

Acknowledgement

would like to express my sincere gratitude to Prof. M. T. R. Jayasinghe, without whom this research could not have been possible. He not only provided direction and guidance through the course of this research, but also inspired me to really learn and understand structural engineering.

In addition, I am grateful to the Vice Chancellor, Dean of the Faculty of Engineering and Head of the Department of Civil Engineering of the University of Moratuwa, for the permission granted for this research work. Further, I wish to offer my thanks to the Co-ordinator of the Post Graduate research work of Structural Engineering and all the lecturers of the Department of Civil Engineering who helped me in numerous ways.

Special thanks go to my parents for their endless support and encouragement and for always believing and helping me to believe, that I can succeed at anything.

I am particularly indebted to Eng. B. A. Dayananda, Managing Director of Dayananda Associates (Pvt) Ltd, who encouraged me and helped in numerous ways to make this research a success.



University of Moratuwa, Sri Lanka
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

I wish to thank the librarian and the staff of the library for the co-operation extended to me for this research work.

In addition, my thanks are due to my fellow graduate students for the academic support and Eng. (Ms.) Leja Thilakaratne, who read parts of the manuscripts and made constructive criticisms.

There are many who helped me to succeed in Education from my childhood to date. Finally, I regret the inability to thank individually them, but I offer my heartiest thanks to them all.

Buddhika Edirisooriya
September 2009

Contents

Acknowledgement	ii
Contents	iii
List of figures	vii
List of Tables	x

Chapter 1

Introduction

General	1
Objectives	2
Methodology	2
Arrangement of the Thesis	3

Chapter 2

Literature review



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

General	4
Analysis of the structure	5
2.2.1 Geometric non-linearity	8
2.2.1.1 Geometric imperfections	8
2.2.1.2 Accidental eccentricities	8
2.2.2 Material non-linearity	9
3 Second Order (non-linear) analysis	10
4 P- Delta effect	10
2.4.1 P- δ Effect	12
2.4.2 Some analytical P- Δ methods	16
2.4.2.1 Method proposed by Schueller W.	16
2.4.2.2 Storey magnifier method	19
2.4.2.3 Multiple-Column magnifier method	21
2.4.2.4 Negative brace method	22
2.4.2.5 "Pseudo" Approaches	23
2.4.2.5.1 "Pseudo Loads" Approach	23
2.4.2.5.2 "Pseudo Displacement" Approach	23

2.4.2.6 The two cycle iterative method	24
2.4.2.7 AISC (American Institute of Steel Construction) Procedure	24
2.4.2.8 Non-Linear Static (Full Newton Rapson) analysis	25
2.5 Requirement for computer based 3-D Modelling for assessment of P-Delta	25
2.6 Structural analysis by software SAP-2000	26
2.6.1 Non-linear analysis in SAP-2000	26
2.6.2 P-Delta analysis in SAP-2000	27
2.6.3 Verification of results of SAP-2000	28
2.7 Summary	30

Chapter 3

Structural forms and loads applied for case study

3.1 General	31
3.2 Geometry of structure	31
3.2.1 Vertical circulation	33
3.2.2 Service core and Shear walls	34
3.2.3 Different floor usages and applied gravity loads	34
3.2.4 Initial member sizing	35
3.3 Properties of structure	35
3.4 Loading to be applied on the structures	36
3.4.1 Dead and Imposed (Live) loads	36
3.4.2 Lateral loads	36
3.4.2.1 Wind speeds to be adopted in Sri Lanka	36
3.4.2.2 Wind Load Calculation	38
3.5 Structural forms for Case Study	38
3.5.1 Case Study (1) – 30 Storeyed building with hard zoning lift arrangement	38
3.5.2 Case Study (2) – 40 Storeyed building with soft zoning lift arrangement	41
3.5.3 Case Study (3) – 40 Storeyed building with hard zoning lift arrangement	42
3.5.4 Case Study (4) – 45 Storeyed building with hard zoning lift arrangement	45

Chapter 4

Computer modelling and case study

4.1 General	48
4.2 Computer modelling	48
4.2.1 Load cases and Combinations	48
4.2.2 Element selection for study	49
4.3 Results and Observation.....	51
4.3.1 Results for 30 storeyed building with hard zoning lift arrangement	52
4.3.2 Results for 40 storeyed building with soft zoning lift arrangement	60
4.3.3 Results for 40 storeyed building with hard zoning lift arrangement	68
4.3.4 Results for 45 storeyed building with hard zoning lift arrangement	76
4.4 Comparison and Interpretation of results	85
4.4.1 Effects on beam elements	89
4.4.2 Effects on column elements	90

Chapter 5

Conclusion and future works

5.1 Conclusion	91
5.2 Future works	92



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

Appendices

Appendix A

Calculations – Determination of structural form for 30 storeyed building with hard zoning lift arrangement

A.1 Initial Member Sizing	93
A.2 Design of lifts (using hard zoning technique) and Staircase	96
A.3 Calculation of shear wall properties at ground floor level	99

Appendix B

Calculations – Determination of structural form for 40 storeyed building with soft zoning lift arrangement

B.1 Initial Member Sizing	101
B.2 Design of lifts (using soft zoning technique) and Staircase	105
B.3 Calculation of shear wall properties at ground floor level	109

Appendix C

Calculations – Determination of structural form for 40 storeyed building with hard zoning lift arrangement

C.1 Initial Member Sizing	111
C.2 Design of lifts (using hard zoning technique) and Staircase	115
C.3 Calculation of shear wall properties at Ground Floor Level	118

Appendix D

Calculations – Determination of structural form for 45 storeyed building with hard zoning lift arrangement

D.1 Initial Member Sizing	121
D.2 Design of lifts (using hard zoning technique) and Staircase	126
D.3 Calculation of shear wall properties at ground floor level	128

Appendix E

Calculation of wind loads

E.1 Specimen Calculation for wind loads	130
E.2 Wind load on 30 storeyed building with hard zoning lift arrangement	132
E.3 Wind load on 40 storeyed building with soft zoning lift arrangement	133
E.4 Wind load on 40 storeyed building with hard zoning lift arrangement.....	134
E.5 Wind load on 45 storeyed building with hard zoning lift arrangement.....	135

References	136
------------------	-----

List of figures

Chapter 2

Figure 2. 1	Structural System	4
Figure 2. 2	Basic equilibrium equation	6
Figure 2. 3	Fixed ended cantilever beam	7
Figure 2. 4	Action vs. Deformation charts for different analysis types	7
Figure 2. 5	Non-Linear Stress-Strain curve	9
Figure 2. 6	Final stiffness of structure is affected by material stiffness, member Geometry And Structure Geometry	9
Figure 2. 7	P-Delta Effect	11
Figure 2. 8	P- δ Effect	12
Figure 2. 9	Moment magnification factor, A_F (AISC specification)	15
Figure 2.10	P- Δ effect upon the building	16
Figure 2.11	P- Δ effect at Storey Level	19
Figure 2.12	P- Δ effect arising from Load/Frame Asymmetry	20
Figure 2.13	Procedure to determine the second-order deflection, Δ and moment, M for Load/Frame Asymmetry	21
Figure 2.14	Example problem for Result Verification	28
Figure 2.15	Output of P- Δ Analysis from SAP2000 Version 12, for the example problem	29

Chapter 3

Figure 3. 1	Wind Zones in Sri Lanka	37
Figure 3. 2	Layout of 30 storeyed building with hard zoning lift arrangement	40
Figure 3. 3	Layout of 40 storeyed building with soft zoning lift arrangement	42
Figure 3. 4	Layout of 40 storeyed building with hard zoning lift arrangement	43
Figure 3. 5	Layout of 45 storeyed building with hard zoning lift arrangement	46

Chapter 4

Figure 4. 1	Local axes of element	50
Figure 4. 2	Selected elements for study	50
Figure 4. 3	30 Storeyed, Hard Zoning Building – Results of Outer Column – OC	52
Figure 4. 4	30 Storeyed, Hard Zoning Building – Results of Inner Column – IC	53

Figure 4. 5	30 Storeyed, Hard Zoning Building – Results of Outer Beam – OB[X]-Wind X	.....54
Figure 4. 6	30 Storeyed, Hard Zoning Building – Results of Outer Beam – OB[X]-Wind Y	.....55
Figure 4. 7	30 Storeyed, Hard Zoning Building – Results of Outer Beam – OB[Y]-Wind X	.....55
Figure 4. 8	30 Storeyed, Hard Zoning Building – Results of Outer Beam – OB[Y]-Wind Y	.....56
Figure 4. 9	30 Storeyed, Hard Zoning Building – Results of Inner Beam – IB[X]-Wind X	.....57
Figure 4.10	30 Storeyed, Hard Zoning Building – Results of Outer Beam – IB[X]-Wind Y	.....58
Figure 4.11	30 Storeyed, Hard Zoning Building – Results of Inner Beam – IB[Y]-Wind X	.....58
Figure 4.12	30 Storeyed, Hard Zoning Building – Results of Inner Beam – IB[Y]-Wind Y	.....59
Figure 4.13	40 Storeyed, Soft Zoning Building – Results of Outer Column – OC	.....60
Figure 4.14	40 Storeyed, Soft Zoning Building – Results of Inner Column – IC	.....61
Figure 4.15	40 Storeyed, Soft Zoning Building – Results of Outer Beam – OB[X]-Wind X	.....62
Figure 4.16	40 Storeyed, Soft Zoning Building – Results of Outer Beam – OB[X]-Wind Y	.....63
Figure 4.17	40 Storeyed, Soft Zoning Building – Results of Outer Beam – OB[Y]-Wind X	.....63
Figure 4.18	40 Storeyed, Soft Zoning Building – Results of Outer Beam – OB[Y]-Wind Y	.....64
Figure 4.19	40 Storeyed, Soft Zoning Building – Results of Inner Beam – IB[X]-Wind X	.....65
Figure 4.20	40 Storeyed, Soft Zoning Building – Results of Outer Beam – IB[X]-Wind Y	.....66
Figure 4.21	40 Storeyed, Soft Zoning Building – Results of Inner Beam – IB[Y]-Wind X	.....66
Figure 4.22	40 Storeyed, Hard Zoning Building – Results of Outer Beam – IB[Y]-Wind Y	.....67
Figure 4.23	40 Storeyed, Hard Zoning Building – Results of Outer Column – OC	.....68
Figure 4.24	40 Storeyed, Hard Zoning Building – Results of Inner Column – IC	.....69
Figure 4.25	40 Storeyed, Hard Zoning Building – Results of Outer Beam – OB[X]-Wind X	.....70
Figure 4.26	40 Storeyed, Hard Zoning Building – Results of Outer Beam – OB[X]-Wind Y	.....71
Figure 4.27	40 Storeyed, Hard Zoning Building – Results of Outer Beam – OB[Y]-Wind X	.....71
Figure 4.28	40 Storeyed, Hard Zoning Building – Results of Outer Beam – OB[Y]-Wind Y	.....72
Figure 4.29	40 Storeyed, Hard Zoning Building – Results of Inner Beam – IB[X]-Wind X	.....73
Figure 4.30	40 Storeyed, Hard Zoning Building – Results of Outer Beam – IB[X]-Wind Y	.....74
Figure 4.31	40 Storeyed, Hard Zoning Building – Results of Inner Beam – IB[Y]-Wind X	.....74
Figure 4.32	40 Storeyed, Hard Zoning Building – Results of Outer Beam – IB[Y]-Wind Y	.....75
Figure 4.33	45 Storeyed, Hard Zoning Building – Results of Outer Column – OC	.....76
Figure 4.34	45 Storeyed, Hard Zoning Building – Results of Inner Column – IC	.....77
Figure 4.35	45 Storeyed, Hard Zoning Building – Results of Outer Beam – OB[X]-Wind X	.....78
Figure 4.36	45 Storeyed, Hard Zoning Building – Results of Outer Beam – OB[X]-Wind Y	.....79
Figure 4.37	45 Storeyed, Hard Zoning Building – Results of Outer Beam – OB[Y]-Wind X	.....79
Figure 4.38	45 Storeyed, Hard Zoning Building – Results of Outer Beam – OB[Y]-Wind Y	.....80
Figure 4.39	45 Storeyed, Hard Zoning Building – Results of Inner Beam – IB[X]-Wind X	.....81

Figure 4.40	45 Storeyed, Hard Zoning Building – Results of Outer Beam – IB[X]-Wind Y	.....82
Figure 4.41	45 Storeyed, Hard Zoning Building – Results of Inner Beam – IB[Y]-Wind X	.....83
Figure 4.42	45 Storeyed, Hard Zoning Building – Results of Outer Beam – IB[Y]-Wind Y	.....84

Appendices

Figure A 3.1	30 Storeyed, Hard Zoning Building – Lift core Arrangement at ground floor level	....99
Figure A 3.2	30 Storeyed, Hard Zoning Building – Shear walls at ground floor level	.....99
Figure B 3.1	40 Storeyed, Soft Zoning Building – Lift core Arrangement at ground floor level	....110
Figure B 3.2	40 Storeyed, Soft Zoning Building – Shear walls at ground floor level	.....110
Figure C 3.1	40 Storeyed, Hard Zoning Building – Lift core Arrangement at ground floor level	....118
Figure C 3.2	40 Storeyed, Hard Zoning Building – Shear walls at ground floor level	.....118
Figure D 3.1	45 Storeyed, Hard Zoning Building – Lift core Arrangement at ground floor level	....128
Figure D 3.2	45 Storeyed, Hard Zoning Building – Shear walls at ground floor level	.....128



University of Moratuwa, Sri Lanka.
 Electronic Theses & Dissertations
www.lib.mrt.ac.lk

List of Tables

Chapter 2

Table 2.1 Basic Analysis Types.....	5
Table 2.2 Values of ψ and C_m factors for beam-columns under transverse loading	14
Table 2.3 Comparison of End moments	29

Chapter 3

Table 3.1 High rise buildings in Sri Lanka (Dharmawardana,2003)	32
Table 3.2 Grade of concrete and their properties as per BS8110:1985.....	35
Table 3.3 Recommended basic wind speed for Sri Lanka	37

Chapter 4

Table 4.1 Result Comparison for Beam Elements	87
Table 4.2 Result Comparison for Column Elements	88
Table 4.3 Moments of resistance for 600mmX300mm beam of Grade 30 concrete	89
Table 4.4 Second moment of area of shear walls at base level	90

Appendices

Table E.1 Wind Force on 30 storeyed building with hard zoning lift arrangement	132
Table E.2 Wind Force on 40 storeyed building with soft zoning lift arrangement	133
Table E.3 Wind Force on 40 storeyed building with hard zoning lift arrangement	134
Table E.4 Wind Force on 45 storeyed building with hard zoning lift arrangement	135