1. INTRODUCTION

1.1 GENERAL INTRODUCTION

A horizontal structural member can bear the load, especially by resisting flexure bending, is called Beam. Bending occurs due to the external load, self-weight. In Beam span, external load and reactions are prominent. Generally, The Beams are classified into three categories Namely Shallow Beam, Moderate Deep Beam, and Deep Beam. As per IS: 456-2000[1]*(page no.51, clause no. 29.1)* a beam shall be define as a Deep Beam when the ratio of effective span to overall depth, l/D is less than:

1. 2.0 for a simply supported beam; and
2. 2.5 for a continuous beam

The beam can be classified according to their span to depth ratio (l/D) and shear span to depth ratio (a/D) in three categories,

1. Shallow beam : $l/D \geq 6.0$ *or* $a/D > 2.5$
2. Moderate Deep beam : $2.0 < l/D < 6.0$ *or* $1.0 < a/D < 2.5$
3. Deep beam : $0.5 < l/D \leq 2.0$ *or* $a/D < 1$

1.1.1 Shallow Beam

Shallow Beams are characterized by linear strain distribution and most of the applied load is transferred through a uniform compression field. Generally, the Analysis of shallow beams is based on Pure Bending Theory with the assumption that plane sections normal to the axis remain plane after bending. The stress distribution across the section is almost linear. Shallow beams are assumed as linear element as to resist transverse loading mainly by bending and shear. In beam it develops Bending and Shear stresses. Normal pressure has a negligible effect on the stress distribution. Generally shallow Beams fails under pure flexure failure. It has very low flexure strength as compared to shear strength.

1.1.2 Moderate Deep Beam

Moderate Deep beam differs from shallow beams considerably. Flexure strength is equivalent to shear strength or almost equal in case of Moderate Deep Beams. The moderate deep beams generally fail in flexure-shear failure. This type of beams is transition between Shallow and Deep Beams concerning all its properties related to its structural behavior under applied loading. As the beam become shorter or deeper the stress distribution becomes non-linear with the tensile stresses concentrating towards the bottom of the beam. The stress at mid span deviate more and more from those predicted by the Simple Bending Theory.

1.1.3 Deep Beam

Deep Beams are structural elements with small span to Depth ratio. The beam is loaded and supported by reactions. In Beam concrete considered as a strut and steel reinforcement as ties using strut and tie approach. As a result, the strain distribution is no longer considered linear, and the shear deformations become significant compared to pure flexure.

1.2 BEHAVIOR OF DEEP BEAM

The elementary Theory of simple Bending may not be applicable to Deep beam. A remarkable difference can be observed in Deep Beam and Shallow Beam is strain distribution along the section. Non-linearity in strain distribution leads to Strut and Tie method for designing of Deep beams. The Strut and Tie method (STM) are lower bound solution approach for capacity that is recognized as an important tool for Design of non-linear beams (deep beams), since it considers the member capacity as a function of $^{a}/_{D}$. The Deep Beam fails as Shear Failure.

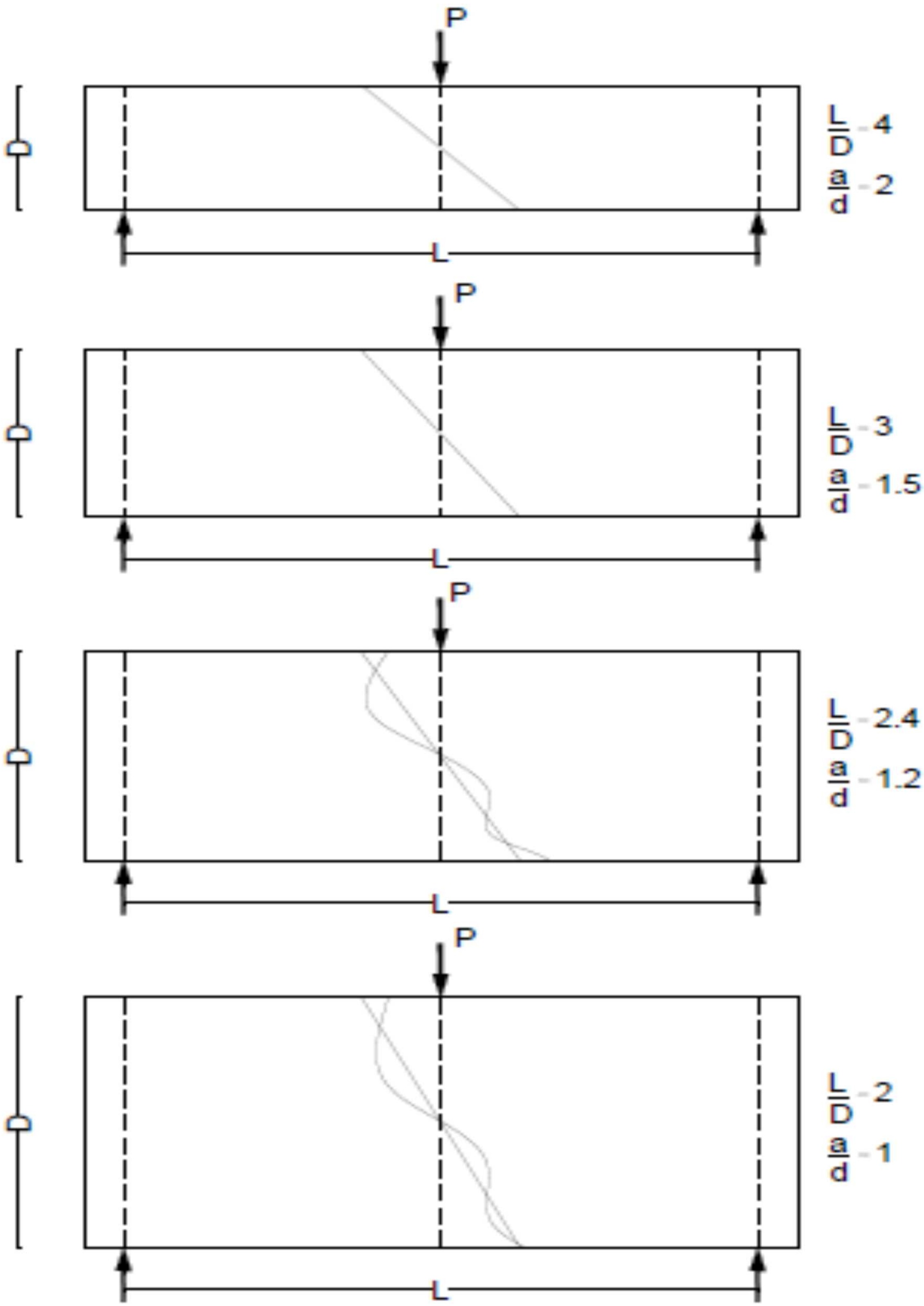

Figure 1-1 Nomenclature of Moderate deep beam having different l/D ratio

1.3 HISTORY OF REINFORCED CONCRETE AND FIBER REINFORCED CONCRETE (FRC)

1.3.1 History of Reinforced Concrete

In 1824 Joseph Aspdin invented Portland cement by burning finally ground chalk and clay material. In 1849, A French gardener by name Joseph Monier first invented the Reinforced concrete. Reinforced concrete can be used to produce foundation, columns, beams, and frames etc. Reinforcement materials have excellent bonding characteristic, high tensile strength, and good thermal compatibility. A perfect bond develops between concrete and steel due to grip on the surrounding surface of the reinforcement. The load transmits from concrete to steel by its bonding property of concrete with the Reinforcement. Thus, the same magnitude of strain occurs in concrete and reinforcement.

1.3.2 History of Fiber Reinforced Concrete

Unremitting evolvement in construction material and demands for High strength, Crack resistant and Lighter concrete resulted in development of Fiber reinforced concrete. Types of Fibers are steel, nylon, asbestos, glass, carbon, sisal, jute, coir and polypropylene etc. The practice of adding certain fibers to construction material used back to the ancient times. When horsehair, straws were used to strengthen the bricks. In 1911 Porter found that fiber could be used in concrete to increase the strength.

1.4 FIBROUS CONCRETE

Plain Portland cement concrete is a brittle material. The concrete is strong in compression and weak in tension because of its brittle nature. Development of Tensile crack in plain concrete occur very soon leads to failure. In presence of reinforcement, the tensile stresses resisted by the reinforcement. Reinforcement is ductile material it delays the failure of the concrete member under heavy load. Further the deflection reduces by incorporating the fibers. Fiber stands as an alternative to increase the load carrying capacity of concrete in tension. By incorporating the fibers in a cement matrix leads to an increase in the Toughness tensile strength, Resistance of cracking and Deformation characteristics of the concrete.

1.4.1 Necessity of Fiber Reinforced Concrete (FRC)

The use of concrete as a structural material is limited to certain extent due to deficiencies like Brittleness, Poor Tensile Strength, and poor resistance to Impact strength, Fatigue, low Ductility and low durability. It is also very much limited to receive Dynamic stresses caused due to explosions.

The Brittleness in Concrete structural member can be controlled by introducing reinforcement (or) pre-stressing steel in the tensile zone. However, it does not improve the basic property of concrete. The main problems of low tensile strength in concrete. By adding different types of reinforcing materials improve the tensile strength of concrete. Further concrete is also deficient in ductility, resistance to fatigue and impact load. The improvement in the requisite characteristics of concrete will solve the structural problems in structural engineers by the addition of fibers and admixtures.

The role of fibers is essentially to arrest any advancing cracks by applying punching forces at the rack tips, thus delay their propagation across the concrete matrix. The Ultimate cracking strain of the composite material increased to many times greater than that of unreinforced matrix. Admixtures like fly ash, silica fume, granulated blast furnace slag and metakaolin can be used for such purposes. However, addition of fibers and mineral admixtures possess certain problems regarding mixing, as fibers tends to form balls nesting resulted into reduction in workability during mixing.

1.4.2 Behavior of Fiber in Concrete

Fibers contribute towards reducing the bleeding in fresh concrete and renders concrete more impermeable in the hardened stage. Contribution of certain percentage of fibers in concrete towards flexural strength is smaller compared to the strength given by rebars. Most importantly fibers restrict the growth of crack under load thereby arresting ultimate cracking. Nonmetallic fibers like alkali resistant glass fiber and synthetic fibers provide resistance against chemicals. Reinforcing capacity of fiber is based on length of fiber, diameter of fiber, the percentage of fiber and condition of mixing, orientation of fibers and aspect ratio. Aspect ratio is ratio of length of fiber to its diameter which plays an important role in the process of reinforcement.

1.5 TYPES OF FIBERS

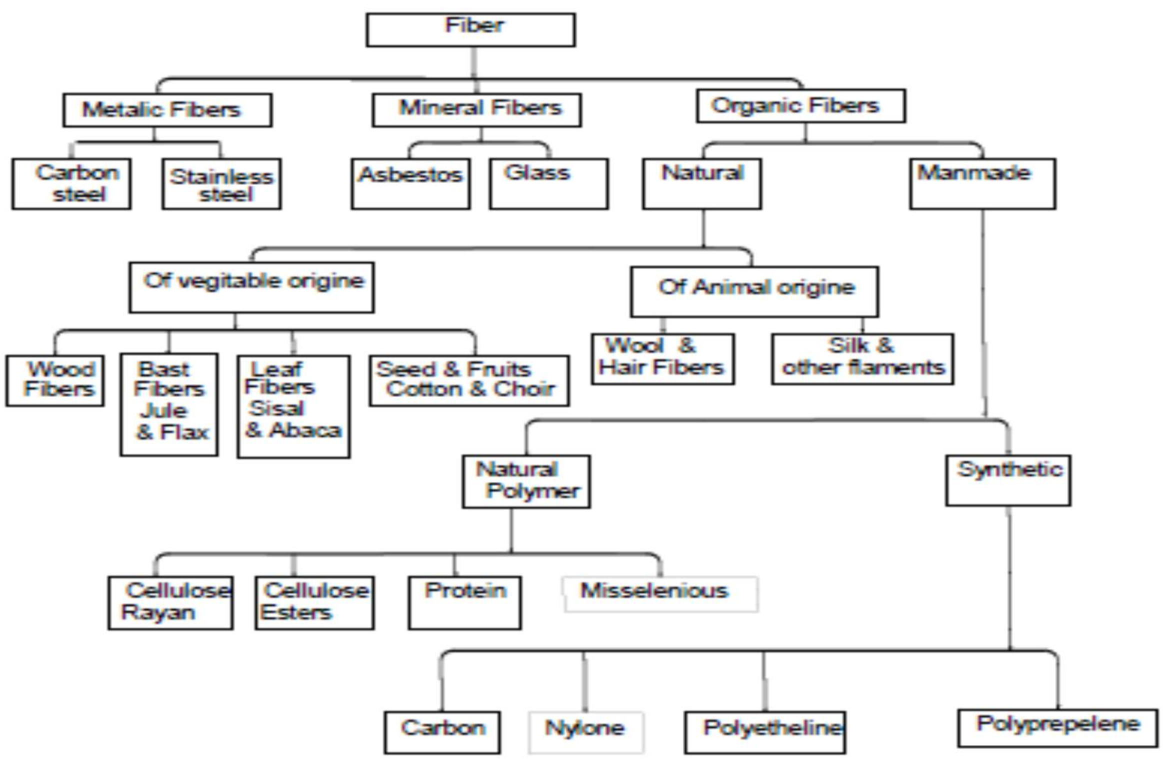

Figure 1-2 Different Types of Fibers (13,14,17)

1.5.1 Asbestos Fiber

This comes under naturally occurring mineral fiber. Asbestos fiber shows very good resistance to heat, electrical, chemical damage and fire. It has average tensile strength. They were originally used in building insulation, electrical insulation for hot plate curing. More water is required when asbestos fiber is mixed with cement due to high absorption. But later it was discovered that asbestos was carcinogenic in nature, hence very hazardous to human health that it was totally banned.

1.5.2 Carbon Fiber

Carbon fiber improves the elasticity and gives good tensile strength. They are formed by oxidation of poly-carbonitrile fibers. After oxidation thermal pyrolysis is carried out thereby producing carbon fibers. They exhibit high elasticity and give good tensile strength. Carbon fibers have high specific strength and elastic modulus. A small volume percent of the fiber is required for producing composites having strengths similar to those of commercial asbestos cement sheet. 1.5 % to 2% addition of the high modulus carbon fiber to cement results in a twofold increase in the modulus of elasticity and fivefold increase in the tensile strength over the values of the unreinforced matrix.

1.5.3 Aramid Fiber

Aramid is a synthetic fiber. As name it is aromatic polyamide. Aramid fiber is another reinforcing material that could be used in construction. Aramid fibers possess light weight and have a high strength compared to other fibers. In these fibers, chain molecules are all oriented along fiber axis, so high strength chemical bond results in its high strength.

1.5.4 Glass Fiber

Glass contain silica with varying amount of oxides of calcium, magnesium and sometimes boron. Fiberglass is a strong and light weight material used for many products. It is not as strong and stiff as composites based on carbon fiber. It is less brittle. Raw material is much cheaper. Its bucking strength and weight are also higher than other fibers. It can be readily molded into complex shapes in construction.

Glass reinforced cement consists of 4 to 4.5 % by volume of glass fiber mixed into cement or cement sand mortar. This glass reinforced cement mortar is used for fabricating concrete products having section of 3mm to 12mm in thickness. These are best suited for application as renovating construction material for restoration of old heritage buildings and for architectural applications.

1.5.5 Natural Fiber

Natural fibers are wood fiber consist of bamboo seed. fruit fiber (coir), stem fiber i.e. jute, kenaf, san, flax, leaf fiber like hen queen, sisal and coconut. They have high water absorption, low alkali resistant. They are prone to insect and fungal attack and have low elastic modulus making it limiting usage in concrete. The high modulus of elasticity, tensile strength, and abundance of naturally available are the major advantage of natural fiber.

1.5.6 Metallic Fibers

They are manufactured by heating the metal until it vaporizes, then depositing it at very high pressure on to polyester film. Metallic fiber is usually aluminized nylon yarn. Actually Metallic fiber is a combination of plastic and metal. They can be drawn from steel wool too. The metallic fibers are carbon steel fiber or stainless-steel fiber.

1.5.7 Polypropylene, Polyethylene and Nylon Fiber

These shows high alkaline resistive and acid resistive property. Polypropylene is a polymer of polyolefin. Polypropylene fiber in the form of fibrillated film fibers show excellent bonding with matrix. The matrix can easily blend into this fibril thus giving good impact resistance. The nylon and polypropylene have very high tensile strength 561– 867 N/mm^2. They could be used where high energy absorption is required because their high elongation (15-25%) absorbs more energy. The low Modulus of this fiber reduces the reinforcing property. They are extensively used in pile shell, non-load bearing, Corrosion proof member, cladding panels, floating unit, guniting crack inhibitor.

1.6 STEEL FIBER REINFORCED CONCRETE (SFRC)

Steel fiber reinforced concrete is a composite material having fibers as the additional ingredients, dispersed uniformly at random in small percentages, i.e. between 0.3% and 2.5% by volume in plain concrete. SFRC products are manufactured by adding steel fibers to the ingredients of concrete in the mixer and by transferring the green concrete into moulds. The product is then compacted and cured by the conventional methods.

Figure 1-3 SFRC Fibers(13,14,17)

Steel fibers are added to concrete to improve the structural properties, particularly tensile and flexural strength. The extent of improvement in the mechanical properties achieved with SFRC over those of plain concrete depends on several factors, such as shape, size, volume, percentage and distribution of fibers. Plain, straight and round fibers were found to develop very weak bond and hence low flexural strength. For a given shape of fibers, flexural strength of SFRC was found to increase with aspect ratio (ratio of length to equivalent diameter).

Even though higher ratios of fibers gave improvement in flexural strength. workability of fresh SFRC was found to be adversely affected with increasing aspect ratios. Generally, aspect ratio is limited to an optimum value to achieve good workability and strength. Mixing steel fibers considerably improves the structural properties of concrete, particularly tensile and flexural strength. Ductility and post cracking strength, resistance to fatigue, spalling and wear and tear of SFRC are higher than in the case of conventional reinforced concrete.

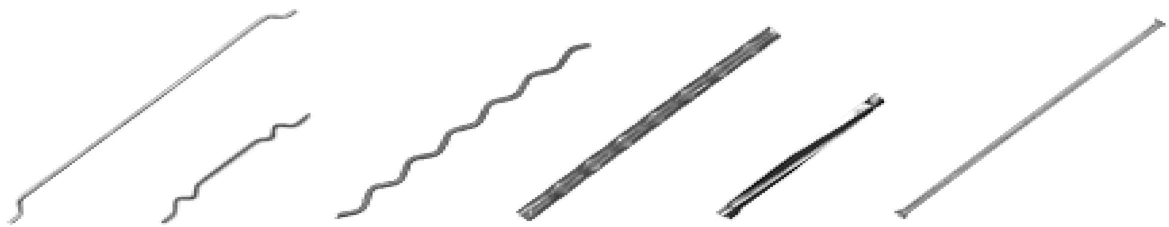

Figure 1-4 Different Types of Steel Fibers (13,14,17)

By adding steel fibers in mixing the concrete, a homogeneous reinforcement concrete is created. This does not notably increase the mechanical properties before failure, but governs the post-failure behavior. Thus, plain concrete, which is a quasi-brittle material, is turned to the pseudo ductile steel fiber reinforced concrete.

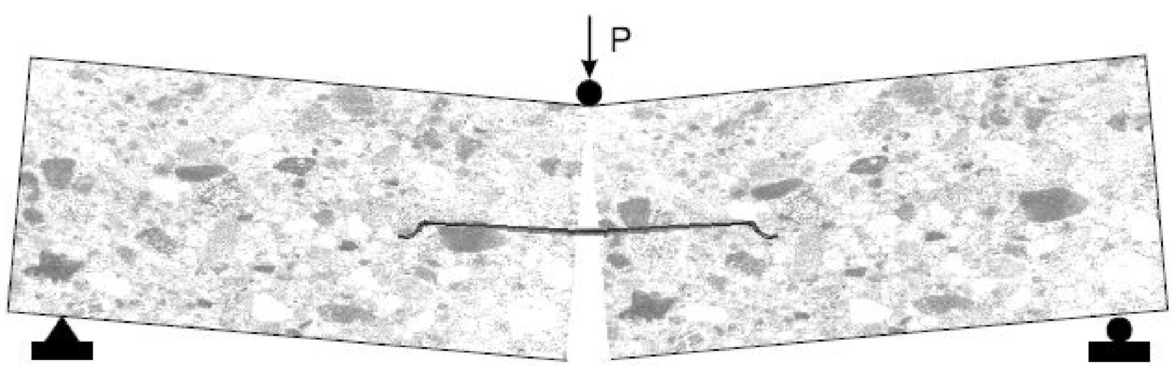

Figure 1-5 Principle of Fiber Reinforcement (13,14,17)

After initiation of crack in material, the stresses are absorbed by bridging fibers which creates redistribution of bending moment in the members. The concrete element does not fail suddenly when the matrix is cracked. Due to ductile property deformation reduces in the concrete material.

1.7 POLYPROPYLENE FIBER REINFORCED CONCRETE (PFRC)

Polypropylene fibers are synthetic fibers obtained as a by-product from textile industry. These are available in different aspect ratios and cheap in cost. Polypropylene fibers are characterized by low specific gravity. Its use enables reliable and effective utilization of intrinsic tensile and flexural strength of the material along with significant reduction of plastic shrinkage cracking and minimizing of thermal cracking. It provides reinforcement, protects damage of concrete structure and prevents spalling in case of fire.

There are two types of polypropylene fibers available,

- Monofilament fibers
- Fibrillated

Figure 1-6 Types of Polypropylene Fibers [13,14,17]

Polypropylene fibers tend to hold the concrete mix together. This slows the settlement of coarse aggregate and thus reduces the rate of bleeding. A slower rate of bleeding means a slower rate of drying and thus less plastic shrinkage cracking. The fibers may increase the initial and final setting time of cement. Polypropylene fibers act as crack arresters in hardened concrete. Like any secondary reinforcement, the fibers tend to stop cracks from propagating by holding the concrete together. so, cracks cannot spread wider or propagate longer. Flexural strength and tensile strength are improved by about 10 percent. The compressive strength of concrete has undergone its potential drying shrinkage. The compressive strength is about the same for concrete with or without polypropylene fibers. The ductility of concrete improves because of polypropylene's low modulus of elasticity.

Polypropylene fibers have been used in precast concrete products like pipe, paving blocks, wall panels, septic tanks, burial vaults, and utility buildings. Cast-in- place applications have ranged from retaining walls, and earth- sheltered, dome-shape homes to all types of works such as streets, sidewalks, driveways, parking areas, floor slabs, even barge deck overlays and helicopter pads.

1.8 ADVANTAGES OF FIBERS IN CONCRETE

- Fibers inhibit and controls the formation of intrinsic cracking in concrete caused both in the plastic and hardened stage of concrete, thus ensuring a more durable concrete construction.
- Fiber reinforced concrete improves the toughness characteristics of hardened concrete against impact force.
- Fibers improve the resistance to moving force caused due to earthquake load and vibration induced in machine foundation, thus making concrete a more versatile material for such critical applications.
- Fibers enhance the hardness property of concrete against material loss due to abrading forces caused by frequent movement of wheel loads. This enhances the service life and safety of concrete pavements.

- Fibers reduce the permeability and water migration in concrete, which ensures protection of concrete due to the ill effects of moisture.
- Fibers reduce plastic shrinkage and control settlement cracks when concrete is still fresh, thus enhancing the overall life of the structure and reducing the maintenance cost.
- Fibers can replace the secondary reinforcement or crack control steel used in grade slabs, thereby reducing the overall cost of the structure.

1.9 APPLICATION OF FIBERS

Fiber Reinforced concrete is recommended in all types of concretes which demonstrate a need for enhanced toughness characteristics, resistance to intrinsic cracking and improved water tightness such as: -

- Industrial floorings
- Canal linings and driveways
- Bridge decks
- Pavements
- Precast, RCC and composite structures
- Water tanks
- Overlays/toppings and tilt-up panels
- Mass concrete
- Walls, thin sections, and terrace slabs.
- Shotcrete

1.10APPLICATION OF MODERATE DEEP BEAM

- Pile caps
- Multistory car parking building
- Shopping malls
- Hotels and theaters
- Ring beam of nuclear reactors
- Bunkers and silos

- Tall building
- Water tank
- Complex foundation system
- Offshore structure
- Girders
- Foundation walls supported by individual columns

1.11 CRACK

Cracks in a building are of common occurrence. Deformation or deterioration occurs in concrete due to uneven loads, temperature change or freezing and thawing. Cracking of concrete occurs due to several reasons like due to constructional movement, shrinkage, etc. After hardening, cracks occur due to chemical reactions and thermal changes etc. A building component develops cracks whenever stress in components exceeds its strength. Cracks are classified into:

- Structural cracks
- Non-structural cracks

The structural ones are due to faulty design, faulty construction or overloading which may endanger safety of buildings. The nonstructural cracks are due to internally induced stresses. Depending on width of crack, these are classified in to thin (<1mm), medium (1mm to 2mm) and wide (>2mm).

1.11.1 Role of fibers in crack control

The mechanical behavior of Fiber reinforced concrete (FRC) depends largely on the interactions between the fibers and the brittle concrete matrix, physical and chemical adhesion, friction, and mechanical anchorage induced by complex fiber geometry or by deformations or other treatments on the fiber surface. As FRC is stressed (either by external loads or by shrinkage or thermal stresses), there is initially elastic stress transfer between the fibers and the matrix. Because the fibers and the matrix have very different elastic modulus, shear stresses develop at the fiber/matrix interface. When the shear stress exceeds between fiber and concrete the debonding gradually begins to occur. The frictional shear stresses become the dominant stress at some point during this gradual transition from elastic to frictional stress transfer, some cracking of the matrix occurs, and some frictional slip take place in the deboned areas.

It must be emphasized that failure by fiber pull-out. It is most preferred mode of failure of FRC. The more energy is consumed in pulling out the fibers from the matrix then after matrix breaks. It is possible to define a critical length (L_c) at which the fibers break rather than pulling out. This must be considered when designing or choosing fibers for a particular application. In a properly designed FRC, following the appearance of the first crack, a process of multiple cracking begins, in which the brittle matrix cracks into successively smaller segments (held together by the fibers bridging these cracks). This leads to toughening of the composite material. The crack width and crack spacing during this process can be controlled by proper selection of the fibers and the matrix.