



بسم الله الرحمن الرحيم

∞∞∞∞

تم رفع هذه الرسالة بواسطة / سامية زكى يوسف

بقسم التوثيق الإلكتروني بمركز الشبكات وتكنولوجيا المعلومات دون أدنى

مسئولية عن محتوى هذه الرسالة.

ملاحظات: لا يوجد





Cairo University

NON-LINEAR ANALYSIS OF STEEL BUILDINGS WITH OPTIMIZATION OF DAMPER PLACEMENT

By

Ismail Ibrahim Ismail Amara

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
Structural Engineering

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2022

NON-LINEAR ANALYSIS OF STEEL BUILDINGS WITH OPTIMIZATION OF DAMPER PLACEMENT

By
Ismail Ibrahim Ismail Amara

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
Structural Engineering

Under the Supervision of

Prof. Dr. Sherif A. Mourad

.....

Professor of Steel Structures and Bridges
Structural Engineering Department
Faculty of Engineering, Cairo University

Dr. Hazem H. El-Anwar

.....

Assistant Professor
Structural Engineering Department
Faculty of Engineering, Cairo University

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2022

NON-LINEAR ANALYSIS OF STEEL BUILDINGS WITH OPTIMIZATION OF DAMPER PLACEMENT

By
Ismail Ibrahim Ismail Amara

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
Structural Engineering

Approved by the
Examining Committee

Prof. Dr. Sherif A. Mourad,

Thesis Main Advisor

Prof. Dr. Sherif S. Safar,

Internal Examiner

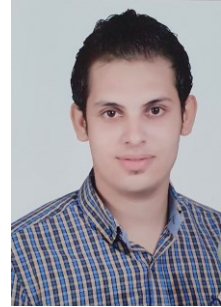
Prof. Dr. Ayman A. Seleema,

External Examiner

- Professor of Structural Engineering
Structural Engineering Department
Faculty of Engineering, Tanta University

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2022

Engineer's Name: Ismail Ibrahim Ismail Amara
Date of Birth: 01/07/1993
Nationality: Egyptian
E-mail: ismailamaraa@gmail.com
Phone: +201012309313
Address: El Gharbia-Egypt
Registration Date: 01/03/2017
Awarding Date: / /2022
Degree: Master of Science
Department: Structural Engineering



Supervisors:

Prof. Sherif A. Mourad
Dr. Hazem Hosam El-Din El-Anwar

Examiners:

Prof. Dr. Sherif A. Mourad (Thesis main advisor)
Prof. Dr. Sherif S. Safar (Internal examiner)
Prof. Dr. Ayman A. Seleema (External examiner)

Professor of Structural Engineering
Structural Engineering Department
Faculty of Engineering, Tanta University

Title of Thesis:

NON-LINEAR ANALYSIS OF STEEL BUILDINGS WITH OPTIMIZATION OF DAMPER PLACEMENT

Key Words:

Structural dynamics; Inelastic behavior; Tuned mass damper; Nonlinear energy sink; Genetic algorithms

Summary:

This thesis investigates the mitigation of excessive vibrations in multistory steel buildings subjected to lateral loads using linear and nonlinear TMDs. Three types of stiffness mechanisms of TMDs were studied: linear, essential nonlinear (without linear part), and nonlinear (with linear part). Also, an algorithm of the nonlinear direct integration dynamic analysis was developed by MATLAB software. In order to evaluate the effectiveness of dampers in suppressing the undesired vibrations, a set of eight earthquake events possessing a diverse frequency content were used. The minimum dynamic response of the structures for each seismic event was obtained by opting for the proper parameters of the damper. Thus, an optimization process via genetic algorithms (GAs) and particle swarm optimization (PSO) methods was adopted in this study to obtain the optimal parameters and location for each type of dampers.

Disclaimer

I hereby declare that this thesis is my own original work and that no part of it has been submitted for a degree qualification at any other university or institute.

I further declare that I have appropriately acknowledged all sources used and have cited them in the references section.

Name: Ismail Ibrahim Ismail Amara

Date: / /2022

Signature:

Dedication

To My Parents, Brothers, and Friends.

Acknowledgments

First and foremost, I would like to express my heartfelt gratitude to Almighty **Allah** for all my achievements.

I am honored to work under the supervision of **Prof. Shrief Ahmed Mourad** and **Dr. Hazem H. AL-Anwar** who brought this work to a higher level. I would like to express my sincere appreciation and thanks to my supervisors on one hand for their extensive knowledge, immense encouragement, and keen intuition when I am encountered with challenges in doing this research. On the other hand, they showed great patience and enthusiasm throughout the whole path to this thesis.

I would also like to extend my sincere thanks to **Dr. Hussam N. Mahmoud**. I strongly believe that I was able to improve my analyses and my knowledge further due to his insightful comments.

Also, I would like to thank my colleagues, Mahmoud and Omar, in my research group for their help and support. I want to thank all those, who helped me with their knowledge and experience. I will always appreciate their efforts.

I want to express my thanks to **Brigadier-General Adel El-Deighedy** for his support and for providing me the time I needed to pursue my courses during my military service in the Egyptian Army.

My best friends, Amr, Talal, Osama, Hassan, and other friends deserve my special thanks for their inspiration and for providing me with the backbone to confront tough times.

Lastly, my family (my parents, my brothers, Ahmed, Mohamed, and Mahmoud) deserves endless gratitude for their unconditional love, encouragement, blessings, and unequivocal supports. The author has no words to express what they gave him or how helpful they are. Briefly, I always am indebted to them.

Table of Contents

DISCLAIMER	I
DEDICATION	II
ACKNOWLEDGMENTS.....	III
TABLE OF CONTENTS	IV
LIST OF TABLES.....	VII
LIST OF FIGURES.....	IX
ABSTRACT	XIII
CHAPTER 1 : INTRODUCTION	1
1.1. GENERAL	1
1.2. STATEMENT OF THE PROBLEM	3
1.3. OBJECTIVES AND MOTIVATION OF THIS STUDY	4
1.4. FRAMEWORK OF THE THESIS	4
1.5. ORGANIZATION OF THE THESIS.....	5
CHAPTER 2 : LITERATURE REVIEW	7
2.1. INTRODUCTION.....	7
2.2. LINEAR TUNED MASS DAMPERS	7
2.3. NONLINEAR TUNED MASS DAMPER.....	10
2.4. OPTIMIZATION TECHNIQUES.....	13
2.4.1. Genetic Algorithms.....	13
2.4.2. Particle Swarm Optimization.....	16
2.4.3. Other optimization methods.....	19
2.5. INELASTIC BEHAVIOR OF STEEL STRUCTURES WITH DAMPERS	21
CHAPTER 3 : COMPUTATIONAL METHODS AND MODELING TECHNIQUES.....	23
3.1. INTRODUCTION.....	23
3.2. METHODOLOGY OF OPTIMIZATION OF DAMPER PARAMETERS.....	23
3.2.1. Numerical modeling of building structures	24
3.2.1.1. Linear structures	25
3.2.1.1.1. TMD-equipped linear structure.....	25
3.2.1.1.2. NES-equipped linear structure.....	26
3.2.1.2. Nonlinear structures	26
3.2.1.2.1. Force analogy method.....	27
3.2.1.2.2. TMD-equipped nonlinear structures.....	32
3.2.1.2.3. NES-equipped nonlinear structures	32
3.2.2. Numerical integration methods.....	32
3.2.2.1. Newmark- β method	33
3.2.2.2. Runge-Kutta method	35
3.2.2.3. Solution procedure for the FAM	36

3.2.3.	Problem formulation for optimization	38
3.2.3.1.	Independent variables.....	39
3.2.3.2.	Constraints.....	39
3.2.3.3.	Objective function	40
3.2.3.4.	Optimization algorithms.....	40
3.2.3.4.1.	Genetic algorithms	41
3.2.3.4.2.	Particle swarm algorithm.....	42
CHAPTER 4 : VERIFICATION OF THE CODE.....		45
4.1.	INTRODUCTION.....	45
4.2.	VERIFICATION FOR THE DYNAMIC RESPONSE.....	45
4.2.1.	Linear structures	45
4.2.1.1.	Linear structure with TMD	46
4.2.1.2.	Linear structure with NES.....	48
4.2.2.	Nonlinear structures	50
4.2.2.1.	Nonlinear structures with TMDs.....	50
4.2.2.2.	Nonlinear structure with NES	52
4.3.	VERIFICATION FOR THE OPTIMIZATION PROCESS	54
4.3.1.	Linear structure with TMD	54
4.3.2.	Linear structure with NES	57
4.3.3.	Nonlinear structures with TMD.....	58
4.3.4.	Nonlinear structures with NES	59
CHAPTER 5 : RELIABILITY ANALYSIS OF OPTIMIZED DAMPERS FOR A SINGLE EXCITATION		61
5.1.	INTRODUCTION.....	61
5.2.	EARTHQUAKE SUITE.....	61
5.3.	CONSTRAINT-HANDLING TECHNIQUE	64
5.4.	DAMPER OPTIMIZATION FOR A SINGLE EXCITATION	65
5.4.1.	Linear structure model.....	65
5.4.1.1.	Optimization of TMD for a single excitation.....	65
5.4.1.2.	Optimization of NES for a single excitation	69
5.4.2.	Nonlinear structure model	72
5.4.2.1.	Optimization of TMD for a single excitation.....	72
5.4.2.2.	Optimization of NES for a single excitation	76
CHAPTER 6 : EFFICIENT DESIGN OF DAMPER PARAMETERS		85
6.1.	INTRODUCTION.....	85
6.2.	OPTIMIZATION PROCESS FOR MULTIPLE EARTHQUAKE EXCITATIONS.....	85
6.2.1.	Linear structure model	85
6.2.1.1.	The optimum design of TMD.....	86
6.2.1.2.	The optimum design of NES	88
6.2.1.3.	Comparison between the optimized design of both TMD and NES	90
6.2.2.	Nonlinear structure model	93
6.2.2.1.	The optimum design of TMD.....	93
6.2.2.2.	The optimum design of NES	95
6.2.2.3.	Comparison between the optimized design of both TMD and NES	97
CHAPTER 7 : CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK.....		103
7.1.	CONCLUSIONS	103

7.1.1.	Nonlinear modeling of structures	103
7.1.2.	The FAM to model the nonlinearity of inelastic structure.....	104
7.1.3.	Numerical methods	104
7.1.4.	Optimization algorithms	104
7.1.5.	Damper design	104
7.2.	FUTURE WORK.....	105
REFERENCES		107

List of Tables

Table 2.1: TMDs configuration for the optimization process.	15
Table 2.2: The TMD parameters for the three algorithms and the percentage of the reduction in RD and AA under Tabas earthquake for the 40-story model. [81]	18
Table 2.3: The TMD parameters for the three algorithms and the percentage of the reduction in RD under El Centro earthquake for the 10-story model. [81]	18
Table 2.4: The TMD design scenarios. [83]	19
Table 2.5: The optimal frequency and damping ratio expressions related to previously mentioned studies.	21
Table 3.6: Numerical procedure for Newmark's method.	34
Table 3.7: Numerical procedure for RK4.	36
Table 3.8: Pseudo code of the FMA.	37
Table 3.9: The design variables for this study.	39
Table 4.1: The linear structure properties.	45
Table 4.2: The properties of the structure and TMDs.	51
Table 4.3: The natural periods of the ten-story MRSF.	51
Table 4.4: Comparison of the local plastic energies.	52
Table 4.5: The properties of the structure and NES.	52
Table 4.6: Ranges of the design variables of TMD.	54
Table 4.7: Optimization results of TMD for the ten-story shear building.	55
Table 4.8: Structure properties of the two-story building.	57
Table 4.9: Optimum parameters of the NES for different optimization methods.	58
Table 4.10: Optimum design of TMD for the inelastic six-story MRSF.	59
Table 4.11: Optimal parameters of the NES for various methods for the inelastic MRSF.	60
Table 5.1: Properties of the selected earthquake suite.	61
Table 5.2: The search domain of the TMD parameters for the linear benchmark.	65
Table 5.3: Results of the optimization process of TMD for different Earthquakes.	66
Table 5.4: Optimal TMD parameters obtained by other optimization methods [3].	66
Table 5.5: Optimal TMD parameters for different PGA of San Fernando earthquake and the allowable stroke length of TMD in the linear benchmark.	67
Table 5.6: The search domain of NES parameters.	69
Table 5.7: Optimal parameters of NES-I.	70
Table 5.8: Optimal parameters of NES-II.	70
Table 5.9: The search domain of the TMD variables for the nonlinear benchmark.	73

Table 5.10: The optimal TMD designs for the nonlinear benchmark.	73
Table 5.11: The search domain of the NES variables for the nonlinear benchmark.	77
Table 5.12: Optimal parameters of NES-I.	77
Table 5.13: Optimal parameters of NES-II.	77
Table 5.14: The optimum design of dampers in the MRSF under the El Centro earthquake for different PGA.	80
Table 6.1: The MRD of the uncontrolled linear model and the weights for each seismic excitation.	86
Table 6.2: The best designs of the TMD for the linear structure from the Pareto-optimal solutions and their ranks.	87
Table 6.3: The best designs of the NES from the Pareto-optimal solutions and their ranks.	88
Table 6.4: The MRD of the uncontrolled inelastic MRSF and the weights for each seismic excitation.	94
Table 6.5: The best designs of the TMD for the inelastic MRSF from the Pareto-optimal solutions and their ranks.	94
Table 6.6: The best designs of the NES for the inelastic MRSF selected from the Pareto-optimal solutions and their ranks.	96
Table 6.7: Various NES designs from the Pareto-front.	96

List of Figures

Figure 1.1: A schematic model of a TMD.....	1
Figure 1.2: Types of the nonlinearity of dampers: (a) damping nonlinearity; (b) nonlinearity due to boundary conditions; (c) geometric nonlinearity of a spring; (d) material nonlinearity of a spring.....	2
Figure 1.3: Force-displacement relationship for the spring of a TMD and NES, cubic nonlinearity.....	3
Figure 1.4: The Framework of the thesis.....	5
Figure 2.1: A schematic model of the two-story shear building with the TNES. [37] ..	11
Figure 2.2: The installation of the TNES at the roof of the building structure. [38]	12
Figure 2.3: A schematic for parallel configuration of NESs attached to linear SDOF system. [39]	12
Figure 2.4: Schematic model of MDOF structure with SSI. [80].....	17
Figure 2.5: Timeline of main metaheuristic algorithms utilized in the optimization of TMD parameters.....	20
Figure 3.1: Models of steel structures: (a) multistory shear frame (linear model); (b) moment-resisting frame (nonlinear model).	24
Figure 3.2: Methodology of damper optimization.....	24
Figure 3.3: Elastic-perfectly plastic model.	27
Figure 3.4: Force-displacement relationship of a structural system.	28
Figure 3.5: Satisfying compatibility and equilibrium conditions with the FAM: (a) Beam element with PHs; (b) Satisfying compatibility condition; (c) Satisfying equilibrium condition.	29
Figure 3.6: Fixed-end reactions due to support rotations.	30
Figure 3.7: Bilinear model of a moment-rotation relationship.	36
Figure 3.8: The flowchart of the optimization formulation.	38
Figure 3.9: The flowchart of GA procedure.	41
Figure 3.10: PSO search technique.....	43
Figure 3.11: The flowchart of PSO procedure.....	43
Figure 4.1: First story displacement for linear structure with and without TMD under Cape Mendocino earthquake: (a) by Bekdaş et al. (2018); (b) by the developed code and SAP2000.	46
Figure 4.2: First story displacement for linear structure with and without TMD under Kobe earthquake: (a) by Bekdaş et al. (2018); (b) by the developed code and ABAQUS.....	47
Figure 4.3: Earthquake ground acceleration time-histories.	48

Figure 4.4: Global responses of the structure with NES: (a) displacement of the sixth floor; (b) displacement of the NES; (c) kinetic energy; (d) strain energy.....	49
Figure 4.5: Ten-story MRSF.	50
Figure 4.6: The global response of the structure without TMDs, (a) and (b), and with TMDs, (c) and (d).....	52
Figure 4.7: Six-story MRSF with NES at the roof.	53
Figure 4.8: Time-history responses: (a) displacement of the top floor; (b) the displacement of the NES; (c) the cumulative input energy; (d) strain energy.....	54
Figure 4.9: Contour plot of the MRD for 3% mass ratio versus the stiffness and damping coefficient of the TMD.	56
Figure 4.10: Contour plot of the MRD for 4% mass ratio versus the stiffness and damping coefficient of the TMD.	56
Figure 4.11: Contour plot of the MRD for 10% mass ratio versus the stiffness and damping coefficient of the TMD.	57
Figure 4.12: Contour plot for the MRD of the controlled linear structure versus the nonlinear stiffness and the damping coefficient of the NES.	58
Figure 4.13: Contour plot for the MRD of the controlled inelastic six-story MRSF versus the stiffness and damping coefficient of the attached TMD.	59
Figure 4.14: Contour plot for the MRD of the damped inelastic ten-story MRSF versus the nonlinear stiffness and the damping coefficient of the attached NES.	60
Figure 5.1: Acceleration time-histories and Fourier amplitudes for the selected earthquake ground motions.	63
Figure 5.2: The maximum stroke length of each TMD design for the linear 10-story structure.	67
Figure 5.3: Maximum story displacements of linear structure for various optimization methods under the Northridge earthquake.	68
Figure 5.4: MRD of linear structure with and without TMD and the percentage of reduction: (a) this study; (b) other methods [3].....	69
Figure 5.5: The maximum stroke length of dampers for the linear benchmark.	71
Figure 5.6: MRD of linear structure with and without NES and the percentage of reduction: (a) NES-I; (b) NES-II.	72
Figure 5.7: The percentage of reduction in roof displacement of the controlled linear structure by TMD, NES-I, and NES-II.....	72
Figure 5.8: The maximum stroke length of each TMD design for the MRSF.	74
Figure 5.9: The Fourier amplitudes of the selected earthquakes, optimum frequencies of the optimum TMDs, and natural frequency of the MRSF.....	75
Figure 5.10: MRD of the nonlinear benchmark with and without TMD and the percentage of reduction: (a) this study; (b) closed-form expressions.....	76
Figure 5.11: The maximum stroke length of dampers for the MRSF.	78