

FLEXURAL BEHAVIOUR OF REINFORCED CONCRETE BEAMS MADE WITH COIR OR STEEL FIBRE CONCRETE

VISHAL CHAND JAIN

Submitted in fulfilment of the
requirements of the Degree of
DOCTOR OF PHILOSOPHY
to the
Indian Institute of Technology Delhi

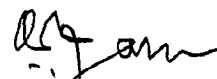
**DEPARTMENT OF CIVIL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY DELHI
NEW DELHI 110016**

SEPTEMBER, 1983

CERTIFICATE

This is to certify that the the^sis, entitled 'FLEXURAL BEHAVIOUR OF REINFORCED CONCRETE BEAMS MADE WITH COIR OR STEEL FIBRE CONCRETE' being submitted by Mr. Vishal Chand Jain to the Indian Institute of Technology Delhi in fulfilment of the requirements of the Degree of Doctor of Philosophy, is a record of bonafide research work carried out by him under our guidance and supervision.

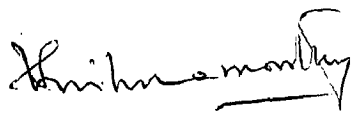
To the best of our knowledge, the thesis has reached the requisite standard. The material presented in this thesis has not been submitted in part or full to any other University or Institution for award of a degree or diploma.


(O.P. Jain)

Formerly Director,
Indian Institute of Technology,
Delhi.


(B.M. Ahuja)

Professor of Civil Engineering
Indian Institute of Technology
Delhi.



(S. Krishnamoorthy)

Professor of Civil Engineering
Indian Institute of Technology
Delhi.

New Delhi,
16th Sep., 1983.

Δ

Δ

ACKNOWLEDGEMENTS

I have the privilege of working under the guidance of Prof. O.P. Jain on several important projects during the last twenty five years. I would like to express my sincere gratitude to him for his inspiration and guidance at all stages of this work.

I am thankful to Prof. B.M. Ahuja and Prof. S. Krishnamoorthy for suggesting an interesting and useful problem for research. I am grateful to them for their guidance and encouragement at all times. I am especially thankful to Prof. S. Krishnamoorthy for carefully checking the manuscript.

I am thankful to the staff of Concrete and Structures Laboratory, Strength of Materials Laboratory, Fibre Testing Laboratory, and Civil Engineering Department Workshop of I.I.T. Delhi, for their cooperation and help. Special thanks are due to Messers Shiv Lal Sachdeva, Shree Chand, Badan Singh, Badle Ram, C.L. Verma and G.K. Mehta for their assistance in experimental work.

I am extremely grateful to my brother Ashok for preparing the tracings, and for his help in compiling the thesis. He also assisted me in cutting the coir fibres.

I am thankful to the Head of Civil Engineering Department and the Vice Chancellor, University of Roorkee, for granting me study leave to work at I.I.T. Delhi. I am also thankful to Mr. R.C. Sharma for typing the thesis neatly.

ABSTRACT

The work relates, principally, to the flexural behaviour of R.C. beams made with fibre concrete. The relationship between fibre content and workability of fibre concrete mixes has also been studied, so that workable mixes of specified fibre contents can be made. The work, further, includes study of the stress-strain behaviour of plain and fibre concretes in compression, as this directly influences the behaviour of a R.C. member.

Two types of fibres, namely steel and coir, have been used. Steel fibres have been mostly favoured for structural use. Coir fibres have been chosen because these are relatively inexpensive, are abundantly available in India, and have adequate durability in a cement concrete matrix.

The Experimental Programme included V-B tests of plain and fibre concrete mixes, tests for compressive strength and modulus of rupture, tests to obtain complete stress-strain curves of concrete in compression, and tests of reinforced fibre concrete beams in flexure under a monotonic loading upto failure.

A method has been developed to determine the maximum volume fraction of fibres, which can be included in a given mix for desired workability.

A performance index for fibre concrete, called Ductility Factor, has been postulated. This factor is a measure of the ductility in compression achieved with the addition of fibres. A relation between ductility factor and volume fraction of fibres has been obtained.

The idealised stress-strain curve of fibre concrete has been related to that of plain concrete by a single parameter, namely, the ductility factor of fibre concrete.

Tests on reinforced fibre concrete beams show that, in the range of service loads, addition of steel fibres results in reduced deflections and crack widths, whereas coir fibres produce little influence at this stage. At ultimate load, the beams exhibit increased ductility if the fibre content is less than a critical fibre content whose value depends on percentage of tension steel.

A method has been developed to determine the stiffening effect of fibres in the tension zone of a R.C. beam, which is an extension of the method adopted by British Code, CP110:1972, to estimate curvature of a cracked section.

CONTENTS

Chapter		Page
	CERTIFICATE	... i
	ACKNOWLEDGEMENTS	... ii
	ABSTRACT	... iii
	LIST OF SYMBOLS	... x
1-	INTRODUCTION	
	1.1 General	... 1
	1.2 Fibre Concrete	... 2
	1.3 Need for the Study	... 3
	1.4 Scope of Study	... 4
	1.5 Brief Outline of Experimental Programme	... 4
2-	LITERATURE REVIEW	
	2.1 Introduction	... 6
	2.2 Fibre Concrete	... 6
	2.3 Concrete Matrix	... 8
	2.4 Fibres	... 9
	2.4.1 Steel Fibres	... 10
	2.4.2 Polypropylene Fibres	... 12
	2.4.3 Vegetable Fibres	... 13
	2.5 Workability and Fibre Content	... 14
	2.6 Behaviour of Fibre Concrete in Tension, Flexure, and Compression	... 16
	2.7 Strength of Fibre Concrete	... 18
	2.7.1 Tensile Strength	... 19
	2.7.2 Flexural Strength	... 19
	2.7.3 Compressive Strength	... 20
	2.7.4 Impact Strength	... 21
	2.7.5 Fatigue Strength	... 22
	2.8 Theory of Fibre Reinforcement	... 22

Chapter		Page
	2.8.1 Cracking Strength	23
	2.8.2 Post-cracking Tensile Strength	25
	2.8.3 Post-cracking Flexural Strength	27
	2.8.4 Critical Fibre Content for Strengthening in Tension or Flexure	29
	2.9 Use in Reinforced or Prestressed Concrete Members	29
	Tables	32
	Figures	34
3-	MATERIALS	
	3.1 Introduction	36
	3.2 Coarse Aggregate	36
	3.3 Fine Aggregate	37
	3.4 Cement	37
	3.5 Coir Fibres	37
	3.6 Steel Fibres	39
	3.7 Reinforcing Bars	40
	Tables	42
	Figures	47
4-	FIBRE CONTENT AND WORKABILITY	
	4.1 Introduction	51
	4.2 V-B Test of Concrete Mixes	52
	4.3 Plots of v_f versus $\log(t)$	53
	4.4 Expression for m	53
	4.5 Determination of n_1 , n_2 , c_a , and c_f	55
	4.6 Relation between v_f and t	57
	Tables	59
	Figures	65
5-	COMPRESSIVE AND FLEXURAL STRENGTHS	
	5.1 Introduction	69
	5.2 Plain Concrete Mix	69
	5.3 Fibre Concrete Mixes	70

Chapter		Page
	5.4 Casting and Curing	... 71
	5.5 Compressive Strength	... 72
	5.6 Modulus of Rupture	... 73
	Tables	... 75
6-	STRESS-STRAIN BEHAVIOUR	
	6.1 Introduction	... 77
	6.2 Preparation of Test Cylinders	... 78
	6.3 Test Set-up	... 78
	6.4 Test Results	... 80
	6.5 Discussion of Test Results	... 80
	6.6 Stress Block Parameters and Ultimate Compressive Strain in Flexure	... 82
	Tables	... 84
	Figures	... 97
7-	DUCTILITY FACTOR AND IDEALISED STRESS- STRAIN CURVE	
	7.1 Introduction	... 101
	7.2 Ductility Factor	... 101
	7.3 Relation between D_f and v_f	... 103
	7.4 Idealised Stress-Strain Curve of Fibre Concrete	... 104
	Tables	... 106
	Figures	... 108
8-	TESTS OF REINFORCED FIBRE CONCRETE BEAMS IN FLEXURE	
	8.1 Introduction	... 110
	8.2 Details of Test Beams	... 110
	8.3 Casting and Curing of Beams	... 113
	8.4 Handling of Beams	... 114
	8.5 Preparation for Testing	... 114
	8.6 Experimental Set-up	... 115

Chapter		Page
	8.7 Test Procedure	... 118
	8.8 Cube Strength of Concrete	... 120
	8.9 Test Results	... 120
	8.10 Discussion of Test Results	... 121
	Tables	... 125
	Figures	... 154
9-	ANALYSIS OF TEST BEAMS	
	9.1 Introduction	... 190
	9.2 Relevant Material Data	... 191
	9.2.1 Compressive Strength of Concrete	... 191
	9.2.2 Modulus of Rupture of Concrete	... 192
	9.2.3 Modulus of Elasticity of Concrete	... 193
	9.2.4 Concrete Strain and Stress Block Parameters at Flexural Strength	... 194
	9.2.5 Stress Block Parameters	... 195
	9.3 Method of Analysis	... 196
	9.3.1 Determination of M_{cr} and ϕ_{cr}	... 196
	9.3.2 Determination of M_u and W_u	... 196
	9.3.3 Determination of M and W for a given f_s	... 198
	9.3.4 Determination of f_t at a given load stage	... 199
	9.4 Values of f_t	... 202
	Tables	... 204
	Figures	... 230
10-	STIFFENING AND DUCTILITY OF R.C. SECTIONS WITH FIBRE CONCRETE	
	10.1 Introduction	... 231
	10.2 Expression for f_t	... 232
	10.3 Stiffening of R.C. Sections with Fibre Concrete at Service Loads	... 234

Chapter		Page
	10.4 Ductility of R.C. Sections with Fibre Concrete	... 235
	10.5 Critical Fibre Content for Ductility	... 236
	Tables	... 238
	Figures	... 240
11-	CONCLUSIONS	... 241
	PLATES	... 249
	REFERENCES	... 254
	AUTHOR'S BIO DATA	... 263