DEDICATION

This project is dedicated firstly to my parents, my family members and my friends who have helped me without getting tired in accomplishing my tasks. It also goes to my entire civil engineering's colleagues.

ACKNOWLEDGEMENT

All praise to ***Allah*** *Subhanahu WA Ta'ala, the Benevolent, Most Gracious, And Most Merciful.*

Our most and sincere deepest appreciation to my parents and my sisters who stood with me through thick and thin, supported me in any way possible and encouraged me continuously to achieve my goals.

My most heartfelt thanks and appreciation to my supervisor ***Prof. Abdelrahman Elzubeir*** *who is one of the most empathic person I have ever met, who spent his time, energy and was with me from the beginning till the end, ever ready to help and show me the right way. I really have no words to express my gratitude but I pray Almighty Allah reward his abundantly and may all the good things in life come his way.*

I sincerely thank ***Eng. Moaaz Siddig*** *for his hard working and patience with me until I achieved my goals, hope Allah help him.*

I have to thank our Dean, lecturers who taught us everything that we need to know. May Allah reward them abundantly.

ABSTRACT

In this research, the structural systems normally used in tall buildings are presented. The linear and nonlinear finite element analysis of tall buildings under wind loads is carried out. The main purpose was to study the importance of nonlinear dynamic analysis by comparison with nonlinear static analysis based on displacement and shear force results.

A selected tall building of reinforced concrete skeleton of 20 stories was modeled and linearly analyzed using the finite element structural analysis program (ETABS). The accuracy of the model was checked by increasing the number of nodes in the corner columns twice. These show monotonic convergence of the results thus confirming the accuracy of the model.

Dead load, live load and wind loads were applied to the selected building in accordance to ASCE7-05. The building model was then analyzed using ETABS nonlinear static mode for two load combinations. These results were checked by comparison with published results .The load combination that gave higher results in the static analysis was then used in the nonlinear dynamic analysis of the building. The results obtained from the dynamic analysis were compared with the p delta plus large displacements (P-Δ-W) static results.

The comparison of the lateral displacements and story shear show a clear difference between the dynamic and static analysis results. The dynamic results for displacements were higher than static by about 22-28% while the dynamic results for maximum shear was less than the static by about 28%. This confirms the importance of carrying out nonlinear dynamic analysis

مستخلص البحث

إستعرض البحث الأنظمة الإنشائية المستخدمة في المباني العالية. أجري التحليل الخطي واللاخطي للمباني العالية تحت تأثير أحمال الرياح وبإستخدام طريقة العنصر المحدد، وقد كان الهدف الأساسي دراسة أهمية التحليل اللاخطي الديناميكي بالمقارنه مع التحليل اللاخطي الاستاتيكي إستنادا علي نتائج الإزاحات وقوى القص.

أختير مبنى خرساني ذو إرتفاع عالي مكون من عشرين طابقاً حيث حلل خطياً بإستخدام برنامج تحليل العنصر المحدد (ETABS). وتم التحقق من النموذج بزيادة عدد العقد مرتان في اللأعمدة الركنيه. حيث أظهرت هذه الطريقه تقارب النتائج بإتجاه واحد وبالتالي أكدت دقة النموذج .

طبقت الأحمال الميته والحية وأحمال الرياح علي المبني المختار وفقا للمدونة ASCE7-05 . طبق التحليل اللاخطي الإستاتيكي علي المبني بإستخدام برنامج ETABS وذلك بنوعين من الأحمال المدمجة . وتم التحقق من هذه النتائج بمقارنتها مع نتائج منشورة. إستخدم الحمل المدمج ،الذي أعطي نتائج أعلي في التحليل الإستاتيكي في التحليل الديناميكي للمبني وقورنت النتائج المأخوذة من التحليل الديناميكي مع نتائج التحليل الإستاتيكي (P delta plus large displacements) .

أظهرت نتائج الإزاحات الجانبية و قوي القص في كل طابق فرق واضح بين التحليل الديناميكي والإستاتيكي . حيث أن نتائج التحليل الديناميكي للإزاحة كانت أعلي من التحليل الإستاتيكي بحوالي 22-28% بينما كان أقصي قص في التحليل الديناميكي أقل من الإستاتيكي بحوالي 28%. وهذا يؤكد اهمية إجراء التحليل اللاخطي الديناميكي .

TABLE OF CONTENTS

Topic	Page
Dedication	I
Acknowledgement	II
Abstract	III
مستخلص البحث	IV
Table of Contents	V
List of Figures	X
List of Tables	XIII
LIST OF Symbols	XV
CHAPTER ONE **Introduction**	
1.1 General	1
1.2 Statement of the Research problem	2
1.3 Objectives	2
1.4 Methodology	3
1.5 Thesis Components	3
CHAPTER TWO **Background and Literature Review**	
2.1Introduction	4
2.2Loads	5
2.3 Structural Systems of Tall Buildings	7

2.3.1 Floor System	9
2.3.2 Vertical Load Resisting System	9
2.3.3 Lateral load Resistance System	10
2.3.3.1 Outrigger and Belt Truss System	10
2.3.3.2 Framed Tube System	12
2.3.3.3 Shear Wall Structures	12
2.3.3.4 Wall-Frame Structures	13
2.3.3.5 Rigid Frame Structures	14
2.4 Static Nonlinear Analysis (P-delta)	14
2.5 Dynamic Analysis	16
2.5.1Dynamic Response to Wind Loading	18
2.5.1.1 Sensitivity of Structures to Wind Forces	18
2.5.1.2 Along-wind Dynamic Response	19
2.5.1.3 Across-wind Dynamic Response	20
2.5.2 Response spectrum analysis	20
2.6 Summary	21
CHAPTER THREE **Nonlinear Analysis Procedure of Buildings Under Wind Loads**	
3.1Introduction	22

3.2 ASCE provision for calculating wind loads	22
3.2.1 Basic wind speed (V)	23
3.2.2 Wind directionality factor (Kd)	23
3.2.3 Exposure categories	23
3.2.4 Topographic factor (Kzt)	23
3.2.5 Gust-Effect Factor	24
3.2.6 Enclosure Classification	26
3.2.7 Internal Pressure Coefficients	27
3.2.8 Velocity Pressure	27
3.2.9 Wind Pressure	28
3.3 Load Combinations according to ACI318-08	28
3.4 Static Analysis	29
3.5 Dynamic Analysis	29
3.5.1 Types of Dynamic loads	29
3.5.2Equation of motion	30
3.5.3 Mode of Vibration	31
3.5.4 Response spectrum analysis	32
3.5.5 Modal analysis procedure	33
3.5.6 Dynamic Structural Response due to wind forces	35
3.5.6.1 Along-Wind Response	35
3.5.6.2 Across-Wind Response	43

3.6 P-delta effect	44
3.7 Analysis using computer program	46
3.7.1 General	46
3.7.2 ETABS Features	46
3.7.3Basic Process	47
3.7.4 Non Linear Static Procedures	48
3.7.5Non Linear Dynamic Procedures	48
CHAPTER FOUR **Analysis Results and Discussion**	
4.1 Introduction	49
4.2 The finite element Model properties	50
4.2.1 The Materials	50
4.2.2 Geometric Properties	50
4.2.3 The Building Loads	50
4.2.4 Wind loads parameters	51
4.2.5Load Combinations According To ASCE 7-05	51
4.3Linear and nonlinear static analysis	52
4.3.1Lateral loads from the program used	52
4.3.2 Model check	54
4.3.3 Analysis and Discussion of the linear and nonlinear static	60

results	
4.3.3.1 Max story displacements results	60
4.3.3.2 Max story Shear results	69
4.4Dynamic Analysis	73
4.4.1 Wind load spectra	73
4.4.1.1The along- wind Response	75
4.4.1.2Along-wind Response assuming constant Acceleration	81
4.4.1.3 Across-wind Response	87
4.4.2Discussion and comparison between nonlinear static and along-wind dynamic results	87
4.4.2.1Max story displacement	87
4.4.2.2Max story shear	89
4.4.2.3Max story drift	91
CHAPTER FIVE Conclusions and Recommendations	
5.1 Conclusions	94
5.2 Recommendations	95
References	97
Appendices	99

LIST OF FIGURES

Figure No	Title	Page No
2.1	Generation of eddies [Mendis, et.al.,2007]	7
2.2	System Structure Classification [Karim and Barua,2010]	9
2.3	Double outrigger effect on a tall building [Taranath, 2005]	11
2.4	Single Outrigger and Belt Truss Schematic [Taranath,2005]	11
2.5	Frame tube [Taranth,2005]	12
2.6	Coupled Shear Walls [Taranth,2005]	13
2.7	Rigid Frame Structures [Taranath,2010]	14
2.8	Figure (2.8) (a) Linear Static analysis is performed in one step (b) P- Delta analysis is performed in two steps [Karim and Barua,2010]	15
3.1	Examples of dynamic loading (time-domain representation) [Maguire and Wayatt,2000]	30
3.2	The first three modes of cantilever beam [Maguire and Wayatt,2000].	32
3.3	Along and cross wind direction (Mosa, 2015)	36
3.4	Schematic representation of Davenport's design procedure (Smith and Coull,1991)	37
3.5	Variation of roughness factor with building height [Smith and Coull,1991]	39
3.6	Variation of background turbulence factor with height and aspect. [Smith and Coull, 1991]	40

3.7	Variation of size reduction factor with reduced frequency and aspect ratio of building. [Smith and Coull,1991]	41
3.8	Variation of gust energy ratio with inverse wavelength [Smith and Coull,1991].	42
3.9	Variation of peak factor with average fluctuating rate [Smith and Coull, 1991]	43
3.10	P-delta effect (simple cantilever model) [Taranath,2005]	45
4.1 a	Plan View of model	49
4.1 b	3D View of model	49
4.2	Lateral Load to storey in y-direction.	53
4.3	Lateral Load to storey in x-direction.	54
4.4	Case One Model	56
4.5	Case one displacements curves	56
4.6	Case Two Model.	57
4.7	Case Two displacements curves	57
4.8	Case Three Model.	58
4.9	Case three Displacements Curves.	58
4.10	The variation of displacements of three cases in x-direction (min).	60
4.11a	Linear displacements case study and Mosa, 2015 model.	65
4.11 b	P-delta displacements for case study and Mosa, 2015 model.	65

4.11 c	P-delta w displacements for case study and Mosa, 2015 model.	66
4.12	Max Storey displacements.	68
4.13	Maximum storey displacement in y-direction (Linear, P-Δ, P-Δ-w).	69
4.14	The maximum storey displacement in y-direction differences %.	69
4.15	Maximum storey shear y-direction.	71
4.16a	Along-wind response spectra (4 periods)	75
4.16b	Cross-wind response spectra (4 periods)	75
4.17	Six mode shapes	76
4.18	Four mode shapes	76
4.19	Maximum storey displacement for 6 modes (along-wind).	78
4.20	Maximum storey shear in y-direction for 6 modes (along-wind).	80
4.21	Max story drift for 6 modes (along-wind)	81
4.22	The application of Constant acceleration spectrum.	82
4.23	Maximum storey displacement for constant acceleration.	84
4.24	Maximum storey shears y-direction for constant acceleration.	85
4.25	Max story drift for constant acceleration.	87
4.26	Nonlinear static and dynamic displacements (along-wind).	89
4.27	Nonlinear static and dynamic story drift (along-wind)	93

LIST OF TABLES

Table No	Title	Page No
4.1	lateral load to storey in y-direction	52
4.2	Lateral load to story in x-direction	53
4.3	The values of drift in y-direction for case study and Mosa, 2015 model	55
4.4	The variation of displacements of three cases in x-direction (min):	59
4.5	Max storey displacement in y-direction for combination U1 and U2	62
4.6	Linear static displacements y-direction for case study and Mosa, 2015	63
4.7	Non linear displacements in y-direction for case study and Mosa, 2015	64
4.8	Maximum storey displacement in y-direction for case study	67
4.9	Maximum storey Shear in y-direction P-delta w(case study)	70
4.10	Comparison of maximum shear (P-Δ-w) between case study and Mosa, 2015	72
4.11	Calculation of along-wind (a_D) and across-wind (a_w) accelerations for 4 periods (10, 5, 3.3, and 2.5)	74
4.12	Calculations of along-wind (a_D) and across-wind (a_w) accelerations for 6 periods (10, 6.7, 5, 4, 3.3, and 2.5)	74
4.13	Maximum storey displacements (along-wind accelerations)	77
4.14	Max storey shear in y-direction for 6modes (along-wind)	78
4.15	Max storey drift for 6 modes (along-wind)	80
4.16	Max storey displacements in y-direction for constant	83

	acceleration	
4.17	Max storey shear in y-direction for constant acceleration	84
4.18	Maximum storey drift for constant acceleration	86
4.19	Comparison between nonlinear static and dynamic displacements (along-wind)	88
4.20	Comparison between nonlinear static and dynamic storey shear forces at the top for along-wind	90
4.21	Comparison between nonlinear static and dynamic storey (along-wind)	92

LIST OF SYMBOLS

g Gravitational acceleration

G Gust factor

g_p Peak factor

n_0 Fundamental natural frequency

r Roughness factor

B Excitation due to the ground turbulence

R Excitation by the turbulence resonant with structure

β Damping ratio

F Frequency

a_D Along-wind acceleration

a_w Cross-wind acceleration

Δ Maximum wind induced deflection at the top of the building

ρ Average density of the building

q Velocity pressure

W Total load

M Mass matrix

U Required strength

u Displacement vector

K_z	The velocity pressure exposure coefficient
K_{zt}	Topographic factor as input by the user
K_d	Directionality factor as input by the user
V	Basic wind speed in miles per hour (mph) as input by the user
I	Importance factor as input by the user.
z	Distance (height) from input bottom story