

QUASI-STATIC AND DROP HAMMER LOADING OF PLAIN AND SKIN REINFORCED CONCRETE PLATES

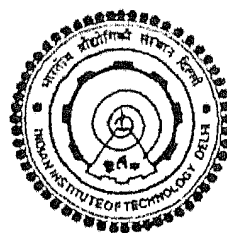
**BY
MEHTAB ALAM**

Department of Applied Mechanics

Submitted in fulfillment of the
requirements of the degree of

DOCTOR OF PHILOSOPHY

to the



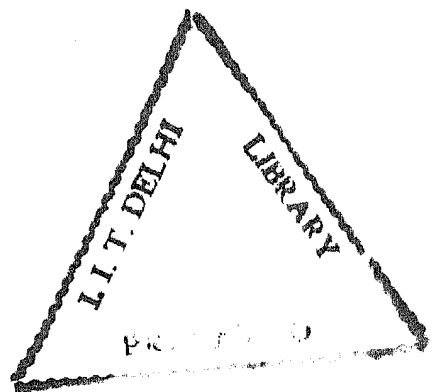
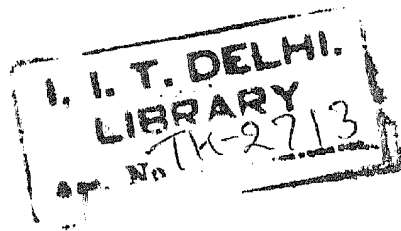
**INDIAN INSTITUTE OF TECHNOLOGY, DELHI
HAUZ KHAS, NEW DELHI-110016, INDIA**

DECEMBER, 1999

© Indian Institute of Technology, New Delhi, 1999
All Rights Reserved

Dedicated to
My daughters

TH
624.073
MEK-9



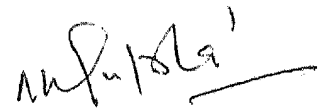
CERTIFICATE

This is to certify that the thesis entitled **“Quasi-static and Drop Hammer loading of plain and skin reinforced concrete plates”** by Mehtab Alam has been prepared under our supervision and has attained a standard required for a Ph.D. degree of the Institute. The thesis is record of bonafide research work carried out by him and its contents have not been submitted to any other University or Institute for the award of any degree or diploma.



(Dr S M A Kazimi)

Professor
Department of Applied Mechanics
Indian Institute of Technology, Delhi
Hauz Khas, New Delhi - 110016



(Dr N K Gupta)

Professor
Department of Applied Mechanics
Indian Institute of Technology, Delhi
Hauz Khas, New Delhi - 110016

ACKNOWLEDGEMENTS

I express my deep sense of indebtedness to Prof. N. K. Gupta and Prof. S.M. A. Kazimi for their valuable guidance, keen interest, inspiration and constant encouragement throughout this work.

I am extremely grateful to Dr. S. K. Gupta for his valuable suggestions, discussions and guidance during this work.

I am very grateful to my Head of the Department and Dean Faculty of Engineering and Technology JMI for allowing me to carry out this research work. I am thankful to all my colleagues in the Department of Civil Engineering who cooperated me in many ways during the period of this study.

I thank Mr. Q. Hassan, Mr. P. K. Gupta, Dr. N. A. Siddiqui and Dr. Hussain Abbas for their help, guidance and encouragement.

I am thankful to Mr. K. K. Mittal and Mr. Narendar Kumar, Impact Lab. for their advice and help during the experimental work in this thesis.

Thanks are due to Mr. Vikram Singh Rawat, Computation Lab. for the prompt help rendered by him.

Thanks are due to Mr. B. S. Rana and Mr. Hoshier Singh, Strength of Material Lab. for their help during the experimental work.

I also wish to thank to Mr. P. K. Khanna and the workshop staff of IDDC for timely help in the fabrication works.

Finally I express my gratitude to my wife Dr. Aisha Perveen for her encouragement and my daughters Ifrah and Mehak for patience during this study.



Mehtab Alam

ABSTRACT

Concrete is the most commonly used building material and should be a natural choice for the construction of impact and blast resistant structures, or in general for structures under heavy dynamic loads. However it is weak in tension and to improve its tensile strength, it is reinforced by steel in the form of embedded bars (unstressed or pre stressed) and it is called reinforced or pre-stressed concrete. Other option to improve could be external reinforcement by steel sheet using some strong binder and it may be named as skin reinforced concrete (SRC). This could be very effective under impact loading.

To understand the behaviour of plain concrete and SRC plates under impact it is necessary to study, first, their behaviour under quasi-static loading.

In the present study experiments have been performed on plain concrete plate specimens of thickness 25 and 35 mm and of regular strength, 15, 25, 35 MPa, with edge ring (peripheral) and without edge ring. To reinforce these plates of plain concrete, thin steel sheets (0.15 mm and 0.2 mm thick) have been used on rear face or on both faces using Araldite glue. Experiments on these plate specimens of plain concrete and skin reinforced concrete have been performed using a cylindrical penetrator with spherical nose positioned at the centre of the plate (under quasi-static loading and under the impact). Experimental results, in the form of load-deformation and energy- deformation curves have been prepared.

Using the data of present experiments, critical loads have been calculated from Nielsen's analytical formula and Regan's empirical relation, necessary to cause punching of conventional reinforced concrete slabs under a flat cylindrical punch

at the centre. These loads have been compared. A common percentage of reinforcement which satisfies the two formulae has been worked out for different combinations of the parameters and diameter of the cylindrical punch.

Results obtained from the present series of experiments on SRC plates are found to follow the trend of Nielsen's analytical results, while results from plain concrete plates are obviously quite different and do not follow Nielsen's formula meant for R.C.C. Nielsen's results have been modified to incorporate the effect of a hemispherical nose added to the flat cylindrical punch by introducing a so called NOSE SHAPE FACTOR (NSF). The flat punch diameter, multiplied by this factor, and then used in Nielsen's formula, gives the experimental results obtained from quasi-static tests on SRC plates. The NSF value is 0.55 for single skin (at back) and 0.95 for double skin (on both faces), and is obtained from ALL the available data for single skin or double skin plates, using the least square method.

Experimental results from plain concrete plates and SRC plates under impact loading (by a cylindrical impactor with hemispherical nose) have been discussed in the later half of the thesis and interesting conclusion have been drawn from these.

Thus the thesis presents an extensive experimental study on plain concrete plates and SRC plates (having skin on rear face or on both the faces) under quasi-static loading and impact; by cylindrical penetrator, having spherical nose. The present work also suggests the use of nose shape factors for the SRC plates so that Nielsen's analytical results, using flat penetrator, can be modified for more practical cases of hemispherical and other shaped noses.

In the end some suggestions for further research work are given.

TABLE OF CONTENTS

	Page No.
CERTIFICATE	i
ACKNOWLEDGEMENT	ii
ABSTRACT	iii
TABLE OF CONTENTS	v
LIST OF FIGURES	ix
LIST OF TABLES	xxv

CHAPTERS

1.	INTRODUCTION	1
1.1	Introduction	
1.2	Literature Review	4
1.2.1	Mechanical Behavior of Concrete	4
1.2.2	Uni-axial Behavior of Concrete	5
(a)	Static Response	5
(b)	Dynamic Response	9
1.2.3	Bi-axial Behavior of Concrete	12
1.2.4	Tri-axial Behavior of Concrete	13
1.2.5	Quasi-static & Dynamic Loading of Concrete Plates	16
1.2.6	Empirical Formulae	24
1.3	Present Attempt	31
1.4	Organisation of Thesis	32

2.	EXPERIMENTAL SET-UPS AND SPECIMENS	35
2.1	Introduction	35
2.2	Specimens	35
2.2.1	Plain Concrete Plate Specimen	35
2.2.2	Skin Reinforced Araldite Bonded Concrete Plate Specimens	37
2.2.3	Steel Sheet Specimens	38
2.3	Quasi-Static Tests	38
2.3.1	Penetrator	38
2.3.2	Loading Arrangement of Quasi-Static Test	41
2.4	Impact Test	43
2.4.1	The Drop Hammer Set-Up	43
2.4.2	The Drop Mass	43
2.4.3	Support System	45
2.4.4	Residual Energy Arrestor	49
2.4.5	Fixing Arrangement of Load Cell	51
2.5	Data Recording and Instruments in Impact Tests	51
2.5.1	Impact velocity Measurement	52
2.5.2	Load Measurement	54
2.5.3	Acceleration Measurement	54
3.	THEORETICAL AND EXPERIMENTAL BACKGROUND	56
3.1	Introduction	56
3.2	Regan's Formula	57
3.3	Nielsen's Analysis	58
3.4	Comparison of Regan's & Nielsen's Results	67
3.5	Conclusion	73

4.	PLANE CONCRETE PLATES UNDER QUASI-STATIC LOADING	81
4.1	Introduction	81
4.2	Plane Concrete Plate Specimens	81
4.2.1	Specimen without Peripheral Ring (Annular Plate)	82
(a)	Simple Support Condition	82
(b)	Specimen held Between Steel Annular Plate (Flanges)	89
4.2.2	Specimen with Peripheral Ring	94
(A)	Simple Support Condition	94
(B)	Specimen held Between the Flanges (Annular Plates + Edge Ring)	98
4.3	Comparison	111
4.3.1	Effect of flanges (annular plates) on plain concrete plate Without edge ring	111
4.3.2	Effect of flanges (annular plates) on plain concrete plate Without edge ring	111
5.	SKIN REINFORCED CONCRETE PLATES UNDER QUASI-STATIC LOADING	117
5.1	Introduction	117
5.2	Test on Steel Skin	118
5.2.1	Tension Tests	118
5.2.2	Punching Tests	118
5.3	Skin Reinforced Concrete Specimens	122
5.3.1	Details of Tests carried out on SRC Specimens (Skin on rear face only)	126

5.3.2	Details of Tests carried out on SRC	137
	Specimens (Skin on both faces)	
5.4	Comparison of Experimental and Analytical Results	149
5.4.1	SRC Plates (Skin on Rear face only)	149
5.4.2	SRC Plates (Skin on both faces)	149
5.5	Conclusion	152
6.	CONCRETE PLATES UNDER DYNAMIC (IMPACT) LOADING	155
6.1	Introduction	155
6.1.1	Description of the terms	155
6.2	Impact Test Details	157
6.2.1	Load-Acceleration Equation	159
6.3	Impact Tests on Plane Concrete plates	160
6.4	Impact Tests on SRC Plates (Skin on rear face)	169
6.5	Impact Tests on SRC Plates (Skin on both faces)	173
6.6	Conclusion	183
7.	CONCLUSIONS	191
7.1	Introduction	191
7.2	Nielsen's and Regan's approaches	191
7.3	Effect of edge restraints	193
7.4	Effect of skin reinforcement	194
7.5	Impact tests on drop hammer	195
7.6	Conclusions	197
	REFERENCES	199
	BIO-DATA OF THE AUTHOR	204