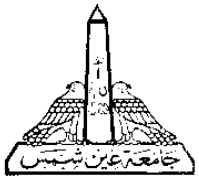


Ain Shams University
Faculty of Engineering
Structural Engineering

FINITE ELEMENT MODELLING OF STRUCTURES SUBJECTED TO THERMAL LOADING

A Thesis submitted in partial fulfilment of the requirements of the degree of

Master of Science in Civil Engineering

(Structural Engineering)

By

Mohamed Ahmed Abdul Rahim Mohamed Turk

Bachelor of Science in Civil Engineering

Faculty of Engineering, Helwan University, 2012

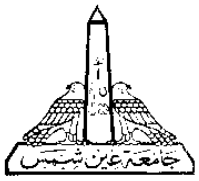
Supervised By

Prof. Gamal Hussein Mahmoud

Ass. Prof. Hisham Ahmed El-Arabaty

Dr. Nasr Eid Nasr

Cairo - (2019)



Ain Shams University
Faculty of Engineering
Structural Engineering

FINITE ELEMENT MODELLING OF STRUCTURES SUBJECTED TO THERMAL LOADING

By

Eng. Mohamed Ahmed Abdul Rahim Mohamed Turk

Bachelor of Science in Civil Engineering
Faculty of Engineering, Helwan University, 2012

Examiners' Committee

Name and Affiliation	Signature
Prof. Hala Mohamed Gamal Eldin Prof. of Structural Engineering Housing and Building National Research Center	…….
Prof. Mohamed Noor Eldin Saad Fayed Prof. of Structural Engineering Faculty of Engineering, Ain Shams University	…….
Prof. Gamal Hussein Mahmoud Prof. of Structural Engineering Faculty of Engineering, Ain Shams University	…….
Ass. Prof. Hisham Ahmed El-Arabaty Ass. Prof. of Structural Engineering Faculty of Engineering, Ain Shams University	…….

Date: 12 June 2019

STATEMENT

This thesis is submitted as a partial fulfilment of Master of Science in Civil Engineering, Faculty of Engineering, Ain shams University.

The author carried out the work included in this thesis, and no part of it has been submitted for a degree or a qualification at any other scientific entity.

Mohamed Ahmed Abdul Rahim Mohamed Turk

Signature

……..…….

Date: 12 June 2019

RESEARCHER DATA

Name :

Mohamed Ahmed Abdul Rahim Mohamed Turk

Date of birth : 22/4/1990

Place of birth : Egypt

Last academic degree : B.Sc. in Civil Engineering

Field of specialization : Structural Engineering

University issued the degree : Helwan University

Date of issued degree : 2012

Current job : Structural design engineer

To My Parents....

ACKNOWLEDGEMENT

First, I should state the greatest thanks to our **God** that it is only by his willing I have succeeded to finalize this work.

I would like to thank deeply my supervisor **Dr. Gamal Hussein Mahmoud**, for his great patience, continued guidance, encouragement, helpful advice and excellent supervision during the research and patience in reviewing the drafts and results during the preparation of this thesis.

I am deeply grateful to **Dr. Hisham Ahmed El-Arabaty**, for his encouragement, helpful advice, excellent supervision and patience in reviewing the drafts and results during the preparation of this thesis. Great thanks also to his fruitful support in the review and correspondences of the publications of this work.

I would like to thank my supervisor **Dr. Nasr Eid Nasr**, for his great patience, continued guidance, encouragement, helpful advice and excellent supervision during the research and patience in reviewing the drafts and results during the preparation of this thesis.

Last but not least, I **dedicate** this thesis to my **"Mother's soul"**, my supportive and loving **"Father"**, my very special, cheerful and loving **"Wife"**, and I am grateful to all of my **"Family"** for their patience, support and encouragement during the research period.

Thank you all….

ABSTRACT

Thermal analysis of RC structures under the effect of uniform temperature change poses a special kind of problem, where the high axial stiffness of horizontal beam elements used in finite element analysis produces correspondingly high lateral forces, and straining actions in the supporting columns, especially the ground floor columns. This effect is most pronounced for the external columns.

In this study, a novel proposal is made for developing an analytical approach for assessment of the effect of bending cracks along the beam length on its axial stiffness. The proposed approach is utilized for the development of a software package for the computation of the effective axial stiffness of beams, taking into consideration the resulting cracked-section strains at the top and bottom fibers of the beam sections along its length. Effect of applying varying axial force levels to the beam is studied in detail, and curves are developed showing the variation of the beam's axial stiffness with the applied axial loads. Effect of different parameters including steel reinforcement level, and span length are also taken into account.

The developed relationship curves are utilized using a newly developed analytical algorithm for the iterative analysis of RC multi-storey frames under the effect of thermal expansion/contraction. A new Excel/Visual Basic software package is developed , and used to control and perform iterative analysis runs on ETABS program, while continually modifying the axial stiffness modification factors of the beams, to reach the accurate value of the modification factors at convergence.

A group of building frames designed according to the Egyptian code of Practice are used for application of the newly devleoped algorithm and software package, and the effect of

different numbers of floors on the axial forces developed in thermal analysis is investigated, with emphasis on estimation of the applicable modification factors in each case. The practical values obtained for these modification factors are compared to the common code specifications, and the common practice in design offices in the Egyptian market. Several gemoetric and section properties of the beam elements in the studied buildings are varied to widen the range of the study. The analysis results are used to develop useful recommendations for design engineers in this field.

Keywords: Thermal Analysis, Temperature Changes, Finite Element Modeling, Concrete Cracking, Axial stiffness, Reinforced Concrete, Tensile Stress.

TABLE OF CONTENTS

STATEMENT III
RESEARCHER DATA IV
ACKNOWLEDGEMENT VI
ABSTRACT VII
TABLE OF CONTENTS IX
LIST OF FIGURES XII
LIST OF TABLES XV
LIST OF SYMBOLS XVI
Chapter 1 1
Introduction 1
1.1 Background 1
1.2 Outline of the Thesis 1
Chapter 2 5
Effect of Concrete Cracking in Thermal Analysis 5
2.1 Introduction 5
2.2 Concrete Cracking 5
2.3 Development of Cracks 5
2.3.1 Causes of Cracking 7
2.4 Effect of Cracking on Axial Stiffness 12
2.5 Different Techniques for Thermal Analysis 13
Chapter 3 18
Analytical Algorithm and Computation of Beam Axial Stiffness Variation 18
3.1 Introduction 18
3.2 Analytical Algorithm 21

3.3 Step by Step Procedure for Computation of Beam Axial Stiffness 25
3.4 Variation of Beam Stiffness with Applied Axial Load 28
3.5 Results and Discussion 31
3.5.1 Effect of Span Length 34
3.5.2 Effect of Section Dimensions 35
3.5.3 Effect of Area of Steel Reinforcement in Section 38
Chapter 4 45
Interactive Implementation of Axial Stiffness Reduction Factors in Thermal Analysis of Multistory Buildings (Case Study) 45
4.1 Introduction 45
4.2 Analytical Algorithm 46
4.3 Selection of Analysis Cases 49
4.4 Iterative Analysis of Model 1 51
4.5 Effect of Building Number of Storeys 56
4.6 Parametric Study 60
4.6.1 Effect of Steel Reinforcement Area 60
4.6.2 Effect of Span Length 64
4.6.3 Effect of Section Dimensions 67
Chapter 5 72
Conclusions and Recommendations for Future Research 72
5.1 Conclusion 72
5.2 Recommendations for Future Researches 75
APPENDICES 78
5.3 Appendix (1): Results of All Cases in Chapter (3) 78

5.4 Appendix (2): Results of All Cases in Chapter (4) 88
REFERENCES..... 94

LIST OF FIGURES

Figure 2-1: Primary and secondary cracks in a reinforced concrete tension member 6
Figure 2-2: Relations between shrinkage and time for concretes stored at different relative humidities. Time reckoned since end of wet curing at 28 days (Troxell, Raphael, and Davis 1958) 7
Figure 2-3: Cracking of concrete due to drying shrinkage 8
Figure 2-4: Effect of creep on tensile stress..... 9
Figure 2-5: Basic concept of shrinkage-compensating concrete 11
Figure 2-6: Length-change characteristics for shrinkage-compensating and portland cement concrete 11
Figure 2-7: Tensile load versus strain diagram..... 13
Figure 3-1: The expected deformed shape of a multistory building under uniform temperature 18
Figure 3-2: Symmetrical RC frame..... 19
Figure 3-3: Influence of temperature change on structure deformation 19
Figure 3-4: a) Elongation of Top & Bottom beam fibers due to vertical loads only b) Beam stresses at specific locations 22
Figure 3-5: a) Compression force “P1” due to beam expansion b) Strain distribution in cracked section at D-D due to moment only c) Strain distribution in cracked section at D-D due to combined effect of moment and axial force together 23
Figure 3-6: Analysis procedure flowchart to calculate the axial modifiers for beams’ stiffness..... 27
Figure 3-7: Beam cross-section for at a) “negative moment” regions b) “positive moment” regions 29
Figure 3-8: Force-Displacement curve for beam in axial direction 30
Figure 3-9: Force-Reduction factor curve for beam in axial direction 31
Figure 3-10: Effect of span length 35

Figure 3-11: Effect of section dimensions 38
Figure 3-12: Effect of steel reinforcement percentage in section 43
Figure 4-1: Flowchart for the iterative computation of applicable modifiers for beams' axial stiffness coefficients in multi-storey building analysis 48
Figure 4-2: Layout of RC frames for 3 multistory buildings a) 12 Storeys b) 8 Storeys c) 4 Storeys 50
Figure 4-3: Force-displacement curve for beam in axial direction (Models 1A, 1B & 1C)..... 51
Figure 4-4: Force-Reduction factor curve for beam in axial direction (Models 1A, 1B & 1C) 52
Figure 4-5: Variation of axial force with iteration number till convergence 54
Figure 4-6: Variation of axial stiffness reduction factors with iteration number till convergence 55
Figure 4-7: Variation of axial force with iteration number for buildings of different numbers of storeys 57
Figure 4-8: Variation of axial stiffness reduction factors with iteration number for buildings of different numbers of storeys 58
Figure 4-9: Final axial force values after convergence for Models 1A, 1B & 1C for expansion and contraction cases 59
Figure 4-10: Final axial stiffness reduction factors after convergence for Models 1A, 1B & 1C for expansion and contraction cases 59
Figure 4-11: Effect of steel reinforcement amount (Thermal expansion case) 62
Figure 4-12: Effect of steel reinforcement amount (Thermal contraction case) 63
Figure 4-13: Effect of span length (Thermal expansion case).. 66
Figure 4-14: Effect of span length (Thermal contraction case) 67
Figure 4-15: Effect of section dimensions (Thermal expansion case) 69

Figure 4-16: Effect of section dimensions (Thermal contraction case) 70

LIST OF TABLES

Table 3-1: Summary of the Data Used in the Analysis to Compute the Variation in Beam Axial Stiffness 33
Table 4-1: Beam data and number of storeys of different analysis models 50
Table 4-2: Beams' axial forces resulting from iterative analysis under thermal Expansion/Contraction for 12-Storeys building (Model 1A)..... 52
Table 4-3: Beams' axial force reduction factors under thermal expansion/contraction for 12-Storeys building (Model 1A)..... 53
Table 4-4: Comparison of analysis results for Cases 1 & 5 under thermal expansion after convergence..... 61
Table 4-5: Comparison of analysis results for Cases 1 & 5 under thermal contraction after convergence..... 61
Table 4-6: Comparison of analysis results for Cases 2, 3 & 4 under thermal expansion after convergence 64
Table 4-7: Comparison of analysis results for Cases 2, 3 & 4 under thermal contraction after convergence..... 65
Table 4-8: Comparison of analysis results for Cases 1 & 2 under thermal expansion after convergence..... 68
Table 4-9: Comparison of analysis results for Cases 1 & 2 under thermal contraction after convergence..... 68
Table I: Results of Software Package (1) ……...…… 78
Table II: Results of Software Package (2) ……..……. 88