CHAPTER 7

CONCLUSIONS

7.1 GENERAL

A beam which has a large depth to thickness ratio and whose shear span to depth (L/D or h) ratio less than 2.5 in the case of concentrated load and 5 for distributed load is known as a deep beam. Deep beams play a very significant role in the design of big as well as small structures. In the case of deep beam the importance of the shear-span/depth ratio and for buckling and instability the depth/thickness ratio are very important.

The transition from the behaviour of conventional simple beam to that of deep-beam is imprecise. The design of deep beams must consider the non-linear distribution of strain over a cross section. Standards of many countries all over the world suggest using Strut and Tie for designing this type of structure and, for non-linear analyses, Finite Element Method (FEM) is recommended. The well-established concept of plane sections before bending remaining plane after bending does not hold good for deep beams. Significant warping of the cross-sections occurs due to high shear stresses. As a consequence flexural stresses are not distributed linearly even in the elastic range.

Materials used in the construction of deep beams are concrete, steel and timber. However, in this thesis deep beams constructed with concrete alone are considered for further discussion. Only reinforced concrete deep
beams are taken up for discussion here. Particularly that are constructed with steel fibre reinforcement are considered.

Generally, RC members crack on application of load. In flexural zone vertical cracks are formed and in shear zone diagonal cracks are formed. The development of inclined cracking tends to cause an increase in the stress in flexural tension reinforcement at the base of the crack. In deep beams, inclined cracking may extend the full length of the shear span. Though reinforcing concrete with steel bars resist adequately the tensile loads, it still fails to prevent the formation of cracks in concrete structure. Addition of steel fibres to concrete helps reduce this problem significantly and also improves the static and dynamic properties of concrete.

Modes of failure of RC deep beams are shear compression, local crushing near the support and loading points, compression strut failure, yielding of tie reinforcement, flexural failure, diagonal tension, supporting column crushing, spalling of concrete due to excessive cover, flexural compression failure, bearing failure and punching shear failure. The behaviour of deep beams is significantly different from that of slender beams, requiring special consideration in analysis, design and detailing of reinforcement. A deep beam is can be considered as a vertical plate subjected to loading in its own plane. However, the strain or stress distribution across the depth is no longer a straight line, and the variation is mainly dependent on the aspect ratio of the beam.

The main objective of the thesis is to study the characteristics of Steel Fibre Reinforced (SFRC) deep beams under loading, to evaluate the ultimate capacity of SFRC deep beams and compare the same with that of the conventional concrete beam, to study in depth the diagonal cracking in SFRC beam and to investigate the reason for the spacing between the cracks both in
SFRC and conventional concrete beams and to perform the numerical analysis to validate the experimental results.

7.2 EXPERIMENTAL INVESTIGATION

Both conventional slender and deep beams were prepared using crushed basalt stone as coarse aggregate, river sand as fine aggregate, Ordinary Portland Cement (OPC) of 53 grade and potable water as per standard. Steel fibre was used for reinforcing plain concrete. Two categories of beams were cast using the concrete developed above, viz., (1) conventional slender beam of size 2000 mm × 125 mm × 200 mm and (2) deep beams of length 600 mm, width of 80 mm and span to depth ratio of 1.0, 1.25, 1.5, and 2.0. Conventional beams were reinforced with 12 mm steel bars as secondary reinforcement and 16 mm bars as main reinforcement on the tension side. The plain concrete was reinforced with 0.5 mm diameter fibres in respect of both categories of beams. A total of 24 deep beams were cast in three series.

Each series comprises of eight beams corresponding to span by depth ratio of 1.0, 1.25, 1.5, and 2.0. Beams in the first series consisted of plain concrete (P series). The second series was prepared using SFRC (F series). The third series was fabricated using SFRC along with horizontal web reinforcement (FSH series). Along with the casting of deep beams slender beams 24 numbers of size 2500 mm × 200 mm × 300 mm were also prepared. All the beams were reinforced with three numbers of 16 mm dia. bars. Twelve of the beams were of plain concrete and the other twelve were reinforced with SFRC. Two grades of concrete M20 and M30 were used in the preparation of beams. Reinforcing steel consisted of Fe415 grade. The specimens were tested using two-point loading in a 600 KN capacity UTM.
7.3 ANALYTICAL METHOD

Experimental results obtained are verified for their credibility by performing analysis on the structure by its discretization into elements. Here numerical analysis using ANSYS software package was carried out. SOLID65 was used for the 3D modelling of concrete with or without reinforcing bars. SOLID65 is capable of cracking in tension and crushing in compression. It can also consider plastic deformation and creep.

For steel rebar, ANSYS presents LINK180 to model reinforcing steel which is simply a pin-joined one dimensional element. Concrete is a quasi-brittle material and has a highly nonlinear and ductile stress-strain relationship. The nonlinear behaviour is attributed to the formation and gradual growth of micro cracks under loading. For steel reinforcement, a linear-elastic perfect-plastic material model was adopted. For practical reasons, steel is assumed to exhibit the same stress-strain curve in compression as in tension.

7.4 RESULTS

Generally two types of diagonal tension cracks were observed in the tested beams. In the first type the origination of diagonal tension crack was at the inner edge the reaction bearing plate. As the load was increased further the second type of diagonal crack formed at D/4 in the span. Complete failure of the beam occurred in any one of the following ways. The failure of the plain concrete beams occurred in flexure with the formation of flexural crack near the mid span.

This kind of failure occurred in the P series beams of plain concrete. The diagonal tension failure occurred in beams of F and FSH series. This was observed by splitting of beam in the direction a line
connecting the inner edge of reaction bearing plate at the support and the outer edge of the loading plate. The failure in shear occurred mainly in FSH series beams. This was displayed by crushing of the strut portion of the concrete along the plane of the diagonal cracks and was further followed by crushing of the web.

In deep beams, a large part of the load is transferred to the supports directly through compression struts formed directly between the load and the support point. This kind of load transfer mechanism commonly leads to shear, in the form of splitting failure. The tensile stresses in concrete in the direction normal to ultimate crack are much higher than the tensile strength of concrete, which justifies the formation of the cracks observed in the experiment. It was observed in the present investigation that steel fibres act like small diameter bars, closely spaced and randomly distributed, causing an increased number of hair cracks, which are preferable to a few wider cracks. Furthermore, crushing and spalling of the concrete at load and support regions, due to bearing stresses or anchorage failure at end supports was also reduced due to the overall rigidity provided by steel fibres in concrete material.

### 7.5 Future Studies

- The behaviour of deep beam may be studied under dynamic loading
- The behaviour of deep beam may be studied under fatigue loading
- The behaviour of deep beam prepared with High Performance Concrete may be studied