CHAPTER - 7

SUMMARY AND CONCLUSION

7.1 Summary

The purpose of this investigation was to develop a method which can be used for the analysis and design of fully fibrous and partially fibrous reinforced concrete deep beams and moderate deep beams. Static testing was done on forty beams subjected to two point loads. Span to depth ratio varied from 1.0 to 6.0. There were five series of beams, each series comprised of eight beams with variable depth. Longitudinal tensile steel in each series upto L/D ratio of 3.0 was of one 16 mm mild steel round bar. For L/D ratios ranging from 4.0 to 6.0, it was of one 12 mm mild steel bar. For this investigation plain and round galvanized iron fibres having aspect ratio of 100 have been used.

Numerical values given in some of the conclusions are valid for the type of materials and conditions of test used in this study. The general technique adopted in obtaining them is valid even for different materials and testing methods. Validity of the analytical formulation has been checked independently by strain measurements and computing the flexural and shear strengths. These loads have been compared with observed values and the agreement between test loads and computed loads is reasonable.

7.2 Conclusions

The conclusions obtained from this study on reinforced concrete deep beams and moderate deep beams using plain round galvanised steel fibres have been summarised in this section.

(1) It is possible to include the steel fibres only over a partial thickness of the concrete flexural members, in the tension zone, just similar to conventinal reinforcement. This results in flexural load enhancement and satisfactory load -deflection performance characteristics. These enhancements are practically comparable with those which could be achieved by reinforcing the entire concrete section fully with fibres.

(2) The partial depth which needs to be fibre reinforced, is the design consideration of partially fibre reinforced flexural members. The design thickness can be computed by determining an engineering parameter viz. tensile strain enhancement factor 't_f', and moment capacity enhancement factor 'β_f'.

(3) Prediction of ultimate strengths of fully fibre-reinforced concrete flexural members can be satisfactorily based on tensile strength obtained in a direct tension test. Direct tensile strength is considered as a more appropriate parameter for fibrous concrete which is ductile in nature.

(4) In all the fibrous concrete beams, concrete strain, steel strain and deflection are reduced at any given load level compared to those of a beam which does not contain the fibres. Right from the beginning of the loading, these deformational characteristics are influenced by the fibres. At service loads, the reduction in these characteristics are more significant. Due to presence of fibres such modifications result in less wide cracks, lower deflection and increased flexural rigidity. All these desired improvements are obtained by including the fibres in the concrete.

(5) Steel fibres are relatively expensive. Hence, cost effective ratio can be kept minimum by including the fibres only over half the depth on the tension side. By this mode of inclusion, the serviceability range is completely covered with practically the same degree of desired modification as the one which could be achieved by full depth fibre inclusion.

(6) Partially fibre reinforced concrete memebrs are cost effective without any sacrifice in the level of performance and strength.

(7) The proposed method to estimate ultimate flexural moment of moderate deep beams provides more reliable results, as it is based on realistic stress-strain curve of concrete rather than the empirical compression block parameters, k_1, k_2 and k_3. The only values required are compressive strength of concrete f_c , yield stress f_y of steel and moment capacity enhancement factor β_f as per conditions of fibrous concrete in beam.

(8) The flexural strength mechanism in fibrous concrete is due to the resultant effect of fibre pull out from the matrix across the crack. This improved post-cracking tensile strength of concrete leads to an enhancement of the strength of reinforced concrete beam significantly, since greater ultimate tensile strengths are realized in bending rather than in direct tension.

(9) The shear strength formula developed in this study appears to provide a satisfactory and reliable approach to estimate the cracking loads and the ultimate shear loads of fibre reinforced concrete deep beams. **Table-6.4** shows that with a few exceptions, the computed loads agree fairly well with the observed value of loads.

(10) A comparison of test results and analytical results shown in **Table-6.4** reveals that the effects of fibre inclusion in deep beam and moderate deep beam can be analytically predicted. Most of the values are within ± 15% of the test values. The theoretical values of the beams of de Paiva and Siess (45) are also calculated. The theoretical values agree well with their test results as shown in **Table-6.5**.

(11) As seen from the photographs of beams of this study (plates), the crack patterns in deep beams depend more on shear span to depth (a/d) ratio than on span to depth (L/D) ratio. For a/d approximately equal to or greater than one, the failure mode is in flexure. For a/d ratios less than 0.5, the failure mode is shear and a/d ratios between 0.5 to 1.0, the failure mode is flexural-shear.

(12) In a steel fibre reinforced concrete deep beam, deflection does not appear to be a problem because of large stiffness. The load-deflection curves in **Figs. 4.9 to 4.16**

show that the deflection in deep beams is proportional to the applied load upto the yield load of beams. After that the load-deflection curve is non-linear.

(13) In all the tested beams no horizontal separation between the fibre reinforced layer and the unreinforced layer was observed as cam be seen from plates. The fracture of specimens occured in the cross section situated in the central span of the members in uniform bending zone of L/D ratios of 4.0, 5.0 and 6.0 while for L/D ratios ranging from 1.0 to 3.0 it is in the shear span.

(14) From the results of the **Table 5.1** of this investigation it can be established that the incorporation of fibres increases the tensile cracking strain of plain concrete. This is true for short discrete steel fibres in direct tension and flexure. The results of Table-5.2 show that the measured matrix cracking strain is a function of the fibre volume fraction. It is observed from this table that the fibres playd significant role in controlling the first cracking of composite.

(15) The analytical method developed in this investigation for predicting quantitatively the influence of the steel fibres in conventionally reinforced flexural members may be used as a design aid in including the fibres in appropriate quantities and locations to bring about the required levels of improvements. See Examples 1 & 2.

(16) As seen from the photographs on page nos. 240 to 244, for shallow beams, the formation of first fully developed crack is synonymous with complete collapse. For moderate deep beams, the formation of fully developed inclined crack is welldefined and beams are able to carry some load beyond that point. However, for

deep beams after the development of an inclined crack, the beams can support considerable additional load before collapse.

(17) Looking to photographs of tested beams it was found that initally a few cracks developed in pure moment zone. Later the diagonal tensile crack developed first at a distance of about D/2 to D/3 from soffit in shear span. The diagonal crack started extending both ways towards loading point and support point. Flexural cracks stopped developing further. These diagonal cracks so formed were nearly parallel to each other with a "strut like" appeareance between the loading points. The clear indication of "strut like" appeareance was observed in beams F1.0 D40, F1.0 D50, F1.0 D60 shown on page no. 241. Diagonal compression failure was observed with an inclined crack developed along the line joining the load and the support point and is followed after a small increase in load by a second parallel crack. Failure is due to the destruction of concrete strut between these cracks. It is observed during testing that shear failure in deep beams is always initiated by spilting action, the phenomenon of failure being similar to that of cylinder under diametrical compression.

(18) The only parameter required to determine when a given type of fibres are used in a given concrete matrix, which may be conventionally reinforced or not, is the direct tensile strength of the fibre concrete composite. Only with this one parameter, the improvements imparted by the fibres to concrete matrices can be determined.

(19) In order to comply with the design requirements of the present code of practice, the servicibility in limit state must be fulfilled. Cracking is one of the criteria which the

designer has to satisfy. This philosophy deals with the computation of maximum allowable crack width.

(20) A formula is proposed to obtain a functional representation of maximum crackwidth in fibre reinforced concrete beams failing under flexure. Due to presence of fibres and different L/D ratios of beams, the ACI formula proposed by Gergely and Lutz (63) is modified using standard optimization least square technique (160). The formula considers the contribution of fibres towards crack resistance at ultimate loads. This approach is more logical and treats the problem in true perspective. The values of maximum crack widths calculated by this procedure alongwith an empirical constant show agreement with in $\pm$ 18% of the experimental values. The maximum calculated crack widths when compared with observed values show close agreement of Sabapathi's (147) results as shown **Table-6.3.**

(21) Load at first visible crack increases by 50% to 200% due to the inclusion of fibres as seen in **Table-4.1**. This implies that fibres are more efficient in resisting the crack in the initial stages of cracking. The effect of fibres on maximum or mean crack spacing has been found to be insignificant irrespective of the volume percentage of fibres as seen from the photographs of tested beams failing under flexure. This agrees with the results of other investigators (116, 147, 164, 165).

(22) From the **Table - 4.2** it can be visualised that upto L/D = 2.0m the fist cracking load and the ultimate load are more when the fibres are dispersed in full depth of the beam. For L/D upto 2.0 the percentahe increase of load is from 10% to 12% whereas for L/D > 2.0, the increase in load is from 20% to 22%. This shows that the

fibres are more effective in resisting the bending moment then the shear. When L/D < 2.0, the beams failed in shear whereas when L/D > 3.0m beams failed due to flexural-shear.

(24) From the **Table - 6.4** it can be observed that when fibres are dispersed in half depth of the beam, the ultimate load shows slightly highr values, than when the fibres are dispersed in full depth. This may be due to the fibre beam pulled to its full capacity without their mutual interference. This trend can be seen for L/D ranging from 3.0 to 6.0. For L/D = 1.5, beams failed by shear. Whereas between 3.- to 4.0, they failed by flexural-shear and between 5.0 to 6.0 they failed by flexural only. This shows clearly the transition of failures from shear to flexural-shear to flexure.

(25) There is a reduction of 50 to 160 percent in the maximum crack width at working load, as seen from the **Fig. 4.29 to 4.36**. This reduction depends on the fibre percentage. The load required to produce maximum crack width of 0.1 mm, 0.2 mm, and 0.3 mm has been found significantly more due to the addition of fibres of different volumes. Load-crack widths in **Fig. 2.29 to 4.36** indicate that with an increase in the fibre percentage, there is an increase in service load at a specified crack width.

(26) Based on the study carried out in this thesis, design examples for a deep beam and a moderate deep beam are presented in **Appendix-E**. Example 2 emphasises on the control of cracks with using steel fibres.

From the limited extent of this work, the findings arising out of this study would find practical applications in the field of Civil Engineering.

7.3 Design Recommendations for Deep Beams

In Chapter 5, analytical procedures were devloped for fibre reinforced ceoncrete deep and moderate deep beams. For design purposes, a deep beam should first be made to satisfy flexural requirements, and then the contribution of shear should be checked. In deep beam, the area of steel required to resist the applied moment is normally quite small, and it is a simple matter to provide a sufficient amount of steel to avoid the likelihood of a flexural failure. Having done this it is important to check the shear strength and to provide a suitable arrangement of web reinforcement.

From the test results, an ultimate shear formula (5.40) has been proposed for application to plain and fibrous concrete beams. The elliptical splitting approach can be easily applied to design of deep beams. This approach may be limited to beams with a/d less than 1.0 for concentrated loads.

Based on this formula, a method is suggested for the design of web reinforcement in deep beam under top loading. The method takes in to consideration the shear strength contribution of the concrete, reinforcing web steel and fibres. For the determination of the contribution of the web steel, the arrangement of web bars is chosen, and then the effect of the web steel on the overall shear strength of the beam can be calculated. The ratio of ultimate shear capacity to ultimate flexural capacity $W_{us}/W_{uf} > 1.0$ and thus ensuring a flexure failure.

Looking to the variation in shear capacity with shear span to effective depth (a/d) for rectangular reinforced concrete beams and fibre reinforced concrete beams it is proposed that deep beam behaviour occured in approximate range $0 < a/d < 1.0$.

Deep beam design should place considerable emphasis on bearing and anchorage details. This can be done by providing steel cages at support and loading points. Special anchorage provisions such as steel plates welded to the ends of bar or hooking the bars in a horizontal plane and wrapping the hooks with wire can be used to prevent this mode of failure.

The existing design methods give either little or no specific guidance regarding the shear strength contribution of web steel. The CEB-FIP model Code 1990 focuses on flexural design and does not give guidance on how to calculate web steel areas to resist specified shear forces, only giving idea about placement of web steel in the form of orthogonal mesh with steel ratio of 0.20% in each direction near each face. Additional bars should be provided near the support, particularly in the horizontal direction. In contrast, the ACI Building Code 318-1989 (5) recommendations, which are based mainly on tests carried out in America by Crist (38), de Paiva and siess, (45) which focus on shear design and do not give any guidance on how to calculate steel areas to resist specified bending moments. IS 456-1978 (76) has made a general statement that a non-linear stress distribution be taken in case of deep beam design and no recommendations are given as to how the design is to be done for flexural moment and shear forces.

It is essential to limit crackwidths in reinforced concrete beams to control corrosion of the reinforcement and because cracks which are visible may be objectionable from an aesthetic point of view.

As flexural and inclined cracking are always present in reinforced concrete deep beam, servicebility may be of prime importance in design. Servicebility relates to performance at working load where crack widths and deflection must be limited.

For a/d values greater than about 2.5 upto a transition point value at which flexural failures begins, the inclined cracking load exceeds the shear-compression failure load.

7.4 Recommendation for Future Research

The review of available literature and the present investigations has encouraged the author to suggest further work to be carried out in this area leading to extensive use of steel fibres in reinforced concrete :

Structural response of partially fibre reinforced concrete deep beams and moderate deep beams with the same L/D ratios as tested in this investigation having different a/d ratios.

Experimental investigation on steel fibre reinforced concrete beams and moderate deep beams using fibres of different geometry is recommended for the reinforcement and generalisation of the proposed theory developed in this investigation.

Crist and Leonhardt (38,100) have tested some large size simply supported deep beams with uniformly distributed loading. On similar lines, experimental work could be carried out for partial fibre reinforced concrete deep beams and moderate deep beams.

Kong and Sharp (87) have done some testing on reinforced concrete deep beams with openings. Robert and HO, and Shanmugam (140, 152) have also done some work for fibre reinforced concrete deep beams with openings. Thus, there is a scope for partially fibre reinforced concrete deep beams and moderate deep beams with different sizes and different locations of openings.

Futher studies can be carried out on ultimate behaviour of deep beams and moderate deep beams using high strength deformed bars in conjunction with steel fibres of different geometry.Such a study will be very much useful in supplementing the theory developed in this investigation.

The understanding of the behaviour of partial fibre reinforcement in concrete beams (both moderate and deep)requires further strengthening by the study of effectiveness of web reinforcement in both horizontal and vertical directions.

Experimental work involving partial fibre reinforced concrete deep beams and moderate deep beams of T - section and L - section could be taken.

Some experimental work is required to study partially fibre reinforced concrete deep beams and moderate deep beams subjected to dynamic loading.

A recent versatile analytical technique known as the finite element method could be developed for partially fibre reinforced concrete deep beams and moderate deep beams.