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,

<table>
<thead>
<tr>
<th>Shallow Beams</th>
<th>• L/D ≥ 6.0 OR a/D &gt; 2.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderate Deep Beams</td>
<td>• 2.0 &lt; L/D &lt; 6.0 OR 1.0 &lt; a/D &lt; 2.5</td>
</tr>
<tr>
<td>Deep Beams</td>
<td>• 0.5 &lt; L/D ≤ 2.0 OR a/D &lt; 1.0</td>
</tr>
</tbody>
</table>
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\textsuperscript{[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>
<thead>
<tr>
<th>Fiber Type</th>
<th>Equivalent Diameter (µm)</th>
<th>Relative Density</th>
<th>Tensile Strength (MPa)</th>
<th>Elastic Modulus (GPa)</th>
<th>Ultimate Elongation (%)</th>
<th>Ignition Temperature (°C)</th>
<th>Melt, Oxidation Or Decomposition Temp (°C)</th>
<th>Water Absorption Per ASTM D 570, % By Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acrylic</td>
<td>13-104</td>
<td>1.16-1.18</td>
<td>270-1000</td>
<td>14-19</td>
<td>7.5-50.0</td>
<td>-</td>
<td>220-235</td>
<td>1.0-2.5</td>
</tr>
<tr>
<td>Aramid I</td>
<td>12</td>
<td>1.44</td>
<td>2900</td>
<td>60</td>
<td>4.4</td>
<td>High</td>
<td>480</td>
<td>4.3</td>
</tr>
<tr>
<td>Aramid II</td>
<td>10</td>
<td>1.44</td>
<td>2350</td>
<td>115</td>
<td>2.5</td>
<td>High</td>
<td>480</td>
<td>1.2</td>
</tr>
<tr>
<td>Carbon, PAN HM</td>
<td>8</td>
<td>1.6-1.7</td>
<td>2500-3000</td>
<td>380</td>
<td>0.5-0.7</td>
<td>High</td>
<td>400</td>
<td>NIL</td>
</tr>
<tr>
<td>Carbon, PAN HT</td>
<td>9</td>
<td>1.6-1.7</td>
<td>3450-4000</td>
<td>230</td>
<td>1.0-1.5</td>
<td>High</td>
<td>400</td>
<td>NIL</td>
</tr>
<tr>
<td>Carbon, Pitch GP</td>
<td>10-13</td>
<td>1.6-1.7</td>
<td>480-420</td>
<td>27.35</td>
<td>2.0-2.4</td>
<td>High</td>
<td>400</td>
<td>03.07</td>
</tr>
<tr>
<td>Carbon, Pitch GPh</td>
<td>9-18</td>
<td>1.8-2.15</td>
<td>1500-3100</td>
<td>150-480</td>
<td>0.5-1.1</td>
<td>High</td>
<td>500</td>
<td>NIL</td>
</tr>
<tr>
<td>Nylon</td>
<td>23</td>
<td>1.14</td>
<td>970</td>
<td>5</td>
<td>20</td>
<td>-</td>
<td>200-220</td>
<td>2.8-5.0</td>
</tr>
<tr>
<td>Polyester</td>
<td>20</td>
<td>1.34-1.39</td>
<td>230-1100</td>
<td>50</td>
<td>17</td>
<td>12-150</td>
<td>600</td>
<td>260</td>
</tr>
<tr>
<td>Polyethylene</td>
<td>90</td>
<td>0.02-0.096</td>
<td>75-590</td>
<td>5</td>
<td>3-80</td>
<td>-</td>
<td>130</td>
<td>NIL</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>90</td>
<td>0.90-0.91</td>
<td>140-700</td>
<td>3.5-4.8</td>
<td>15</td>
<td>600</td>
<td>165</td>
<td>NIL</td>
</tr>
</tbody>
</table>

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.

![Berry Type Mechanical Strain Gauge](image)

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.