

NONLINEAR ANALYSIS OF PLANE FRAME-WALL SYSTEMS

by

SULATA KAYAL

Thesis submitted to the Indian Institute of Technology, Delhi,
for the award of the Degree of


DOCTOR OF PHILOSOPHY

Department of Civil Engineering
Indian Institute of Technology, Delhi

July, 1978

CERTIFICATE

This is to certify that the thesis entitled "Nonlinear Analysis Of Plane Frame-Wall Systems" being submitted by Mrs. Sulata Kayal to the Indian Institute of Technology, Delhi, for the award of the degree of Doctor of Philosophy in Civil Engineering is the bonafide research work carried out by her. Mrs. Kayal has worked under my guidance and supervision and has fulfilled the requirements for the submission of this thesis which to the best of my knowledge has reached the requisite standard. The material contained in this thesis has not been submitted, in part or full to any other University or Institute for the award of any degree or diploma.

 19/7/78

(A.K. Basu)

Professor and Head of the Department,
Department of Civil Engineering,
Indian Institute of Technology,
Delhi

ACKNOWLEDGEMENTS

It is indeed a pleasure to express my profound sense of gratitude to Dr. A.K. Basu (Professor and Head of the Department, Department of Civil Engineering, Indian Institute of Technology, Delhi), for suggesting the problem and supervising the research work reported in this thesis. I recall with the deepest sense of indebtedness the valuable suggestions and kind encouragement of Professor Basu throughout the period of the doctoral programme.

I wish to express my gratitude to all my colleagues for the help extended at various stages. Thanks are especially due to Mrs. Indra Aggrawal of Computer Centre, Dr. A.K. Nagpal, Dr. Anil Kumar and Mr. K.K. Gupta, (my erstwhile colleagues in Indian Institute of Technology, Delhi) for their whole hearted help and encouragement all these years.

The help rendered by Miss Neelam for typing the manuscript and Mr. Raj for tracing the drawings is highly acknowledged.

Last but not the least, it is my pleasure to acknowledge the sympathetic co-operation rendered by Mr. Sunil Kumar Kayal, my husband and Mr. Soumyanil Kayal, my son throughout the period of this project.

Sulata Kayal

(Sulata Kayal)

ABSTRACT

In the thesis analytical methods have been presented for obtaining the complete load-deflection curves of reinforced concrete columns and frames. The methods are based on the finite element technique and take into account both material and geometric non linearity.

A computer method for the analysis of reinforced concrete columns subjected to axial load and uniaxial bending is first presented. Both braced and unbraced columns are considered. The columns can be either elastically restrained or pin ended. A few braced and unbraced reinforced concrete columns are analysed by this method and the results checked against the existing solutions.

This method is then extended to the case of columns under biaxial bending. Again, both braced and unbraced columns are considered. The computer program is verified by solving a few pin-ended and restrained braced columns and comparing the results with existing solutions.

The method is then applied to the computation of the complete load-deflection response of reinforced concrete plane frames subjected to proportional vertical and lateral loading. The program is checked against certain existing solutions.

LIST OF CONTENTS

	<u>Page No.</u>
ABSTRACT	1
NOTATION	3
CHAPTER-1 :	
INTRODUCTION AND LITERATURE REVIEW	8
1.1 Methods of Computation of Collapse Load of Frames.	8
1.2 Methods of Generating Load-Deflection Curves.	10
1.2.1 Individual members.	10
1.2.2 Steel frames	11
1.2.3 Reinforced concrete frames.	14
1.2.4 Reinforced concrete frame-shear wall systems.	19
1.2.5 Comments on the existing methods.	19
1.3 Scope of the Present Thesis.	21
CHAPTER-2 :	
ANALYSIS OF RESTRAINED REINFORCED CONCRETE COLUMNS UNDER UNIAXIAL BENDING.	28
2.1 Method of Analysis.	28
2.1.1 System analysed.	29
2.1.2 Material properties.	29
2.1.3 Assumptions.	32
2.1.4 Finite element method.	33
2.1.4.1 Linear systems.	33
2.1.4.2 Material nonlinearity.	36
2.1.4.3 Geometric nonlinearity.	42
2.1.4.4 Material and geometric nonlinearity.	44

	<u>Page No.</u>	
2.1.5	Selection of beam-column element and derivation of its properties.	45
2.1.6	Analysis for specified load.	63
2.1.7	Analysis for specified nodal edge strain.	67
2.1.8	Subroutines.	69
2.1.8.1	Determination of moment at a cross-section for a given axial load and curvature.	69
2.1.8.2	Determination of axial load and moment at a cross-section for a given edge strain (maximum compressive) and curvature.	72
2.1.9	Steps in the complete analysis.	75
2.2	Numerical Results.	77
2.3	Discussion.	88
2.4	Conclusions.	92
CHAPTER-3:	ANALYSIS OF RESTRAINED REINFORCED CONCRETE COLUMNS UNDER BI-AXIAL BENDING.	94
3.1	Method of Analysis.	94
3.1.1	System analysed.	94
3.1.2	Assumptions.	97
3.1.3	Analysis for specified load.	97
3.1.4	Analysis for specified corner strain.	102
3.1.5	Subroutines.	103
3.1.5.1	Determination of axial load and bi-axial moments for a given corner strain and bi-axial curvatures.	104
3.1.5.2	Determination of bi-axial moments for given axial load and bi-axial curvatures.	108
3.1.6	Steps in the complete analysis.	110
3.2	Numerical Results.	113
3.3	Conclusions.	124

		<u>Page No.</u>
CHAPTER-4:	NON-LINEAR ANALYSIS OF REINFORCED CONCRETE PLANE FRAMES	127
4.1	General.	127
4.2	Method of Analysis.	128
4.2.1	Assumptions and limitations.	129
4.2.2	System analysed.	129
4.2.3	Elastic properties of frame members.	132
4.2.4	Analysis for specified load.	135
4.2.5	Analysis for specified edge strain in the column.	136
4.2.6	Steps in the complete analysis.	138
4.3	Numerical Results.	141
4.4	Summary and Conclusions.	146
CHAPTER-5:	BEHAVIOUR OF REINFORCED CONCRETE FRAME-WALL SYSTEMS	149
5.1	Introduction.	149
5.2	Method of Analysis.	155
5.2.1	Assumptions and limitations.	155
5.2.2	Elastic properties of frame-wall members.	155
5.2.3	Analysis for specified load.	158
5.2.4	Analysis for specified edge strain in the column.	159
5.2.5	Steps in the complete analysis.	159
5.3	Behaviour of the Frame-Wall System.	160
5.3.1	Different variables studied.	160
5.3.2	Cross-sections used.	161
5.3.3	Non-dimensionalisation of the results.	163
5.3.4	Forces, moments and deflections of the systems at failure - single storeyed system.	164

	<u>Page No.</u>
5.3.4.1	Single storeyed system - case 1. 168
5.3.4.2	Single storeyed system - case 2. 176
5.3.4.3	Effect of nonlinearity in the shear wall on the failure load of the system - single storeyed cases. 179
5.3.5	Forces, moments and deflections of the systems at failure - two storeyed system. 181
5.3.5.1	Two storeyed system - case 1. 181
5.3.5.2	Two storeyed system - case 2. 187
5.3.5.3	Effect of nonlinearity in the shear wall on the failure load of the system - two storeyed cases. 190
5.3.6	Behaviour of the frame-wall systems under progressive loading upto failure - single storeyed system. 193
5.3.6.1	Single storeyed system - case 1. 193
5.3.6.2	Single storeyed system - case 2. 216
5.3.7	Behaviour of the frame-wall systems under progressive loading upto failure - two storeyed systems. 218
5.3.7.1	Systems with flexible walls ($I_W/I_C = 1$). 218
5.3.7.2	Systems with stiff walls ($I_W/I_C = 50$). 236
5.4	Conclusions. 240
CHAPTER-6:	APPLICATION TO DESIGN 243
6.1	General 243
6.2	Method of Checking the Design 243
6.3	Numerical Example. 250

CHAPTER-7:	CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK	260
7.1	Conclusions.	260
7.1.1	Computational aspects	261
7.1.2	Behaviour of frame-wall systems	263
7.2	Recommendations For Further Research	264
APPENDIX -1	ALTERNATIVE APPROACH OF TAKING GEOMETRIC NONLINEARITY INTO ACCOUNT	266
APPENDIX -2	DERIVATION OF SIX-DEGREE BEAM- COLUMN ELEMENT	269
