

**TRANSVERSE COLLAPSE OF SQUARE AND
RECTANGULAR TUBES
AND THEIR CROSS LAYERS**

By

ATUL KHULLAR

APPLIED MECHANICS DEPARTMENT

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**

FEBRUARY, 1993

CERTIFICATE

This is to certify that the thesis entitled ' **Transverse Collapse of Square and Rectangular Tubes and their Cross Layers** ' by Atul Khullar has been prepared under my supervision and has attained a standard required for a Ph.D. degree of the Institute. The thesis is a 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.



(N.K.GUPTA)

Professor,

Applied Mechanics Department,

Indian Institute of Technology, Delhi.

ACKNOWLEDGEMENTS

I am extremely grateful to Professor N.K.Gupta, Department of Applied Mechanics, Indian Institute of Technology, Delhi, for his guidance, inspiration and encouragement throughout this work.

I am grateful to the staff of the Strength of Materials laboratory, the Departmental Workshop, Impact Mechanics Laboratory and the Computational Laboratory for their cooperation.

Finally, I express my gratitude to all my colleagues, friends and family members who have encouraged me during the period of this study.

A handwritten signature in black ink, reading 'Atul Khullar'. The signature is fluid and cursive, with the first letters of the first and last names being capitalized and prominent.

ATUL KHULLAR

**TRANSVERSE COLLAPSE OF SQUARE AND RECTANGULAR TUBES
AND THEIR CROSS LAYERS**

ABSTRACT

Study of the collapse behavior of square and rectangular tubes under lateral loading is very necessary and important as it finds application in the design of energy absorbing devices employed to dissipate kinetic energy of impact in a collision. These devices absorb energy by undergoing large plastic deformation in a controlled manner and the devices or their components are normally discarded and replaced after a single use.

Understanding the mechanics of transverse collapse of square and rectangular tubes is also important, as the tubes represent in shape important vehicular and other structures which need to be designed for their crash-worthiness under impact.

The modes of collapse of these tubes undergoing large plastic deformation are quite complex primarily because of the inherent instability of the slender tube walls. Further, as the compression of tubes proceeds, the manner in which energy is dissipated in the stationary and rolling plastic hinges changes. These changes reflect in the nature of the load-compression and energy-compression curves and, therefore, are important to be understood.

In the present work a systematic study of the lateral compression of single tubes of square and rectangular cross-sections, and their orthogonal and non-orthogonal cross layers was undertaken. Single tubes were laterally compressed between (i) two rigid flat overhanging platens; (ii) between a short width indenter and a platen; and (iii) symmetrically between two short width indenters. Short width indenters were placed both orthogonally and non-orthogonally.

Analyses were carried out for all these cases by considering the appropriate hinge patterns formed and the energy absorbed in the stationary and rolling plastic hinges during the collapse of the tubes.

Experiments were conducted wherein orthogonal and non-orthogonal cross layers of single tube on tube were compressed and their results were compared with those of single tubes compressed between short width indenters and platens. Both orthogonal and non-orthogonal cross layers of these tubes were also laterally compressed between flat platens; number of layers as well as number of tubes in each layer were varied in different experiments. The collapse behavior of these combinations were analyzed and related to the behavior of single tube multi-layered cross systems, and results are presented.

The computed results of the analyses in all the cases have been compared with the respective experiments. Predicted location of hinges, the modes of deformation at different compressions, collapse loads, and the load-compression and energy-compression curves show very good agreement with the experiments in each case.

TABLE OF CONTENTS

	PAGE No.
CERTIFICATE	i
ACKNOWLEDGEMENTS	ii
ABSTRACT	iii
TABLE OF CONTENTS	vi
LIST OF FIGURES	ix
LIST OF TABLES	xviii
NOTATIONS	xix

CHAPTERS

1. INTRODUCTION

1.1 Introduction	1
1.2 Review of Literature	4
1.3 The Present Attempt	8

2. LATERAL COMPRESSION OF A SINGLE TUBE

BETWEEN TWO PLATENS

2.1 Introduction	13
2.2 Experiments	15
2.3 Analysis	20
2.4 Collapse Load Analysis	21
2.4.1 Horizontal Arms	22
2.4.2 Vertical Arms - First set of hinges	26
2.4.3 Vertical Arms - Second set of hinges	32
2.5 A Note on Possible Mid-span Hinges in Horizontal Arms	37
2.6 Post Collapse Analysis	40

2.7 Results and Discussions	45
2.8 A Parametric Study of Collapse Load Variation	61
2.9 Conclusions	67
3. LATERAL COMPRESSION OF A SINGLE TUBE BETWEEN A NARROW WIDTH INDENTER AND A FLAT RIGID PLATEN	
3.1 Introduction	71
3.2 Experiments	71
3.3 Analysis	83
3.4 Results and Discussions	113
3.5 Conclusions	114
4. LATERAL COMPRESSION OF A SINGLE TUBE BETWEEN TWO PARALLEL NARROW WIDTH INDENTERS	
4.1 Introduction	117
4.2 Experiments	119
4.3 Analysis	128
4.4 Results and Discussions	148
4.5 Conclusions	154
5. COLLAPSE OF CROSS LAYERED ARRANGEMENTS OF SQUARE AND RECTANGULAR TUBES	
5.1 Introduction	156
5.2 Experiments	159
5.3 Analysis	178
5.4 Sway Mode	184
5.5 Results and Discussions	195
5.6 Conclusions	201

6. CONCLUSIONS	203
----------------------	-----

REFERENCES	212
------------------	-----

BIO DATA OF THE AUTHOR