Chapter 1

INTRODUCTION

1.1 Opening remarks

The beam when loaded is subjected to the combination of bending moment and shear force. It is observed that the beam with little or no transverse reinforcement will fail by flexure or shear. Out of which the shear failures are sudden and catastrophic which occurs without any symptoms or ample warning to inhabitants. This is why the shear failure of beam is a topic of debate and research. One most commonly referred example of shear failure of beam is the failure of U.S. Air Force Warehouse.

The traditional method of resisting shear is the stirrups of different types. The casting of concrete with closely spaced stirrups is difficult and may lead to voids resulting in poor bonding between concrete and steel reinforcement. The conventional horizontal web reinforcements are also showing very little or no effects on ultimate shear strength [55]. It, therefore, is necessary to have alternate solution to the use of web reinforcement like stirrups which will equally enhance the shear capacity of reinforced concrete beams.

1.2 Need of study

The plain unreinforced concrete is a brittle material with a low tensile strength and low strain energy. The use of fibers for the brittle building material is not a new concept and technique. For the last two decades, numbers of investigations are being carried out on the behavior of fiber reinforced composites. The fibers were basically used to improve the ductility of brittle concrete and improve strength and deformation characteristics of deep beams. [24, 38, 61]

The past researchers found the use of randomly oriented discrete fibers in concrete enhances the shear performance of RC beams [20, 39, 47, 48, and 52]. It is established from many previous studies that the addition of steel fibers in concrete significantly increases the shear capacity and help in mitigating the size effect in shear [7, 10, 44]. Somehow, the interaction between the steel fiber and concrete is very complex which makes it difficult to accurately predict the shear strength.
The previous research is mainly carried on steel fiber reinforced concrete (SFRC) shallow beams \((a/d > 2.5)\). The proposed equations \([4, 11, 36, 37, 48]\) are also, based on tests carried on a certain type of fibers. If steel fibers are to be used in actual structural members, then behavior of SFRC deep beam in shear needs to be investigated for different parameters for generalized shear strength equation. The shear strength calculated by using provisions of different national codes is also showing diversity with experimental results. \([1, 46]\) The use of fibers will be more attractive if it can replace the web reinforcement fully or partially. \([15, 23, 31, 45, 64]\)

Now days, the use of high strength concrete is growing rapidly but it has demerits such as lack of ductility \([3,35]\) which can be overcome by adding fibers. But the interaction of fibers with high strength concrete is not yet fully understood. The crack propagation and load carrying capacity is influenced by shear span of the beam \([51]\)

Most of the national codes \([3, 16, 17, 28]\) have not yet recommended the design equations for SFRC beams. The use of deformed steel fibers is recently permitted by American code section 11.4.6 of (ACI 318-2008) \([3]\). The empirical and semi empirical equations proposed by previous investigators have been based on a particular type of fibers, concrete grade or limited range of material and geometrical properties of various parameters affecting concrete shear strength \([68]\). Therefore, the results obtained are conservative. The fiber shape \([5, 50]\), fiber aspect ratio \([69]\), orientation of fibers \([27, 32, 56]\) in matrix and distribution of fibers \([19, 22]\), fiber-concrete interaction \([59]\) also, affect the shear capacity of concrete. The study regarding these parameters is yet being explored \([9, 13, 18, 26, 57, 66]\).

The ambiguities associated with shear in reinforced concrete, complexity involved in interaction between steel fibers and concrete and their dependence on various factors, prompted the researchers to implement advanced computational techniques like non-linear regression \([21, 42]\), artificial neural network technique \([14, 34, 41, 43, 49, 54, 58]\) for predicting shear capacity of steel fiber reinforced concrete beams and RC deep beams \([67]\).
1.3 Reinforced Concrete Deep Beams:

This section introduces the reinforced deep beam and its load carrying mechanism and possible failures.

1.3.1 Deep Beams

According to the Indian Standard Code IS: 456-2000 [28], the beam is considered deep, when the ratio of clear span to overall depth (l/D) is less than 2.0 for simply supported members and 2.5 for continuous members. The ACI code [2] defines the beam as deep if the effective span to overall depth ratio is less than 1.25, while the Canadian code categorized the beam as deep if shear span to depth ratio (a/d) is less than 2.

Many structural elements like walls of bunkers, load-bearing walls in buildings, plate element in folded plates and pile caps, transfer girders in tall buildings behave as deep beams.

1.3.2 Failure of deep beams and load carrying mechanism

Deep beams transfer heavy gravity loads predominantly through shearing action by forming a diagonal crack. The conventional plane section remaining plane approach is not applicable to analyses of deep beams. Besides, for beams without web reinforcement, it has been shown that shear strength decreases as member size increases. This is associated with a phenomenon called size effect. The mechanism of load transfer significantly differs from the structural behavior of shallow beams. The increase in depth of beam keeping the span constant increases the stiffness in such way that the load at the top is transferred through compression and tension zones to the support rather than shear and flexure action in case of shallow beams [33].

1.3.2.1 Shear mechanism

The load at which the diagonal crack forms is taken as the strength of beam in shear. The mechanism formed in the beam at the ultimate state of shear due to the formation of the diagonal crack, separating the beam in to two segments I & II along the diagonal is shown in Figure 1.1. This mechanism is known as mechanism of shear transfer at ultimate state.
Figure 1.2: Shear failure mechanism of beam without shear reinforcement

Figure 1.1: Shear failure of beam without shear reinforcement at ultimate load

Figure 1.2 shows shear resisted by ordinary beam consisting of the following shear carrying components:

a) At the tensile reinforcement, shear is resisted by the dowel action of the longitudinal bar. This is known as dowel shear capacity. ($V_s$)

b) Shear carried by the vertical component of the interface shear along the crack due to aggregate interlock. ($V_a$)

c) The un-cracked concrete in compression has the resisting effect to prevent the propagation of cracks in the compression zone. ($V_c$)

Therefore, the load causing diagonal crack, and hence the shear resisting capacity of the beam without the shear reinforcement, is given by:

$$V = V_s + V_a + V_c$$

The research has shown that the mechanism of shear failure commences with dowel action reaching its capacity first, thereafter aggregate interlock is destroyed, resulting in transfer of large shear force to compression zone, leading to sudden and explosive failure.
1.4 Failure modes

Various failure modes generally observed in structural members are given below.

1.4.1 Diagonal failure

Many types of structural concrete members other than beams have been reported to fail due to diagonal failure e.g. slabs, column, and shear wall. It is believed that the shear transfer mechanism is similar in all the cases but the cracking pattern may differ. A combination of shear force and moment is the fundamental cause of diagonal failure. The diagonal failure is shown in Figure 1.3.

![Figure 1.3: Diagonal failure](image)

1.4.2 Flexural failure:

Flexural cracks are mostly moment dependent and occur in long beams. Consequently the cracks develop where the maximum moment is in the beam. The cracks are almost vertical and cause failure to the beam due to either of these two cases:

1. Under-reinforced beam
2. Over reinforced beams.

The flexural failure is shown in Figure 1.4.

![Figure 1.4: Flexural failure](image)
1.4.3 Deep beam failure

Deep beam can withstand considerably more load than at diagonal cracking and are considered by many to be the result of arch action, as mentioned earlier. The arch action occurs near the end of the beams where the load is transferred from compression zone to the support point directly through the strut while the beam action describes the shear transfer by changes in the magnitudes of the actions by compression zone and longitudinal steel [65]. It can lead to at least two following cases,

1.4.3.1 Anchorage failure

A slip or a loss of bond of the longitudinal reinforcement can be considered as anchorage failure. It can be linked to dowel action where the aggregates interlocking resistance around the bar has failed resulting in splitting of the concrete. The anchorage failure is shown in Figure 1.5.

1.4.3.2 Bearing failure

Failure of the support is a result of bearing stresses exceeding the bearing capacity of the concrete and causes local crushing under point of application of the load. The bearing failure is shown in Figure 1.6
1.5 Fiber reinforced concrete

Fiber reinforced concrete may be defined as a composite material made with cement, aggregates, and incorporating discrete discontinuous fibers. Plain, unreinforced concrete is a brittle material, with a low tensile strength and a low strain capacity. FRC contains fibrous material which increases its structural integrity. It contains short discrete fibers which are uniformly distributed and randomly oriented. The role of randomly distributed discontinuous fibers is to bridge across the cracks that provides some post-cracking ductility. If the fibers are sufficiently strong, sufficiently bonded to material, and permit the FRC to carry significant stresses over a relatively large strain capacity in the post-cracking stage. Fibers include steel fibers, glass fibers, synthetic fibers and natural fibers, each of which lends varying properties to the concrete. In addition, the character of fiber reinforced concrete changes with varying fiber materials, geometries, distribution, orientation, and densities.

In plain concrete and similar brittle material, structural cracks (micro-cracks) developed even before loading, particularly due to drying shrinkage or other causes of volume changes. The width of these initial cracks seldom exceeds a few microns, but their other two dimensions may be of higher magnitude. When loaded, the micro cracks propagate and open up, and owing to the effect of stress concentration, additional cracks form in places of minor defects. The structural cracks proceeds slowly by tiny jumps because they are retarded by various obstacles, changes of direction in bypassing the more resistant grains in concrete. The development of such micro cracks is the main cause of in elastic deformations in concrete [6, 12, 54]. The combination of conventional longitudinal steel and steel fibers forms the different crack pattern observed as closely spaced and lesser crack width [25].

It has been recognized that the addition of small, closely spaced and uniformly dispersed fiber to concrete would act as a crack arrester and would substantially improve its static and dynamic properties. This type of concrete is known as fiber reinforced concrete.

Fiber is a small piece of reinforcing material possessing certain characteristic properties. They can be circular or flat as shown in Figure 1.7. The fiber is often
described by a convenient parameter called fiber aspect ratio. The aspect ratio of the fiber is the ratio of its length to its diameter. Typical aspect ratio ranges from 30 to 150. Basically fibers are classified as metallic fibers and polymeric fibers. Since ancient times, fiber reinforcement has been used in popularity and application (ACI 544, 2002). Caused by this wide range of fiber utilization, numerous fiber types are available for commercial and experimental purposes. Among the basic fiber categories, one can name steel, glass, synthetic and natural fiber materials (ACI 544, 2002). According to manufacturing process, steel fibers are classified as: cut wire (cold drawn), cut steel, melt-extracted and other fibers. This classification has been done by ASTM A 820 as shown in Figure 1.7. Different fibers give different effects such as:-

**Metallic fibers**

1. Increase of fracture energy, which subsequently improves ductility
2. Increase of strength such as compressive strength, tensile strength etc.
3. Reduction of tendency for cracking

**Polymeric Fibers**

1. Decrease of microscopic crack growth with high loading
2. Gain in fire resistance
3. Decrease of early shrinkage

**Glass Fibers:**

1. Decrease of early shrinkage
2. Reduces crack width

Figure 1.7: Types steel fibers (ACI 544, 2002)
1.5.1 Metallic fibers

From Figure 1.8, metallic fibers are made of either carbon steel or stainless steel. The tensile strength ranges from 345 to 1380 MPa. The minimum strength specified in ASTM is 345 MPa. The modulus of elasticity for metallic fiber is 200 GPa. The fiber cross section may be circular, square, or irregular. The length of the fiber is normally less than 75 mm even though longer fibers have been used. The length-diameter ratio typically ranges from 30 to 100 or more.

![Variety and c/s of steel fibers](image)

Figure 1.8: Variety and c/s of steel fibers [9]

1.5.2 Polymeric fibers

Synthetic polymeric fibers have been produced as a result of research and development in the petrochemical and textile industries. Fiber types that have been tried with cement matrices include acrylic, aramid, nylon, polyester, polyethylene, and polypropylene. They all have a very high tensile strength, but most of these fibers (except for aramid) have a relatively low modulus of elasticity. The quality of polymeric fibers that makes them useful in FRC is their very high length-to-diameter ratios. The number of studies on FRC containing polymeric fibers is very limited.
1.6 Properties of fiber reinforced concrete

The interactions between the fiber and cement matrix, as well as the structure of fiber reinforced cementitious material are the essential properties that affect the performance of a cement based fiber composite material. However, to understand these properties, the need for estimating the fiber contribution and the prediction of the composite’s behavior is necessary. Such considerations includes

1. The matrix composition
2. The un-cracked and cracked condition of the matrix
3. Type, geometry and surface characteristics of the fibers
4. The length and orientation of fibers through the cement matrix
5. Critical volume dosage rate of fibers
6. Prediction of the behavior and properties of fiber reinforced concrete

As the bonding of fiber and the matrix plays a major role in the composite behavior, properties of concrete are influenced. The mechanical behavior of fiber reinforced concrete materials is dependent on the structure of the composite, which involves the properties of the concrete and the properties of the fiber type used.

Hence, analysis and prediction on the performance of composites under various loading conditions, such internal structure of the composite must be characterized. The properties may be,

1. The structure of the cement matrix
2. Shape, geometry and distribution of the fibers in the cement matrix
3. The interface between the fiber and cement matrix

There are some factors which can affect the mechanical properties of fibers such as type of fiber, volume fraction of fibers, surface of fiber.

1.7 Basic mechanism of fiber reinforcement

Fiber influences the mechanical properties of concrete in all modes of failure, especially those that induce fatigue and tensile stresses. The strengthening mechanism of fibers involves transfer of stress from the matrix to the fiber by interfacial shear or by interlock between the fiber and matrix. With the increase in the applied load, stress is
shared by the fiber and matrix in tension until the matrix cracks then the total stress is progressively transferred to the fibers, till the fibers are pulled out, or break in tension.

Fiber efficiency and the fiber content are the important variables controlling the performance of FRC. Fiber efficiency is controlled by the resistance to pullout, which depends on the bond at the fiber matrix interface. Pullout resistance increases with fiber length. Since pull-out resistance is proportional to the interfacial area, the smaller the diameter, the larger is the interfacial area available for the bond. For a given fiber length, smaller the area, more effective is the bond. The composite effect of these two variables is expressed by the fiber aspect ratio (length/diameter).

1.8 Factors influencing FRC

Fiber reinforced concrete improves various aspects in the concrete mix only if it is added properly in sufficient quantity and by considering the factors relating concrete, fiber, steel, mix etc. Following are the factors which influences the fiber reinforced concrete.

a) Relative fiber matrix stiffness
b) Volume of fibers
c) Aspect ratio of the fiber
d) Size of coarse aggregate
e) Orientation of fiber.
f) Workability of concrete
g) Fiber matrix interfacial bond

1.8.1 Relative fiber matrix stiffness

The modulus of elasticity of matrix must be lower than that of fiber for efficient stress transfer. It follows, therefore, that there is a minimum modular ratio below which improvement in the mechanical strength properties of the composite cannot be obtained. Low modulus of fiber such asnylons and polypropylene, therefore unlikely give the increase in the strength, but they help in absorption of large energy and therefore impart greater degree of toughness and resistance to impact. High modulus fibers such as steel, glass, and carbon impart strength and stiffness to the composite.
1.8.2 Volume of fibers

The strength of the composite largely depends on the quantity of fibers used in it. Use of higher percentage of fiber is likely to cause segregation and harshness of concrete and mortar.

1.8.3 Aspect ratio of the fiber

Another important factor which influences the properties and behavior of the composite is the aspect ratio of fiber. It has been reported that up to aspect ratio of 75, increase in the aspect ratio increases the ultimate strength of the concrete linearly. Beyond 75, relative strength and toughness is reduced.

1.8.4 Size of coarse aggregate

Several investigators recommended that the maximum size of coarse aggregate should be restricted to 10 mm, to avoid appreciable reduction in the strength of composite. Fibers also in effect, act as aggregate. Although they have simple geometry, their influence on the properties of fresh concrete is complex. The inter-particle friction between fibers and aggregates controls the orientation and distribution of the fibers and consequently the properties of composite. Friction reducing admixtures that improve the cohesiveness of mix can significantly improve the mix.

1.8.5 Orientation of fibers

One of the differences between conventional reinforcement and fiber reinforcement is that in conventional reinforcement, bars are oriented in the direction desired while fibers are randomly oriented. Fibers aligned parallel to the applied load offered more tensile strength and toughness than randomly distributed or perpendicular fibers.

1.8.6 Workability of concrete

Due to the use of fibers in the concrete the workability of concrete gets decreased considerably. Another consequence of poor workability is non-uniform distribution of the fibers. Generally, the workability and compaction of the mix is improved through increased w/c ratio or by the use of some type of water reducing admixtures.

g) Fiber matrix interfacial bond
The interfacial bond between the matrix and the fiber determines the effectiveness of stress transfer from the matrix to the fiber. Fiber length and fiber diameter are thus, critical in influencing static and dynamic properties. For short discontinuous fibers, there is the additional criterion that the interfacial bond must be such that the anchorage length on one side of the crack does not result in fiber pull-out.

1.9 Applications of SFRC

The previous part of the introduction covered the definition of SFRCs. In this part, the different applications of SFRCs are illustrated according to the literature. Applications of SFRC are based on some significant properties of this type of fiber reinforced concrete. These properties are improved flexural toughness, impact resistance, and flexural fatigue. For these reasons, SFRC has been used in many structural elements (ACI 544, 2002). The difficulty of placing bars for reinforcement of some concrete structures is caused to utilize SFRC in some applications those are needed to be reinforcement, such as hydraulic structures, large industrial slabs, tunnel lining, and also bridge decks [26]. In addition to the applications mentioned above, SFRC has also been used in flat slabs on grade when it is subjected to high loads and impact. Also, SFRC is utilized in Shot-Crete applications, ground support, rock slope stabilization, and repairs. Figure 1.9 is showing mixed concrete by steel fibers before placed in molds.

Figure 1.9: Steel Fibers mixed with concrete
1.10 Objectives of study:

Based on the literature survey carried in Chapter 2 and the need of study discussed in section 1.2, the main objective of present investigation is to study the effectiveness of steel fibers in reinforced concrete deep beams in shear without stirrups and develop a generalized equation which will include major influencing factors to predict the ultimate shear strength of SFRC deep beams in shear besides the complexity involved therein.
The objectives of the present study are summarized as-

1. Develop an artificial neural network to predict the ultimate shear capacity of normal and high strength steel fiber reinforced concrete deep beams in shear.

2. Investigate effect of volume fraction and fiber aspect ratio on ultimate shear strength of SFRC deep beams in shear.

3. Investigate effect of compressive strength of concrete on ultimate shear strength of SFRC deep beams in shear.

4. Investigate effect of percentage of longitudinal (tensile) steel on ultimate shear strength of SFRC deep beams in shear.

5. Compare the results obtained by developed neural network with results obtained by empirical or semi-empirical equations proposed by previous researchers and experimental results for normal and high strength concrete.

1.11 Concluding remarks:

Although a considerable advancement has taken place in last few decades, the research work is still in progress for understanding the complex behavior of steel fiber concrete composites subjected to predominating shear force due to several important parameters affecting intricate shear transfer mechanism.

The artificial neural networking seems to be the available powerful and versatile tool which can overcome the limitations of experimental and theoretical studies.