.400
		S7.5	1.33	4	26.480	24.428	25.061	26.057
	PPFRC (FT)	**S0.0**	1.33	4	25.650	24.750	25.312	26.400
	HFRC (MT + CCT)	**S0.0**	1.33	4	25.450	24.717	25.287	26.365
One Point Load	**RCC**	**S0.0**	2	4	22.700	29.377	30.049	30.497
	PPFRC (FT)	**S0.0**	2	4	20.450	18.106	18.506	19.313
		S5.0	2	4	20.600	18.014	18.435	19.214
		S7.5	2	4	20.750	18.060	18.470	19.264
	SFRC (CCT)	**S0.0**	2	4	21.850	18.014	18.435	19.214
		S5.0	2	4	21.380	18.060	18.470	19.264
		S7.5	2	4	21.300	18.129	18.524	19.337
	PPFRC (MT)	**S0.0**	2	4	21.400	17.991	18.417	19.190
	HFRC (MT + CCT)	**S0.0**	1.33	4	21.900	18.106	18.506	19.313

Table 7.4.2.2 % difference of $V_{u\ (exp)}$ and $V_{u\ (th)}$ for D60 beams

D60			a/D	L/D	ACI 318-08 (Tons)	Nielsen (1984) (Tons)	Schlaich et al. (1987) (Tons)
Two Point Load	**RCC**	**S0.0**	1.33	4	4.13	6.64	8.37
		S5.0	1.33	4	21.48	23.54	24.96
		S7.5	1.33	4	20.53	22.55	24.05
	PPFRC (MT)	**S0.0**	1.33	4	5.69	3.76	0.91
		S5.0	1.33	4	4.78	2.60	1.77
		S7.5	1.33	4	7.15	4.77	0.46
	SFRC (FCT)	**S0.0**	1.33	4	9.03	6.57	2.22
		S5.0	1.33	4	7.40	5.01	0.68
		S7.5	1.33	4	8.40	5.66	1.62
	PPFRC (FT)	**S0.0**	1.33	4	3.64	1.33	2.84
	HFRC (MT + CCT)	**S0.0**	1.33	4	2.96	0.64	3.47
One Point Load	**RCC**	**S0.0**	2	4	22.73	24.46	25.57
	PPFRC (FT)	**S0.0**	2	4	12.95	10.50	5.89
		S5.0	2	4	14.36	11.75	7.21
		S7.5	2	4	14.90	12.34	7.72
	SFRC (CCT)	**S0.0**	2	4	21.30	18.53	13.72
		S5.0	2	4	18.39	15.75	10.99
		S7.5	2	4	17.49	14.98	10.15
	PPFRC (MT)	**S0.0**	2	4	18.95	16.20	11.52
	HFRC (MT + CCT)	**S0.0**	1.33	4	20.96	18.34	13.40

CHAPTER-8
DISCUSSION OF TEST RESULTS

8.1 GENERAL

The main aim of present research work is to carry out in-depth comprehensive study of shear strain and cracking characteristics of Fibrous Moderate Deep beam. An attempt is made to predict Ultimate shear load of Fiber Reinforced Concrete Moderate Deep Beams without stirrups using proposed empirical equation and to compare with experimental values. The important objective is to predict the maximum crack width of Fiber Reinforced Concrete Moderate Deep Beams without stirrups using proposed empirical equation and to compare with experimental results of crack width.

In addition to this, various other parameters such as first crack load, ultimate load, crack patterns, crack width profile, shear strain, principal strain, failure mode etc. are studied. The effectiveness of various fibers such as Polypropylene (monofilament type and fibrillated type) and Steel (flat corrugated and circular corrugated type) fibers is studied to replace stirrups in Moderate Deep Beam.

Loading was applied gradually in a regular incremental interval of load. First cracking loads and Ultimate loads were noted. Crack initiation, its occurrence, patterns and propagation and modes of failures were observed. Paths of propagation of cracks were traced by marking with pencil. At the same time the crack tips were marked in corresponding to the applied load at various stages up to failure of the specimen.

Results of experimental values of Ultimate load were tabulated for all FRC beams (PPFRC-MT, PPFRC-FT, SFRC-FCT and SFRC-CCT). The theoretical Ultimate load is calculated using proposed empirical equations and compared with experimental values of Ultimate load **[Table 5.1]**.

Results of experimental values of maximum crack width were tabulated for all FRC beams (PPFRC-MT, PPFRC-FT, SFRC-FCT and SFRC-CCT). The theoretical maximum crack width is calculated using proposed empirical equations and compared with experimental values of maximum crack width **[Table 6.89]**.

8.2 DISCUSSIONS

8.2.1 Effect of L/D Ratio

● From the observations and photographs of tested specimen [**Fig.6.1-6.88 (chapter-6)]** regarding crack width and its patterns it reveals that for the beams having L/D ratio 3 or more (i.e. D30 and D40 series beams), wide and distinct flexure cracks were observed. The predominant crack was observed in the flexure zone leading to flexure failure. Few thin cracks were observed in shear zone of D30 and D40 beam series, which shows that the shear strength is higher than flexural strength in D30 and D40 series beams. For D30 beams, the failures were due to pure flexure. For D40 beams, the failures were due to more flexure and less shear. The first crack load was observed nearly about 45 to 65 % of Ultimate load for D30 and D40 series of beams **[Table group 4.2]**.

● In case of D50 and D60 series beams (L/D ratio less than 3) it was observed from **Fig.6.1-6.88 [chapter-6]**, that predominant crack occurs in shear zone. Flexure cracks were formed prior to shear cracks and flexure cracks were few and thin. In D50 series of beams the shear cracks were comparable to flexural cracks. In D50 series of beams, the failure was due to more shear and less flexure. In D60 series of beams, the failure was pure shear failure because shear cracks were wide and predominant. The first crack load was observed nearly about 38 to 43 % of Ultimate load for D50 and D60 series of beams **[Table group 4.2]**.

● In majority of beams of series D50 and D60; it was observed that the major diagonal shear cracks were formed all of a sudden before Ultimate load. These cracks were initiated by splitting action about 40 to 45% of Ultimate load value. The phenomenon of failure was similar to that of cylinder under diametrical compression [split cylinder test]. The principal tensile strain was formed along the inclined planes. They were formed in the vicinity of diagonal shear crack along the line joining the load and support point. The plots of principal tensile strain **[Fig. 4.39-4.49]** reveal the generation of elliptical pattern of strain distribution. This phenomenon is consistent with the theoretical assumptions made by F.K.KONG [92] and others.

8.2.2 Effect of a/D Ratio

- The shear span (a) to depth (D) ratio has more influence on the shear capacity than span (L) to depth (D) ratio. As a/D ratio increases, the shear capacity of Moderate Deep Beam decreases **[Table group 4.2]**.

- For D30 series of R.C.C. Moderate Deep Beams, as a/D ratio increased by 50% (i.e. a/D ratio from 1.33 to 2.0), the Ultimate shear load capacity was decreased by 15% **[Table 4.6.1]**. For D40 series of R.C.C. Moderate Deep Beams, as a/D ratio increased by 50% (i.e. a/D ratio from 1 to 1.5), the Ultimate shear load capacity was decreased by 40% **[Table 4.6.1]**. For D50 series of R.C.C. Moderate Deep Beams, as a/D ratio increased by 50% (i.e. a/D ratio from 0.8 to 1.2), the Ultimate shear load capacity was decreased by 50% to 60% **[Table 4.6.1].** For D60 series of R.C.C. Moderate Deep Beams, as a/D ratio increased by 50%(i.e. a/D ratio from 0.67 to 1.0), the Ultimate shear load capacity was decreased by 30% to 40% **[Table 4.6.1]**.

In general, for L/D ratio more than 3 of R.C.C. Moderate Deep Beam series *(D30 and D40)*, as a/D ratio increased by 50%, the Ultimate shear load capacity was decreased by 15% to 40% range. For L/D ratio less than 3 of R.C.C. Moderate Deep Beams series *(D50 and D60)*, as a/D ratio increased by 50%, the Ultimate shear load capacity was decreased by 30% to 60% range **[Table group 4.6]**.

- For D30 series of PPFRC (MT) Moderate Deep Beams, as a/D ratio increases by 50% (i.e. a/D ratio from 1.33 to 2.0), the Ultimate shear load capacity was decreased by 10% **[Table 4.6.1]**. For D40 series of PPFRC (MT) Moderate Deep Beams, as a/D ratio increased by 50% (i.e. a/D ratio from 1 to 1.5), the Ultimate shear load capacity was decreased by 40% to 45%. For D50 series of PPFRC (MT) Moderate Deep Beams, as a/D ratio increased by 50% (i.e. a/D ratio from 0.8 to 1.2), the Ultimate shear load capacity was decreased by 35% to 40%. For D60 series of PPFRC (MT) Moderate Deep Beams, as a/D ratio increased by 50% (i.e. a/D ratio from 0.67 to 1.0), the Ultimate shear load capacity was decreased by 35% to 40% **[Table group 4.6.1]**.

In general, for L/D ratio more than 3 of PPFRC (MT) Moderate Deep Beam series (D30 and D40), as a/D ratio increased by 50%, the Ultimate shear load capacity was decreased by 10% to 45% range. For L/D ratio less than 3 of PPFRC (MT) Moderate Deep Beams series (D50 and D60), as a/D ratio increased by 50%, the Ultimate shear load capacity was decreased by 35% to 40% range **[Table group 4.6]**.

- For D30 series of SFRC (FCT & CCT) Moderate Deep Beams, as a/D ratio increased by 50%(i.e. a/D ratio from 1.33 to 2.0), the Ultimate shear load capacity was decreased by 25% to 30%. For D40 series of SFRC (FCT & CCT) Moderate Deep Beams, as a/D ratio increased by 50% (i.e. a/D ratio from 1 to 1.5), the Ultimate shear load capacity is decreased by 45% to 50%. For D50 series of SFRC (FCT & CCT) Moderate Deep Beams, as a/D ratio increased by 50% (i.e. a/D ratio from 0.8 to 1.2), the Ultimate shear load capacity was decreased by 40% TO 45%. For D60 series of SFRC (FCT & CCT) Moderate Deep Beams, as a/D ratio increased by 50% (i.e. a/D ratio from 0.67 to 1.0), the Ultimate shear load capacity was decreased by 30% to 35% **[Table group 4.6]**.

In general, for L/D ratio more than 3 of SFRC (FCT & CCT) Moderate Deep Beam series *(D30 and D40)*, as a/D ratio increased by 50%, the Ultimate shear load capacity was decreased by 25% to 45% range. For L/D ratio less than 3 of SFRC (FCT & CCT) Moderate Deep Beams series (D50 and D60), as a/D ratio increased by 50%, the Ultimate shear load capacity was decreased by 30% to 45% range **[Table group 4.6]**.

- For D30 series of PPFRC (FT) Moderate Deep Beams, as a/D ratio increased by 50% (i.e. a/D ratio from 1.33 to 2.0), the Ultimate shear load capacity was decreased by 30% to 35%. For D40 series of PPFRC (FT) Moderate Deep Beams, as a/D ratio increased by 50% (i.e. a/D ratio from 1 to 1.5), the Ultimate shear load capacity was decreased by 35% to 40%. For D50 series of

PPFRC (FT) Moderate Deep Beams, as a/D ratio increased by 50% (i.e. a/D ratio from 0.8 to 1.2), the Ultimate shear load capacity was decreased by 40% to 45%. For D60 series of PPFRC (FT) Moderate Deep Beams, as a/D ratio increased by 50% (i.e. a/D ratio from 0.67 to 1.0), the Ultimate shear load capacity was decreased by 35% to 40% **[Table group 4.6]**.

In general, for L/D ratio more than 3 of PPFRC (FT) Moderate Deep Beam series (D30 and D40), as a/D ratio increased by 50%, the Ultimate shear load capacity was decreased by 30% to 45% range. For L/D ratio less than 3 of PPFRC (FT) Moderate Deep Beam series (D50 and D60), as a/D ratio increased by 50%, the Ultimate shear load capacity was decreased by 35% to 45% range **[Table group 4.6]**.

- For D30 series of HFRC (MT+CCT) Moderate Deep Beams, as a/D ratio increased by 50% (i.e. a/D ratio from 1.33 to 2.0), the Ultimate shear load capacity was decreased by 15% to 20%. For D40 series of HFRC (MT+CCT) Moderate Deep Beams, as a/D ratio increased by 50% (i.e. a/D ratio from 1 to 1.5), the Ultimate shear load capacity was decreased by 40% to 45%. For D50 series of HFRC (MT+CCT) Moderate Deep Beams, as a/D ratio increased by 50% (i.e. a/D ratio from 0.8 to 1.2), the Ultimate shear load capacity was decreased by 40% to 45%. For D60 series of HFRC (MT+CCT) Moderate Deep Beams, as a/D ratio increased by 50%(i.e. a/D ratio from 0.67 to 1.0), the Ultimate shear load capacity was decreased by 35% to 40% **[Table group 4.6]**.

In general, for L/D ratio more than 3 of HFRC (MT+CCT) Moderate Deep Beam series (D30 and D40), as a/D ratio increased by 50%, the Ultimate shear load capacity was decreased by 15% to 45% range. For L/D ratio less than 3 of HFRC (MT+CCT) Moderate Deep Beams series (D50 and D60), as a/D ratio increased by 50%, the Ultimate shear load capacity was decreased by 35% to 45% range **[Table group 4.6]**.

● It was observed from tested beams **[Fig. 6.1-6.88 (chapter-6)]** that the inclination of predominant crack has been changed from 60°to approximately 45° by increasing a/D ratio 50%.

8.2.3 Effect of Types of Fibers

Steel fibers, Polypropylene fibers and Hybrid (Steel + Polypropylene mix) were used in this research work. Monofilament type (MT) and Fibrillated type (FT) of polypropylene fibers were used. Circular corrugated type (CCT) and Flat corrugated type (FCT) of steel fibers were used. The crack width of RCC beam was decreased due to addition of fibers or Hybrid fibers **[Fig. 6.1-6.88 (chapter–6)]**.

● Ultimate load in Polypropylene Fiber Reinforced Concrete (PPFRC) Moderate Deep Beams without web reinforcements is observed lesser value as compared to Steel Fiber Reinforced Concrete (SFRC) Moderate Deep Beams without web reinforcements **[Table group 4.2]**. This shows that Steel fibers provide more effective resistance to cracking as Steel fibers possesses higher tensile strength and high modulus of elasticity.

● In all Fibrous Moderate Deep Beams without web reinforcements numbers of cracks observed in flexure and shear zone are less compared to RCC moderate deep beams with web reinforcements **[Fig. 6.1-6.88 (chapter–6)]**

● Experimental results reveal that fibers play significant role as crack arrestor and delay in propagation of crack due to random dispersion of fibers throughout the concrete **[Table group 4.2]**.

● Ductility in case of both PPFRC & SFRC Moderate Deep Beams without stirrups decreases as compare to RCC Moderate Deep Beams with stirrups **[Table group 4.2]**. Probably confinement due to web reinforcement is not available in FRC member than RCC member.

- Comparison between PPFRC and SFRC Moderate Deep Beams without stirrups shows that the ductility of SFRC Moderate Deep Beams was found more than PPFRC Moderate Deep Beams **[Table group 4.2]**.

- First cracking load observed higher value by 50 to 70 % in case of both PPFRC & SFRC Moderate Deep Beams without stirrups compared to RCC Moderate Deep Beams without stirrups. This is due to significant role of fibers in bridging and arresting the cracks **[Table group 4.2]**.

- In RCC Moderate Deep Beams diagonal shear cracks developed suddenly at D/3 or D/2 from soffit of beam and reaches towards support point and load point. In Fibrous Moderate Deep Beams also, the diagonal shear cracks starts at height of D/3 or D/2 from soffit of beam and reaches towards support point and load point.

- The area under load deflection curve is nearly 30 % more for RCC with stirrups compared to Fiber Reinforced Beam without stirrups **[Fig. 4.1-4.4]**. This shows that RCC beam with stirrups absorbs more stain energy compared to FRC beams. This may be due to more confinement of the concrete due to stirrups.

8.2.4 Effect of Depth of Strain Measurement

Results stated in **[Table group 4.2]** indicates that the ductility factor for beams of series S 0.0, S 5.0 and S 7.5 were in range of 2 to 8. This reveals that crack must have been propagated through the holes. The release of the stress or stored strain energy at particular point took place because of the presence of holes in the path of propagation. As the depth of strain measurement was more, ductility was reduced comparatively. It was observed that ductility factor has no appreciable influence on the load deflection.

8.2.5 Cost Effectiveness of FRC

It has been observed that Polypropylene fiber is the cheapest material among all other types of fibers **[Appendix-I]**. Although Steel fibers having more strength compared to Polypropylene fibers but cost of Steel fiber used per m^3 of concrete is comparatively very high which may reduce the effective use of SFRC in practical applications. Polypropylene fibers are better than steel fibers in comparison of cost to benefit ratio.

8.2.6 Post Cracking Behavior

No significant increase in load carrying capacity of the beam was observed after first crack in plain concrete beam. While in fibrous concrete beam, significant load carrying capacity of the beam was observed after first crack load. This shows that fibers plays important role in increasing reserved strength of the beam. The large deflection at collapse for fiber reinforced concrete beams indicates the post cracking ductility imparted by the fibers.

8.2.7 Variation of Principal Strain along Inclined Axis

The graphs plotted for the variation of principal tensile strain **[Fig. 4.39-4.49]** along the inclined axes in shear zone show good agreement with the P. J. Robins and F. K. Kong's concept of an elliptical stress pattern along the line joining the load and support point. Graphs were plotted assuming a zero value of principal tensile strain at the top most and bottom most edges of beams. There is minor irregularity in shape of some graphs. This may be due to improper mixing of the material during casting, non-homogeneity of material due to non-uniform distribution of fibers etc.

8.2.8 Variation of Shear Stain With Respect To Depth of Beam

The graphs plotted for the variation of shear strain **[Fig. 4.5- 4.38]** at top surface and at in-depth surface along the vertical axes in shear zone show D shape of strain distribution. This is in good agreement with the theoretical shear stress distribution of parabolic nature along the vertical axes of the beam. In this case also, graphs were plotted assuming zero shear strain value at the top most and bottom most edges of the beams. There is minor irregularity in shape of some graphs. This may be due to improper mixing of the material during casting, non-homogeneity of material due to non-uniform distribution of fibers etc.

8.2.9 Comparison of Ultimate Shear Strength of Fibrous Moderate Deep Beams (Without Stirrups) With R.C.C. Moderate Deep Beams (With Stirrups)

The following observations were noted regarding the comparison of Average Ultimate shear strength of Fibrous Moderate Deep Beams (without stirrups) with R.C.C. Moderate Deep Beams (with stirrups) **[Table group 4.7]**.

- For a/D ratio 1.33 to 0.67 the Ultimate shear strength in PPFRC (MT) Moderate Deep Beams without web reinforcements is nearly 80% to 90% of the RCC Moderate Deep Beams with web reinforcements **[Table 4.7.1.1]**.
- For a/D ratio 1.33 to 0.67 the Ultimate shear strength in SFRC (FCT) Moderate Deep Beams without web reinforcements is nearly 75% to 90% of the RCC Moderate Deep Beams with web reinforcements **[Table 4.7.1.1]**.
- For a/D ratio 1.33 to 0.67 the Ultimate shear strength in PPFRC (FT) Moderate Deep Beams without web reinforcements is nearly 75% to 90% of the RCC Moderate Deep Beams with web reinforcements **[Table 4.7.1.1]**.
- For a/D ratio 1.33 to 0.67 the Ultimate shear strength in HFRC (MT+CCT) Moderate Deep Beams without web reinforcements is nearly 75% to 90% of the RCC Moderate Deep Beams with web reinforcements **[Table 4.7.1.1]**.
- For a/D ratio 2.00 to 1.00 the Ultimate shear strength in PPFRC (MT) Moderate Deep Beams without web reinforcements is nearly 95% of the RCC moderate deep beams with web reinforcements **[Table 4.7.1.2]**.
- For a/D ratio 2.00 to 1.00 the Ultimate shear strength in SFRC (CCT) Moderate Deep Beams without web reinforcements is nearly 95% of the RCC Moderate Deep Beams with web reinforcements **[Table 4.7.1.2]**.

- For a/D ratio 2.00 to 1.00 the Ultimate shear strength in PPFRC (FT) Moderate Deep Beams without web reinforcements is nearly 95% of the RCC Moderate Deep Beams with web reinforcements **[Table 4.7.1.2]**.
- For a/D ratio 2.00 to 1.00 the Ultimate shear strength in HFRC (MT+CCT) Moderate Deep Beams without web reinforcements is nearly 90 % of the RCC Moderate Deep Beams with web reinforcements **[Table 4.7.1.2]**.

8.2.10 Comparison of Ultimate Shear Strength of Fibrous Moderate Deep Beams With R.C.C. Moderate Deep Beams (without Stirrups)

The following observations were noted regarding the comparison of average Ultimate Shear Strength of Fibrous Moderate Deep Beams (without stirrups) with R.C.C. Moderate Deep Beams (without stirrups) **[Table group 4.8]**.

- For a/D ratio 1.33 to 0.67 the Ultimate shear strength in PPFRC (MT) Moderate Deep Beams without web reinforcements is nearly 73% more than that of the RCC Moderate Deep Beams without web reinforcements **[Table 4.8.1.1]**.
- For a/D ratio 1.33 to 0.67 the Ultimate shear strength in SFRC (CCT) Moderate Deep Beams without web reinforcements is nearly 75% more than that of the RCC Moderate Deep Beams without web reinforcements **[Table 4.8.1.1]**.
- For a/D ratio 1.33 to 0.67 the Ultimate shear strength in PPFRC (FT) moderate deep beams without web reinforcements is nearly 68% more than that of the RCC Moderate Deep Beams without web reinforcements **[Table 4.8.1.1]**.
- For a/D ratio 1.33 to 0.67 the Ultimate shear strength in HFRC (MT+CCT) Moderate Deep Beams without web reinforcements is nearly 70% more than that of the RCC Moderate Deep Beams without web reinforcements **[Table 4.8.1.1]**.
- For a/D ratio 2.00 to 1.00 the Ultimate shear strength in PPFRC (MT) moderate deep beams without web reinforcements is nearly 81% more than

that of the RCC Moderate Deep Beams without web reinforcements **[Table 4.8.1.2]**.

● For a/D ratio 2.00 to 1.00 the Ultimate shear strength in SFRC (FCT) Moderate Deep Beams without web reinforcements is nearly 81% more than of the RCC Moderate Deep Beams without web reinforcements **[Table 4.8.1.2]**.

● For a/D ratio 2.00 to 1.00 the Ultimate shear strength in PPFRC (FT) Moderate Deep Beams without web reinforcements is nearly 73% more than that of the RCC Moderate Deep Beams without web reinforcements **[Table 4.8.1.2]**.

● For a/D ratio 2.00 to 1.00 the Ultimate shear strength in HFRC (MT+CCT) Moderate Deep Beams without web reinforcements is nearly 79% more than that of the RCC Moderate Deep Beams without web reinforcements **[Table 4.8.1.2]**.

● Shear resistance offered by Fibrous Moderate Deep Beams without stirrups is nearly 30 % more for beam having a/D ratio less than 1.5 than for the beam having a/D ratio more than 1.5 **[Table group 4.8]**.

CHAPTER-9
SUMMARY AND CONCLUSIONS

9.1 SUMMARY

In the present investigation, in-depth comprehensive study was made regarding the distribution and variation of shear strain along the vertical axis of the beam. The aim of the investigation is to provide a systematic and comprehensive study on the cracking characteristics with respect to crack width & crack patterns in Fiber Reinforced Cement Concrete Moderate Deep Beams. In course of investigations, three empirical equations are proposed to estimate the shear strength of Fibrous Moderate Deep Beams using different types of fibers. Also, five empirical equations are proposed to calculate the maximum crack width of Fibrous Moderate Deep Beams.

9.2 CONCLUSIONS

9.2.1. For the beams having L/D ratio 3 or more (i.e.D30 and D40 series beams), the predominant failure is flexure failure in flexure zone. In all these beams cracks were initiated in flexure zone and failed due to predominant flexure crack in flexure zone. Minor thin shear cracks were developed but not extended further even due to increase in load.

In case of beams having L/D ratio less than 3 (i.e. D50 and D60 series), the predominant failure is shear failure in shear zone. Examining the photographs of tested beams it was found that initially few cracks were developed in pure moment zone. Later, the diagonal tensile crack was developed at a distance of about D/2 to D/3 from soffit in shear span with the increase of load further. The diagonal crack started extending both ways towards loading point and support point. It was also observed that no flexural cracks were developed further. These diagonal cracks so formed were nearly parallel to each other with a “strut like” appearance between the loading points. The indication of “strut like” appearance was observed in beam of series D50 and D60. Diagonal compression failure was observed with an inclined crack developed along the line joining the load and support point which is followed by second parallel crack after a small increase in load. Failure is due to destruction of concrete strut between these cracks. It is observed during testing that shear failure in D50 and D60 series of beams is always initiated by splitting action, this phenomenon of failure being similar to that of cylinder under diametrical compression i.e. Brazilian split test.

9.2.2. For a/D ratio less than 1.5, R.C.C. beams with stirrups provide little more shear resistance than Fibrous Moderate Deep Beams without stirrups and for a/D ratio more than 1.5; shear resistance of Fibrous Moderate Deep Beams without stirrups is nearly same as the R.C.C. Moderate Deep Beams with stirrups. This shows that stirrups (conventional shear reinforcement) may be effectively partially replaced by fibers with proper design **[Table group 4.6].**

9.2.3. On comparison of the variation of strain at varying depth, it can be concluded that no significant strain variation is observed at depth 0.0 to 75 mm from outer surface of beam.

9.2.4. Steel fibers are relatively expensive. Polypropylene fibers are better than Steel fibers in comparison of cost to benefit ratio as well as rusting **[appendix-I]**.

9.2.5. The large deflection at collapse in Fiber Reinforced Concrete beams indicates the post cracking ductility imparted is due to the fibers. In all the fibrous concrete beams, deflections are reduced at any given load level compared to those of a beam which does not contain the fibers. Right from the beginning of the loading, these deformational characteristics are influenced by the fibers. Due to presence of fibers it is concluded such modifications results in less wide cracks, lower deflection. It is concluded all these desired improvements are obtained due to inclusion of fibers in the concrete.

9.2.6. The graphical presentations for the variation of principal tensile strain **[Fig. 4.39-4.49]** along the inclined axes in shear zone show good agreement with the P. J. Robins and F. K. Kong’s concept of an elliptical stress pattern along the line joining the load and support point. From the results, it can be established that the incorporation of fibers increases the tensile cracking strain of plain concrete. The result also shows that fibers played significant role in controlling the first cracking of composite.

9.2.7. The graphical presentations for the variation of shear strain **[Fig. 4.5-4.38]** at top surface and at in-depth surface along the vertical axes in shear zone show D shape of strain distribution. This is in good agreement with the theoretical shear stress distribution of parabolic nature along the vertical axes of the beam.

9.2.8. By the detailed analysis and from the results presented in the previous chapter, it can be concluded that fibers are better option compare to the conventional web reinforcement (i.e. stirrups) to resist shear. At the beam-column junctions where more shear reinforcement is required, fibers can be the best alternatives to avoid congestion of reinforcement along with crack arresting mechanism. It is also logically concluded that the fibers may be the partial replacement of web reinforcement (stirrups).

9.2.9. Steel fibers helps in strength enhancement of concrete beams, Polypropylene fibers helps in strain enhancement of concrete beams and Hybrid fibers (Steel and Polypropylene fibers combined) helps in both strength and strain enhancement.

9.2.10. The proposed empirical equations to estimate Ultimate Shear Strength of Fibrous Moderate Deep Beam gives satisfactory and reliable result. From the **Table 5.1** it is concluded that with a few exceptions, the computed shear capacity agrees fairly well with the observed value of shear loads.

9.2.11. The proposed empirical equations to estimate maximum crack width of Fibrous Moderate Deep Beam gives satisfactory and reliable result. From the **Table 6.89** it is concluded that with a few exceptions, the computed maximum crack width agrees fairly well with the observed value of crack width.

9.2.12. After careful observation of photographs of the tested beams **[Fig.6.1-6.88 (Chapter-6)]**, it is concluded that the crack patterns in the Fibrous Moderate Deep Beam depend more on shear span to depth (a/D) ratio rather than on span to depth (L/D) ratio.

9.2.13. Use of Steel fiber arrests Macro-cracks in the concrete, whereas use of Polypropylene fiber arrests Micro-crack. From the results, it is inferred that Fibrous Beams shows good strain energy absorption and ductile nature of failure before collapse.

9.2.14. It may be suggestive that the Ultimate shear strength of Fibrous Moderate Deep Beams without web reinforcements (stirrups) is 70 to 75 % more than that of the RCC Moderate Deep Beams without web reinforcements **[Table group 4.8]**. It may be concluded that shear reinforcement in the form of stirrups can be effectively partially replaced by fibers with proper design.

From the limited extent of this work, the findings arising out of this study would find practical applications in the field of Civil and Structural Engineering.

9.3 SUGGESTIONS

The following suggestions should be adopted to get good result of tested beams:

- Proper mixing and compaction should be done to avoid honey combing in concrete.
- Leveling of beams should be done properly to avoid unsymmetrical loading.
- Use admixture to get proper workability.
- Add 10% to 15% grit in concrete mix to get homogeneous concrete.
- Use needle vibrator to get proper compaction.

9.4 SCOPE FOR THE FUTURE WORK

- Investigation can be extended on Polypropylene fiber and/or Steel fiber for different volume proportions of fibers.
- Wide scope for analysis of shear deformational behavior of Moderate Deep Beams by FEM using linear or non-linear approach.
- Investigation can further be extended for Moderate Deep Beams for Hybrid FRC for different volume proportions of fibers.
- Effect of variation of a/D ratio can also be analyzed with changed fiber types.
- Investigation can be extended for high strength Moderate Deep beam using various fibers.
- Effect of fibers on Pre-stressed concrete Moderate Deep Beam can be studied in detail.

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APPENDIX-I

COST COMPARISION

❖ GENERAL DESCRIPTION:

Cost is an important factor when research work is implemented in actual practice. In current work, the cost of various types of fibers are compared with the cost of conventional shear reinforcement i.e. stirrups. Below mentioned Table is useful in cost comparison of various types of fibers.

Type of Beam	*Type of shear reinforcement*	*Quantity required per M^3*	*Rate*	*Amount per M^3*
R.C.C (W/S)	8 mm stirrups	97.89 Kg	45 per Kg	4405/-
PPFRC (MT)	Monofilament Polypropylene Fibers	6.83 Kg	360 per Kg	2460/-
SFRC (FCT)	Flat Corrugated Steel Fibers	78.46 Kg	64 per Kg	5021/-
PPFRC (FT)	Fibrillated Polypropylene Fibers	6.83 Kg	444 per Kg	3035/-
SFRC (CCT)	Circular Corrugated Steel Fibers	78.46 Kg	60 per Kg	4707/-
HFRC (MT+CCT)	Monofilament Polypropylene Fibers	3.42 Kg	360 per Kg	3585/-
	Circular Corrugated Steel Fibers	39.23 Kg	60 per Kg	

APPENDIX-II

SAMPLE CALCULATION OF SHEAR STRAIN

❖ SAMPLE CALCULATION OF SHEAR STRAIN FOR PPFRC (FT) 2P D50 S 0.0

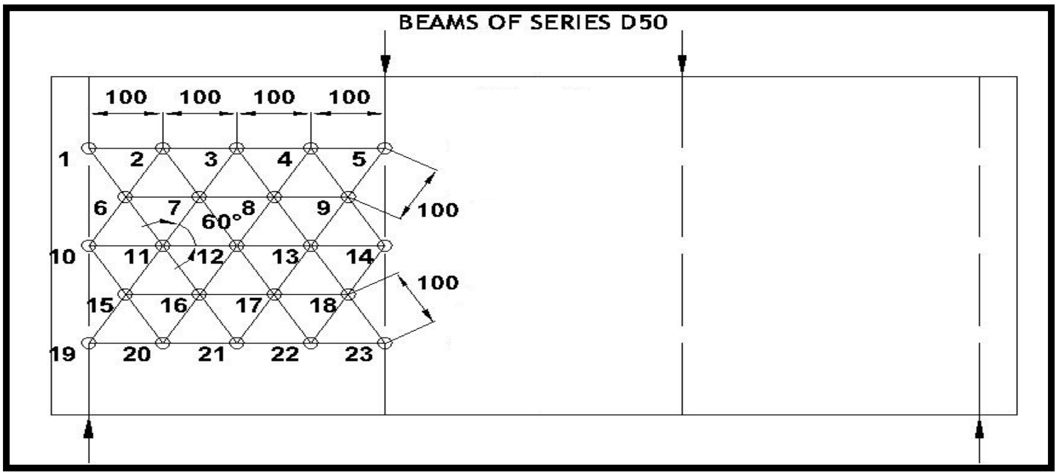


Fig. A.1 Demec Target Arrangement For Beam Of Series D50 2P

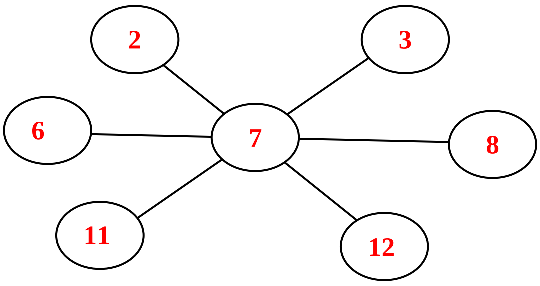


Fig. A.2 Demec points incorporated for calculating stress at Demec target No. 7

Extensometer reading at Demec target No. 7 for load 18 tone given below.

Extensometer reading	IR	FR	Diff.	δl
2-12	125	98	18	0.18
3-11	379	406	-18	-0.18
6-8	174	147	-24	0.24

The corresponding strain is,

Strain= $^{change\ in\ length}/_{original\ length}$ = $^{\delta L}/_{L}$

ϵ_A = 0.27/200 = -0.0009

ϵ_B = -0.27/200 = 0.0009

ϵ_C = 0.27/200 =- 0.00120

Calculate principal strain:

$$\epsilon_{1,}\epsilon_2 = \frac{1}{3}(\epsilon_A + \epsilon_B + \epsilon_C) \pm \frac{\sqrt{2}}{3}\sqrt{(\epsilon_A - \epsilon_B)^2 + (\epsilon_B - \epsilon_C)^2 + (\epsilon_C - \epsilon_A)^2}$$

ϵ_1 = 0.00135

ϵ_2 = -0.00225

Calculate principal stress:

$$\sigma_{1,}\sigma_2 = E\left\{\frac{1}{3(1-\mu)}(\epsilon_A + \epsilon_B + \epsilon_C) \pm \frac{\sqrt{2}}{3(1+\mu)}\sqrt{(\epsilon_A - \epsilon_B)^2 + (\epsilon_B - \epsilon_C)^2 + (\epsilon_C - \epsilon_A)^2}\right\}$$

***E* =** 5000 **=**22.36 x 10^3 N/mm^2

= 0.2

$_1$ = 13.26 N/mm^2

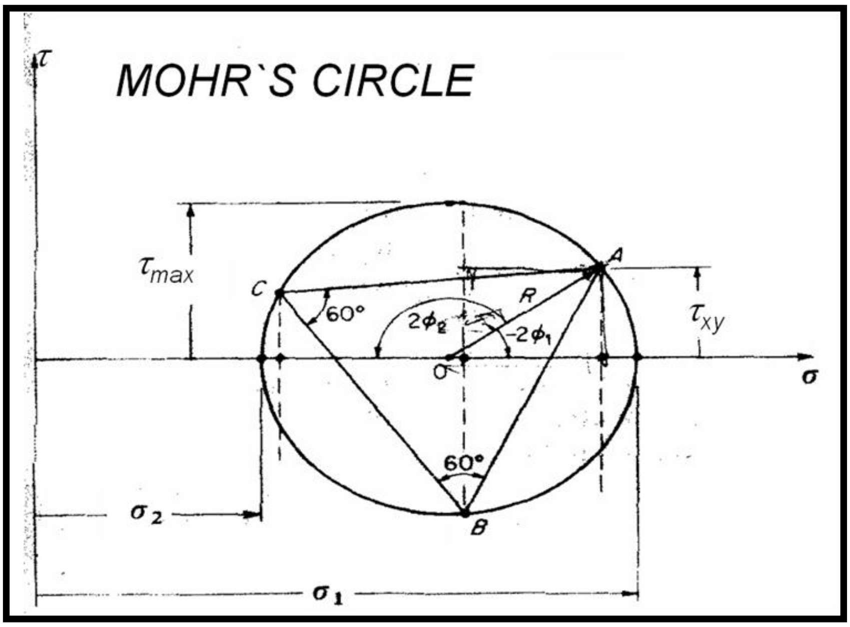
$_2$ = -35.61N/mm^2

fck = 20 N/mm^2

Calculate maximum shear stress:

ζ_{max} = ($_1$ - $_2$) / 2 = 23.43 N/mm^2

From Mohr's circle calculate shear stress ζ_{xy}:



ζ_{xy} = *2.28 N/mm²*

Calculate shear strain:

$$\gamma_{xy} = \frac{2\sqrt{3}}{3}(\epsilon_C - \epsilon_B)$$

$_{xy}$= -0.003117

❖ **Method for calculating strain on vertical axis by using delta rosette:**

Sample calculation for PPFRC (FT) 2P D50 S 0.0 on vertical axis 2-11-20 at 18.0 tone load:

To calculate strain on verticle axis 2-11-20 consider trianlges 1-3-11, 2-10-12, 10-12-20, 11-19-22.

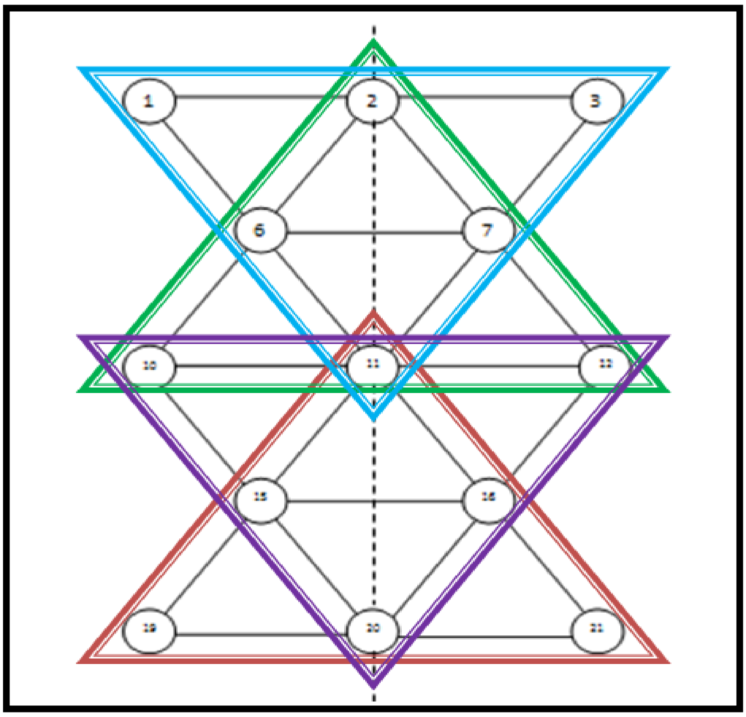
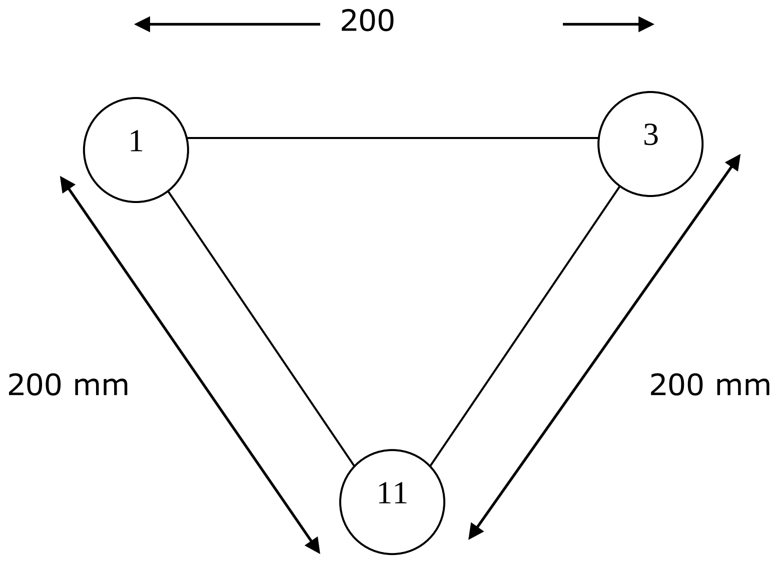


Fig. A.3 Triangles incorporated to calculate strain onvertical axis 2-11-20

Now for triangle 1-3-11,



Take Initial and Final reading of extensometer for demec target 1-3, 3-11, 1-11.

Now, the corresponding strain can be calculated by the equation,

Strain= $^{change\ in\ length}/_{original\ length}$ = $^{\delta L}/_{L}$

ϵ_A = -0.18/200 = -0.0009

ϵ_B = 0.18/200 = 0.0009

ϵ_C = -0.24/200 = -0.0012

Now the strain for triangle 1-3-11 can be calculated by using the equation,

$$\gamma_{xy} = \frac{2\sqrt{3}}{3}(\epsilon_C - \epsilon_B)$$

$_{xy}$ — = -0.0024

This strain is at the C.G. of the triangle 1-3-11.

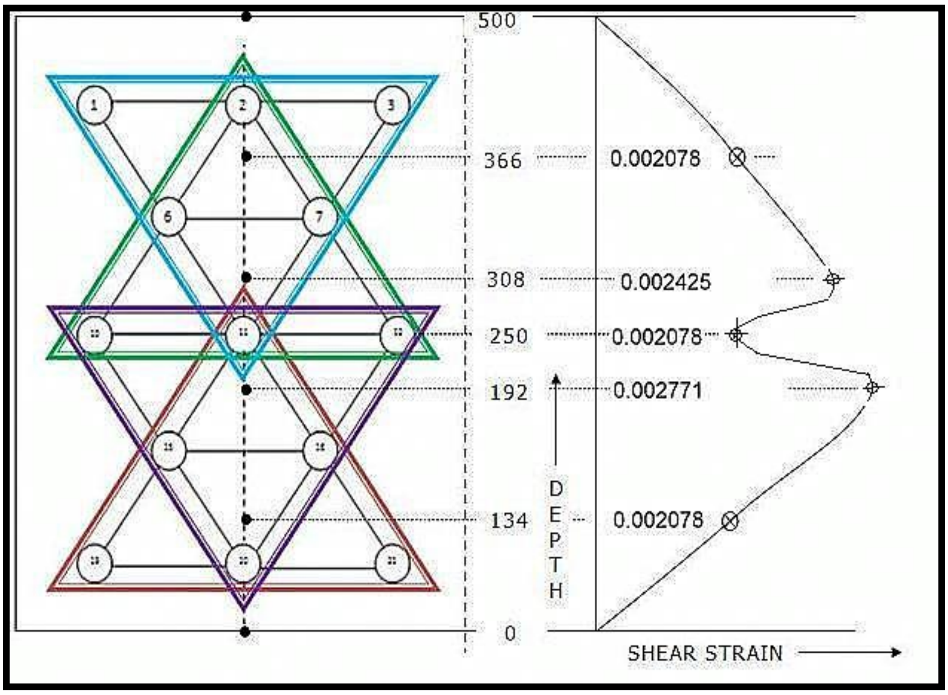


Fig. A.4 Shear strain distribution diagram along 2-11-20

Now, similarly calculate strain for triangle 2-10-12, 10-12-20, 11-19-22, and plot it at c.g of triangle.

Using this methodology we can calculate strain on other vertical axes like 3-12-21 and 4-13-22.

Similarly for calculating strain on inclined axes like 7-11-15, 8-12-16, 9-13-17; we can follow the same procedure as we discussed above in sample calculation for PPFRC (FT) 2P D50 S 0.0 for load 18.0 tone, but for inclined axis we are going to plot the graph berween Depth along inclined axis vs. Principal tensile strain (ϵ_1 & ϵ_2).

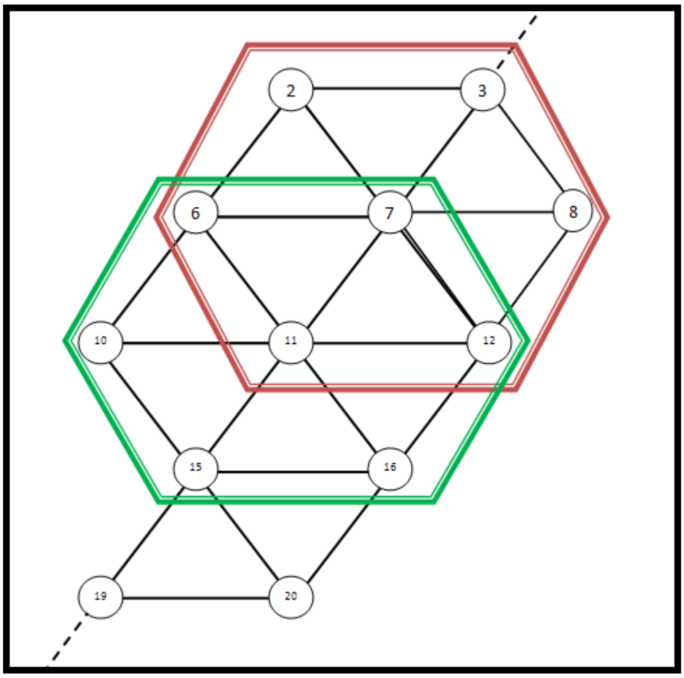


Fig. A.5 Demec points incorporated to calculate principal strain on inclined axis 7-11-15

APPENDIX-III

SAMPLE CALCULATION OF ULTIMATE SHEAR STRENGTH

(I)SAMPLE CALCULATION OF ULTIMATE SHEAR STRENGTH USING PROPOSED EMPIRICAL EQUATION OF POLYPROPYLENE FIBER REINFORCED MODERATE DEEP BEAMS WITHOUT WEB REINFORCEMENT

Sample of calculation for ultimate shear strength for **PPFRC (FT) 2P D40** is given below.

$$\mathbf{Vu = Vu_c + Vu_{ppfrc}}$$

Where,

V_u =Ultimate Shear load carrying capacity of PPFRC moderate beam in Ton.

Vu_c = shear resistance offered by concrete in Ton

Vu_{ppfrc} =shear resistance offered by polypropylene fibers in Ton

$Vu_c = (\tau_C \ B \ d) \ 10^{-4} = 2.376$ T

Where,

τ_C = Design shear strength of concrete, as per Is:456-2000 in N/mm^2 = 0.440 N/mm^2

B = Width of beam in mm= 150 mm

d = effective depth of beam in mm=360 mm

— – – +1.412

= 7.971 T

Where,

D = overall depth of beam in mm = 400 mm

b = width of beam in mm = 150 mm

a/D = shear span to depth ratio = 1.0

v_f =Volume of fibers in cm^3 = 585 cm^3

F_{crf} = modulus of rupture of concrete. = $0.7*(F_{cuf})^{½}$ in N/mm^2 = 4.76 N/mm^2

F_{cuf} = Average cube compressive strength in N/mm^2 = 46.16 N/mm^2

A_{st} = Area of longitudinal tensile reinforcement in mm^2 = 226.19 mm^2

d = effective depth of beam in mm = 360 mm

F = fiber factor = 1.021

L = length of beam in mm = 1200 mm

F_{spf} =Average split cylinder strength in N/mm^2 = 3.89 N/mm^2

= 1.021

Where,

F = fiber factor

ρ_f = fiber density in kg/m^3 = 910 Kg/m^3

l_f = length of fiber in Meter = 0.038 m

β = bond factor = 1.0(1.0 for indented fibers;0.75 for semicircular fibers; 0.50 for circular fibers).

d_f = denier of fiber/1000 = 0.006

$Vu = Vu_c + Vu_{ppfrc}$ = 10.35 T

(II) SAMPLE CALCULATION OF ULTIMATE SHEAR STRENGTH USING PROPOSED EMPIRICAL EQUATION OF STEEL FIBER REINFORCED MODERATE DEEP BEAMS WITHOUT WEB REINFORCEMENT

Sample of calculation for ultimate shear strength for **SFRC (CCT) 1P D60** is given below.

Vu = Vuc+ Vusfrc

Where,

Vu = Total ultimate load carrying capacity of SFRC moderate beam in Ton.

Vu_c = Shear resistance offered by concrete in Ton

Vu_{sfrc} = Shear resistance offered by steel fibers in Ton

$Vu_c = (\tau C \;\; B \;\; d\;) \; 10^{-4}$= 3.612 T

Where,

τ_C = Design shear strength of concrete as per IS:456-2000 in N/mm^2 = 0.430 N/mm^2

B = Width of beam in mm = 150 mm

d = Effective depth of beam in mm = 560 mm

+1.168

= 20.62 T

Where,

D = Overall depth of beam in mm= 600 mm

b = Width of beam in mm= 150 mm

a/D = Shear span to depth ratio = 1.0

V_f =Volume of fibers in cm^3 = 877.5 cm^3

F_{crf} = Modulus of rupture for concrete. = 0.7*(Fcuf) ^{½} in N/mm^2= 4.44 N/mm^2

F_{cuf} = Average cube compressive strength in N/mm^2= 40.32 N/mm^2

A_{st} = Area of longitudinal tensile reinforcement in mm^2=339.29mm^2

d = Effective depth of beam in mm= 560 mm

F = Fiber factor= 1.023

L = Length of beam in mm. = 1200 mm

F_{spf} = Average split cylinder strength in N/mm^2= 3.93 N/mm^2

= 1.023

Where,

F = Fiber factor

ρ_f = Fiber density in kg/m^3 = 7850 Kg/m^3

l_f = Length of fiber in Meter = 0.036 M

β = Bond factor= 0.5

(1.0 for indented fibers; 0.75 for semicircular fibers; 0.50 for circular fibers).

d_f = Diameter of fiber in mm /1000 = 0.0045 M

Vu = Vuc + Vusfrc = 24.23 T

(III) SAMPLE CALCULATION FOR ULTIMATE SHEAR STRENGTH USING PROPOSED EMPIRICAL EQUATIONS OF HYBRID FIBER REINFORCED MODERATE DEEP BEAMS WITHOUT WEB REINFORCEMENT

Sample of calculation for ultimate shear strength for **HFRC (MT+CCT) 2P D50** is given below.

$Vu = Vu_c + [Vu_{ppfrc} + Vu_{sfrc}]$

Where,

Vu =Total ultimate load carrying capacity of HFRC moderate beam in Ton.

Vu_c = Shear resistance offered by concrete in Ton.

Vu_{ppfrc} = Shear resistance offered by polypropylene fibers in Ton

Vu_{sfrc} = Shear resistance offered by steel fibers in Ton

$Vu_c = (\tau_C \ B \ d\ ) 10^{-4} = 2.760$ T

Where,

τ_C = Design shear strength of concrete as per IS:456-2000 in N/mm^2 = 0.400 N/mm²

B = Width of beam in mm = 150 mm

d = Effective depth of beam in mm = 460 mm

Vu_{ppfrc} =to be calculated as below

Vu_{sfrc} = to be calculated as below

— – – +1.412

= 13.04 T

Where,

D = overall depth of beam in mm = 400 mm

b = width of beam in mm = 150 mm

a/D = shear span to depth ratio = 1.0

v_f =Volume of fibers in cm^3 = 585 CM^3

F_{crf} = modulus of rupture of concrete. = $0.7*(Fcuf)^{½}$ in N/mm^2 = 4.76 N/mm²

F_{cuf} = Average cube compressive strength in N/mm^2 = 46.16 N/mm²

A_{st} = Area of longitudinal tensile reinforcement in mm^2 = 226.19 mm²

d = effective depth of beam in mm = 360 mm

F = fiber factor = 1.021

L = length of beam in mm = 1200 mm

F_{spf} =Average split cylinder strength in N/mm^2 = 3.89 N/mm²

= 1.021

Where,

F = fiber factor

ρ_f = fiber density in kg/m^3 = 910 Kg/m³

l_f = length of fiber in Meter = 0.038 M

β = bond factor = 1.0

(1.0 for indented fibres;0.75 for semicircular fibers; 0.50 for circular fibers).

d_f = denier of fiber/1000 = 0.006

— – – +1.168

= 13.30 T

Where,

D = Overall depth of beam in mm= 600 mm

b = Width of beam in mm= 150 mm

a/D = Shear span to depth ratio = 1.0

V_f =Volume of fibers in cm^3 = 877.5 cm^3

F_{crf} = Modulus of rupture for concrete. = 0.7*(Fcuf) ^{½} in N/mm^2= 4.44 N/mm^2

F_{cuf} = Average cube compressive strength in N/mm^2= 40.32 N/mm^2

A_{st} = Area of longitudinal tensile reinforcement in mm^2 =339.29mm^2

d = Effective depth of beam in mm= 560 mm

F = Fiber factor= 1.023

L = Length of beam in mm. = 1200 mm

F_{spf} = Average split cylinder strength in N/mm^2= 3.93 N/mm^2

= 1.023

Where,

F = Fiber factor

ρ_f = Fiber density in kg/m^3 = 7850 Kg/m^3

l_f = Length of fiber in Meter = 0.036 M

β = Bond factor= 0.5

(1.0 for indented fibers; 0.75 for semicircular fibers; 0.50 for circular fibers).

d_f = Diameter of fiber in mm /1000 = 0.0045 M

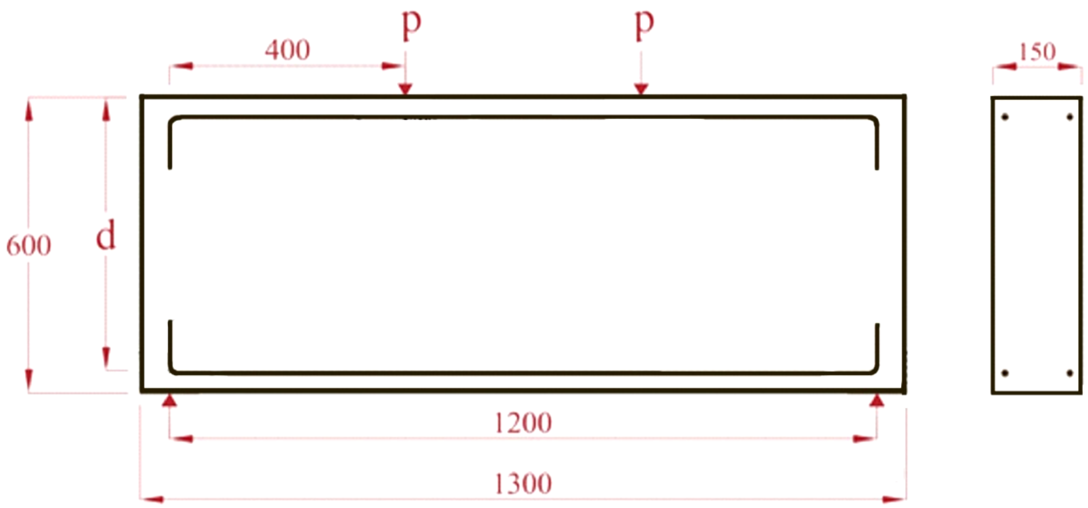
Vu = Vu_c+ –[Vuppfrc+Vu_{sfrc}] = 2.76 + 0.5[13.04+13.30] =15.93 T

APPENDIX-IV

SAMPLE CACULATION FOR CRACK WIDTH

EXAMPLE OF PPFRC (MT) FIBROUS MODERATE DEEP BEAM WITHOUT STIRRUPS

To calculate maximum crack width for PPFRC (MT) of D60 S 0.0 series Beam for given data.



Given Data:-

Clear span	L	= 1200mm
Width of beam	B	= 150 mm
Depth of beam	D	= 600 mm
Dia. of bars	Φ	= 12 mm
Nos. of bars (Main Steel)	n	= 3 Nos.
Clear cover to main steel	d_c	= 25mm
Ultimate load (P)		= 53.2 T
Shear span	L	= 400 mm
Yield strength of steel	f_y	= 415 N/mm^2

Calculation:-

Step 1: Calculate maximum crack width parameters For PPFRC (MT)

W_{max}=(——— x F_{be}xf_xx B x ———) +6.46

FIBER FACTOR:

F_{MT}

Where,
F_{MT} = fiber factor
ρ_f = 910 kg/m^3.
l_f = 0.012
β = 500
d_f =0.00600denier
V_f =0.75%
F_{MT}

1.0529

Area of steel:

339.29 mm^2

B=Ratio of distances to the neutral axis from the extreme beam bottom level and from the centroid of longitudinal bars.

d'= Effective concrete cover= 25+5= 30 MM

B= (X_u / X_u–d')

= (300/300-30)

=1.11

Bending stress

f_x –

f_x

23.64 N/mm^2

Maximum Crack width:

W_{max} ——————x F_{be} x f_xx B x ————)+6.46

W_{max} (——————x1x23.64x1.11x ————) +6.46

=6.97 mm

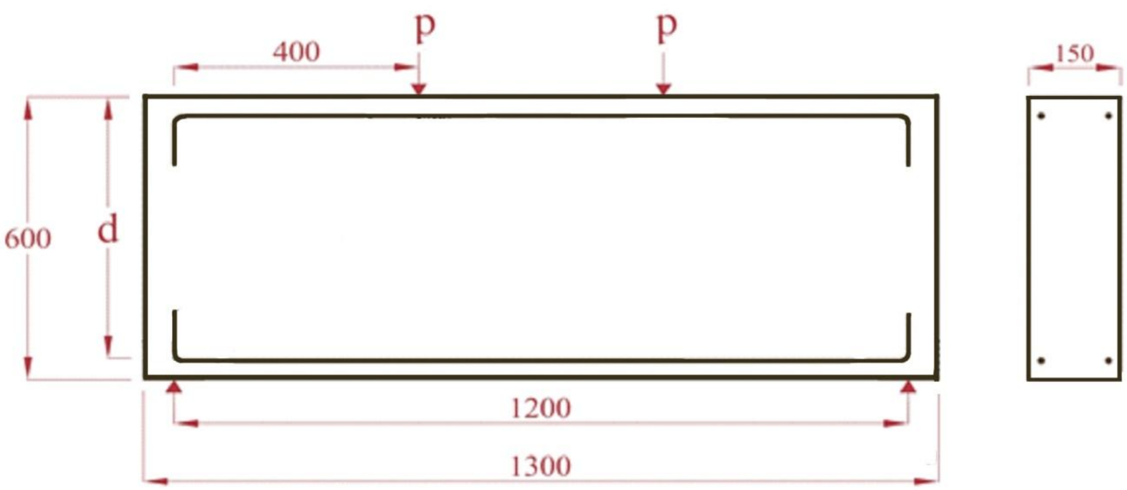
% Errors (EXP. – THEO.)/ (THEO.)*100

(7.1–6.97)/6.97)*100

1.9%.

EXAMPLE OF SFRC (FCT) FIBROUS MODERATE DEEP BEAM WITHOUT STIRRUPS

To calculate maximum crack width for SFRC (FCT) of D60 S 0.0 series beam for given data.



Given Data:-

Clear span *L* = 1200mm

Width of beam	b	=	150 mm
Depth of beam	D	=	600 mm
Dia. of bars	Φ	=	12 mm
Nos. of bars (Main Steel)	n	=	3 Nos.
Clear cover to main steel	d_c	=	30 mm
Ultimate load(P)		=	53.9 T
Shear span	L	=	400 mm
Yield strength of steel	f_y	=	415 N/mm^2

Calculation:-

Step 1: Calculate maximum crack width parameters using equation (4) for SFRC (FCT)

$$W_{max}=(\quad \text{x } F_{be} \text{ x } f_x \text{ x } B \text{ x } \quad) +10.662$$

FIBER FACTOR:

F_{FCT}

Where,
F_{FCT} = fiber factor
ρ_f = 9750 kg/m^3.
l_f = 0.050
β = 750
d_f =0.00063 mt.
V_f =1%
F_{FCT}
=
= 1.008

Area of steel:

339.29 mm^2

B Ratio of distances to the neutral axis from the extreme beam bottom level and from the centroid of longitudinal bars.

B $(X_u / X_u - d')$

(300/300-30)

1.11

Bending stress

f_x –

23.96 N/mm^2

W_{max}=(x F_{be} x f_xx B x) +10.662

W_{max} (x 1x 23.96 x 1.11x) +10.662

10.86 mm

% error (Exp. – Theo.)/(Theo.)*100

(9.2-10.85)/ (10.85)*100

-15.21 %

APPENDIX-V

RESEARCH PAPERS PUBLISHED/PRESENTED

INTERNATIONAL JOURNAL (9)

1) Vinu R. Patel and I. I. Pandya: "Micromechanical Measurement of Concrete Strain to evaluate principlal strain distribution in Steel Fiber Reinforced Cement Concrete Moderate deep Beams across its width and depths" International Journal of Applied Engineering Research, Dindigul, volume 1, no.2, October-2010. ISSN: 0976-4259.

2) Vinu R. Patel, Atul Bansal and Dr. I. I. Pandya: "Shear strength of steel fiber reinforced concrete moderate deep beams without stirrups", American Society of Civil Engineers-IS section, pp.6-10, August-2010.

3) Vinu R. Patel and Dr. I. I. Pandya and Sandeep C. Patel: "Prediction of Shear Strength of PPFRC Moderate Deep Beams Using Strut-and-Tie Models", International Journal of Engineering research and Applications (IJERA),vol.1, issue 2, pp.149-152, Jul-Aug-2011. ISNN: 2248-9662.

4) Vinu R. Patel and Dr. I. I. Pandya: "Comparative study of shear capacity of RCC with Fibrous Moderate Deep beams", International Journal of Earth Science and Engineering (IJEE), ISSN-0974-5904 (Indexed in Scopus Compendex and Geobase (products hosted on Engineering Village) Elsevier, Amsterdam, Netherlands, Chemical Abstract Services-USA, Geo-Ref Information Services-USA) published by Cafet-Innova Technical Society, Hyderabad, June-2012.

5) Vinu R. Patel and Dr. I. I. Pandya: "Evaluation of shear strength of SFRC Moderate deep beams using Strut-and Tie Models", International Journal of Modern Engineering and research (IJMER), Vol.1, Issue.1, pp. 15-20, Sep-Oct-2011.

6) Vinu R. Patel, Bhavin Mojidra and Dr. I. I. Pandya: "Ultimate shear strength of fibrous moderate deep beams without stirrups", International Journal of Engineering Research and Development, volume.1, no.1, May-2012, ISSN: 2278-067X.

7) Vinu R. Patel, Nikunj S. Darji and Dr. I. I. Pandya: "Experimental Study of cracking behavior for SFRC beams without stirrups with varying a/D ratio", International Journal of Engineering Research and Development, volume.1, no.2, May-2012, ISSN: 2278-067X.

8) Vinu R. Patel and Dr. I. I. Pandya: "Ultimate shear strength of fibrous moderate deep beams without stirrups", International Journal of Applied Science and Engineering Research, volume 1, No.1, May-2012, ISSN: 2277-94

9) Vinu R. Patel and I. I. Pandya: "Evaluation of Shear Strain Distribution In Polypropylene Fiber Reinforced Cement Concrete Moderate Deep Beams" International Journal of Civil and Structural Engineering, Volume.1, No.3, 2010, ISSN: 0976-4399

NATIONAL JOURNAL (4)

10) Vinu R. Patel, Ankur Rana and Dr. I. I. Pandya: "Shear Strength of Polypropylene Fiber Reinforced Concrete Moderate Deep Beams without Stirrups", Journal of Structural Engineering, SERC, CHENNAI, Vol.37, No.5, Dec-2010, pp.364-368, Jan-2011.

11) Vinu R. Patel, Dr. I. I. Pandya and Niraj C. Joshi : "Micro mechanical measurement of concrete strain to evaluate principal strain distribution in RCC moderate deep beams across its width and depths", Journal of Indian Concrete Institute, Chennai (under communication).

12) Vinu R. Patel, Dr. I. I. Pandya and Niraj C. Joshi: "Evaluation of shear strain distribution in reinforced cement concrete moderate deep beams", The Indian Concrete Journal, Bombay(under communication).

13) Vinu R. Patel, Dr. I. I. Pandya and Hitendra B. Solanki: "Cracking Behavior of PPFRC Beams without stirrups with varying shear span by depth ratio" at The Indian Journal of Technical Education, Special issue of the first national conference in the Emerging Vistas of Technology in 21st Century, organized by Gujarat Technological University, Ahmedabad, ISSN: 0971-3034, April-2012.

INTERNATIONAL CONFERENCE (4)

14) Vinu R. Patel, Atul Bansal and Dr. I. I. Pandya: "Study of Crack Patterns, Crack width profile and Modes of failure for SFRC Moderate deep beams " , International conference on emerging Trends in Engineering ICETE-2010, Dr. J.J. Magdum College of Engineering, Kolhapur, Feb-2010.

15) Vinu R. Patel, Desai Niraj and I.I. Pandya: "Study of Crack Patterns and Modes of Failure of RCC Moderate Deep Beams", International conference on Materials, Mechanics and Management (IMMM -2010), The college of Engineering, Trivandrum 695016, Kerala, India,14-16 January-2010.

16) Vinu R. Patel and I. I. Pandya: "Evaluation of Shear Strain Distribution In Polypropylene Fiber Reinforced Cement Concrete Moderate Deep Beams" International Conference on current Trends in Technology (NUiCONE-2010), Nirma University, Ahmedabad, 9–11 December-2010.

17) I. I. Pandya and V. R. Patel: "Comparative Study of Cracking Behavior and Modes of Failure for RCC and SFRC Moderate Deep Beams ", ICIWSE-2010-Interantaional Conference on Innovative World of Structural Engineering, Govt. College of Engineering, Aurangabad, Maharashtra, India, 17-19 September-2010.

NATIONAL CONFERENCE (4)

18) Vinu R. Patel, Rana Ankur and Dr. I. I. Pandya: "Study of Crack Patterns, Crack width profile and Modes of failure for PPFRC Moderate deep beams ", National conference CRDCE-10, 21-22 Jan-2010, SVIT, VASAD.

19) Vinu R. Patel and Dr. I. I. Pandya: "Comparative Study of Cracking behavior and modes of failure for PPFRC and SFRC Moderate Deep Beams", National Conference on Fly ash/Futuristic Materials in Civil Engineering Construction For Sustainable Development, BVM, V.Vidyanagar, 12 August-2010.

20) V.R. Patel and I. I. Pandya: "Experimental Study of Cracking Behavior and Modes of Failure for RCC and Fibrous Moderate Deep Beams", Department of Civil and Structural Engineering, Annamalai University, Annamalainagar, Tamil Nadu, India. The Seventh Structural Engineering Convention, 8-10 December-2010.

21) V. R. Patel, Dr. I. I. Pandya and Sandeep Patel: "Prediction of shear strength of SFRC moderate deep beams using strut-and-tie models", National conference on Fibre Reinforced Concrete Global Developments", Nagpur, 13-14 February-2012.

APPENDIX-VI

ANSWER OF COMMENTS

Comment-1:

In literature review chapter, candidate has reviewed the reference restricting to Deep beams. He should highlight to Moderate Deep Beams.

Comment-2:

Chapter 2 lacks strong links with each reviewed papers and consolidated critical analysis. Summary of critical observation at the end of review would have set up the perfect platform for the identification of clear objective and scope of the work. Candidate can include these sections

Answer of comments-1 and 2:

To identify the clear objective of present research work and its scope, we have summarized and reviewed the critical observations of some of the researchers/investigators are as under. The summary will provide perfect platform for carried out research work in the area of Deep beams and Moderate Deep beams.

It was observed that the major research work was carried out to determine the shear capacity with and without stirrup using various types of fibers namely steel fibers and polypropylene fibers. Some of the research work was carried out with specific objective of a/D ratio in the range of 0.5 to 4 along with L/D ratio in the range of 1 to 6. The distinct demarcation between Deep

Beam and Moderate Deep beam was partially reflected in earlier research work published by researchers namely Narayan, Darwish, Kukreja, Ashour etc.

The critical observations and conclusions drawn by different researcher have suggested the critical behavior of beam for a/D ratio less than 1.0 and L/D ratio less than 2.0. As per cracking patterns & Modes of failure, they have concluded that such beams are shear predominant members. Few research works carried out by researchers namely Ghosh, Kameshwarrao, Sachan, Nemkumar banthia have highlighted that a/D greater than 2.0 or L/D greater than 6.0 are failing in flexural mode which were identified as flexural predominant members. Most of cracks were observed in the zone of maximum moment leading to flexural failure of the beams. Very few researchers have carried out research in the range of a/D ratio 1 to 2.5 and L/D ratio between 2 to 6, where they have observed the combined mode of failure i.e. flexural and shear both. Such variation was observed due to complex mechanism of transfer of stresses with respect to a/D and L/D ratio.

To generate the clear understanding of this complex behavior, in the present research work, the critical observations related to shear parameters in Moderate Deep beams using steel and Polypropylene fibers was carried out. The nomenclature of the beams having a/D ratio 1 to 2.5 and L/D ratio 2 to 6 are generalized as Moderate Deep Beams. Due to complex behavior in this range and to set up a perfect platform of understanding, the flexural & shear capacity of such section were evaluated as per their modes of failure.

As per track proven research, Steel fibers play vital role in enhancement of strength. Considering the strength aspect, we have added optimum volume of fibers as 1% by volume of concrete in our research work as suggested by Swami, Kukreja etc. We have also considered the significant role of Polypropylene fibers which impart the strain enhancement by transferring stresses and providing good control over cracking. Due to less density of Polypropylene fibers, we have reduced volume of Polypropylene fibers from 1% to 0.75% which can allow appropriate mixing and compaction in the given volume of concrete. In the present research work, we have focused the strength and strain enhancement concept as an innovative hybrid combination looking to the present need of structural members having effectiveness of fibers towards strength and strain both hence we have adopted this hybrid combination of steel and polypropylene fibers.

Comment-3:

In chapter 3, candidate has not clearly justified the reason of selecting the Polypropylene fiber, Steel fiber and hybridization of these fibers for the present study. Also, rationale behind selecting proportioning of these fibers also not clearly discussed. Discuss the same.

Answer of comment-3:

The justification for Steel and Polypropylene fibers was highlighted in detail in chapter-01 page no. 7 art. 1.3 in very distinct manner indicated and incorporated with clear objective and scope of work. To avoid repetition of matter again and again, it was not included in chapter 3.

Comment-4:

Provide motivation selecting the Reinforced Concrete design explained in Figure 3.8:

Answer of comment 4:

In RCC members when depth is large, it leads to under reinforced section hence minimum steel will satisfy all major requirements. The minimum % of steel is 0.204 for Fe 415 as per IS 456. As per above provision, we have provided flexural steel in section. Addition of more steel in flexure need not enhance any more shear strength. The effective utilization of steel may not be achieved. As per past investigation of researcher, flexural reinforcement will not have direct impact on shear strength of section. Therefore it is more prudent to provide the minimum reinforcement in the beam for range of a/D from 1 to 2.5 or L/D ratio between 2 to 6. As per conventional practice of RCC design, we have adopted quantity of the reinforcement in the present investigation. The range of a/D and L/D ratio reflects the shear predominance of the member. This range of members will fail under shear only. By considering shear aspect we have provided minimum reinforcement in flexure in our test specimens of the present investigation.

Comment-5:

In chapter 4, Figures from 4.1 to 4.4 should be separated for 1P and 2P cases and give observations based on the same. Also compare the results for 1P and 2P cases from the symmetric measurement point of view and comment on the same.

Answer of comment 5:

Our objective was to make a comparison between 1P and 2P in the same graph for same size of specimen. Such combined graphs provide better understanding and reflects strength aspect with respect to relative volume of fibers. The relative increase or decrease in strength can be observed in one stroke only. As desired and suggested by examiner, we have prepared separate graphs (fig 4.1 to fig 4.4) for 1P and 2P with incorporation of suggested comments as additional graphs.

Comment-6:

Chapter 4 represents large number of tables and figures towards presentation and comparison of test results. But it does not represent extremely critical analysis also comparative study of the observations from the present study with reference to other reported results in literature. Candidate's major contribution will be if he provides striking observation based on these vast results.

Answer of comment 6:

During our research work, we have considered concept and philosophy suggested by F K Kong and P J Robbins i.e. the concept of elliptical stress pattern between load and support point as a major axis and other as minor axis. The shear strain distribution along vertical axis is resembled to theoretical stress distribution of D shape. The striking observation and appropriate comparisons of various parameters of the study is provided in the conclusion part and not in chapter 2. We have followed the pattern of most of published research papers of researchers. We have discussed our critical observations of analysis and comparative study with respect to a/D ratio, L/D ratio and % of fibers clearly and distinctly in chapter 8 (page 277 to 288).

Comment-7

For section 5.3 to 5.5 what was the inspiration or background of proposing the equations?

Answer of comment 7:

The inspiration of proposing equation was from the fundamental basic equation i.e. Vu= Vuc+ Vus which is purely applicable for RCC beams. Vuc represents resistance offered by concrete. Vus represents shear resistance offered by stirrups. In the present investigation, as we have added fibers in the concrete, we have added new parameter as Vufrc to account the contribution made by fibers towards shear resistance. Looking to this additional parameter the fundamental equation is modified by considering all material properties. Thus the final equation considered as

Vu= Vuc+ Vus + Vufrc in the present investigation.

Comment-8:

Plot the results given in Tables 5.1/6.89 in scatter form and give the correlation coefficient.

Answer of comment 8:

The correlation coefficient was generated using Regression analysis which is well known statistical methods for finding constants in the condition of large random variables method to identify unknown constant. As desired by examiner, we have provided the separate table of our observation on page no. 167 to 168. To have clear understanding, we have added the graphs for indicating generation of correlation coefficient constant in various condition of L/D and a/D with and without stirrups using steel and polypropylene fibers.

Comment-9:

For the Table 5.1/6.89, provide error results separately for 1P and 2P in absolute form. Also comment why in some cases it has positive or negative results?

Answer of comment 9:

As per comment, the tables related to crack width are also modified in the separate table and graphs are plotted on page no. 258 to 259.

Comment-10:

Comment for the table given in section 7.2, where in some cases present study results are extremely far or close with reference to other case. What are the reasons?

Answer of comment 10:

Section 7.2 summarizes all test results in the wide range of a/D and L/D ratio. The upper range falling under shear predominant condition where STM provides theoretical values of load in the close range of Experimental results. For beams having more value of a/D and L/D, STM do not provide close range of theoretical to experimental result. It reflects limitation of Model, which can be justified looking to the modes of failures and crack pattern in the members.

Comment-11:

Candidate must provide comprehensive design guidelines for the designer base on the systematically carried out experimental studies in the thesis.

Answer of comment 11:

For the suggestion of comprehensive guidelines, the chapter-5 i.e. analytical formulation provides substantial guidelines in the thesis; Chapter 5 highlights the guideline for the design engineer to design Moderate Deep Beams by incorporating suggested parameters. In Chapter 5, an attempt is made to provide systematic methodology to evaluate the theoretical load carrying capacity which can be compared with the experimental test results as per practical aspect of the construction.