



AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
DEPARTMENT OF STRUCTURAL ENGINEERING

PERFORMANCE OF POST TENSIONED RAFT FOUNDATION

A Thesis Submitted In Partial Fulfillment for the
Requirement of the Degree of
Master of Science in Civil Engineering (Structural)

By

Eng. Mohammad Ahmad Salem Alnawafleh

Bachelor Degree in Civil Engineering
Mutah University - Jordan, 2008

Supervisors

Prof. Dr. Omar A. El-Nawawy

Professor of Structural Engineering
Department of Structural Engineering
Faculty of Engineering
Ain Shams University

Prof. Dr. Yasser M. El-Mossallamy

Professor of Geotechnical Engineering
Department of Structural Engineering
Faculty of Engineering
Ain Shams University

Cairo – 2014



APPROVAL SHEET

PERFORMANCE OF POST TENSIONED RAFT FOUNDATION

By

Eng. Mohammad Ahmad Salem Alnawafleh

Bachelor Degree in Civil Engineering

Mutah University - Jordan, 2008

A Thesis Submitted In Partial Fulfillment for the Requirement
for Degree of Master of Science in Civil Engineering (Structural)

Examiners Committee:

Prof. Dr. Osman M.O. Ramadan

Professor of Structural Engineering

Department of Structural Engineering

Faculty of Engineering - Cairo University

O. Ramadan

Prof. Dr. Amin Saleh Aly

Professor of Structural Engineering

Department of Structural Engineering

Faculty of Engineering - Ain Shams University

A. S. Aly

Prof. Dr. Omar A. El-Nawawy

Professor of Structural Engineering

Department of Structural Engineering

Faculty of Engineering - Ain Shams University

O. El-Nawawy

Prof. Dr. Yasser M. El-Mossallamy

Professor of Geotechnical Engineering

Department of Structural Engineering

Faculty of Engineering - Ain Shams University

Y. El-Mossallamy

Date: 11/01/2014

INFORMATION ABOUT THE RESEARCHER

Name : Mohammad Ahmad Salem Alnawafleh
Date of Birth : February 27, 1985
Place of Birth : Ma'an, Jordan
Academic degree : Bachelor degree in Civil engineering
Field of specialization degree : Structural Engineering
University issued the degree : Mutah University, Jordan
Date of issued degree : January 2008
Current job : Post-Tension Design Engineer

STATEMENT

This thesis is submitted as partial fulfillment of MSc Degree in Civil Engineering (Structural), 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 qualification at any other scientific entity.

Date: / /

Name: Eng. Mohammad Ahmad S. Alnawafleh

Signature:

ACKNOWLEDGMENTS

First of all, I would like to thank God for every gift bestowed on me.

*Next, I would like to thanks my advisers **Prof. Dr. Omar El-Nawawy** and **Prof. Dr. Yasser El-Mossallamy** for the opportunity to conduct this research, providing me endless insight on the nature of the problem, and for being always available for assistance and for queries.*

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

*I would like to extend sincere thanks to my seniors at work who supported me and taught me post-tensioning technology, especially **Dr. Musa Alawneh** and **Eng. Mohammad Badran**.*

Finally, I would like to thank all of my friends, past and present for all the good times we've had and all the good times yet to have. I would especially like to thank all my friends and colleagues in Cairo for their kindness and hospitality.

DEDICATION

*This thesis is lovingly dedicated to my dear **mother**. Appreciated her support, encouragement, and constant love have sustained me throughout my life.*



ABSTRACT of MSc THESIS

Thesis Title: **Performance of Post Tensioned Raft Foundation**

Prepared by: **Eng. Mohammad Ahmad Salem Alnawafleh**

Bachelor Degree in Civil Engineering - Mutah University, Jordan, 2008

Supervisors: **Prof. Dr. Omar A. El-Nawawy**

Prof. Dr. Yasser M. El-Mossallamy

ABSTRACT

This thesis contains numerical and analytical studies to investigate the performance of post-tensioned raft foundation to prove it as a better alternative to the conventional R.C system, especially for foundation in sever exposure conditions.

The numerical analysis includes calculations of selected case study using the Finite Element Method for which a parametric study has been carried out to investigate the influence of different variables on the behavior of the post tensioned raft foundation. In order to evaluate the proposed alternative system efficiency, it was necessary to compare the PT raft design and results against conventional RC raft. The design was carried out for most widespread code ACI318, and extent to compare the design requirements and the design results with BS8110 and ECP203.

A high performance of the post tensioned raft foundation is noticed for the Serviceability Limit States and Ultimate Limit States, in addition to profitable saving in the quantities especially for foundations of low rise buildings.

KEY WORDS:

Post tensioned, Post tensioned raft, Post tensioned mat, Raft foundations

TABLE OF CONTENTS

Acknowledgement	V
Dedication	VI
Abstract	VII
Table of contents	VIII
List of figures	XXIII
List of tables	XXXI
Notation	XXV
 CHAPTER 1: INTRODUCTION	 1
1.1 General	1
1.2 Thesis objectives	1
1.3 Scope of work	2
1.4 Thesis organization	3
1.5 Limitations	3
 CHAPTER 2: LITERATURE REVIEW	 4
2.1 Introduction	4
2.1.1 History and development	4
2.1.2 Chapter overview	5
2.2 Geotechnical exploration	5
2.3 Raft foundations	7
2.3.1 Type of the raft foundations	7
2.3.2 Purpose of raft foundation	8
2.3.3 Method of analyses	8
2.3.4 Performance requirements of raft foundations	14

2.4	Post tension concrete.....	19
2.4.1	Introduction.....	19
2.4.2	Type of prestressed concrete.....	19
2.4.3	Procedure of post tensioning concrete	20
2.4.4	Type of post tension system.....	21
2.4.5	Applications of post tensioning systems.....	23
2.4.6	Advantages of post tensioning in foundations	24
2.4.7	Components of Post-Tensioning.....	25
2.4.8	Tendons arrangement and profile	27
2.5	Review of design specifications.....	31
2.5.1	Introduction.....	31
2.5.2	Basic concept of prestressing.....	32
2.5.3	Stresses calculations.....	32
2.5.4	Flexural design concept of prestressed concrete.....	34
2.5.5	Codes strength calculation procedure	36
2.5.6	Pre stressed steel strain components	39
2.5.7	Sections containing non-prestressed reinforcement and bonded tendons.....	42
2.5.8	Soil structure interaction	44
2.5.9	Punching shear in the post tensioned raft foundations.....	54
2.5.10	Stressing stages	55
2.5.11	Post tension losses in raft foundations	58
2.5.12	Tendon spacing	67
2.5.13	Crack control.....	68
2.6	Previous research works	71
2.6.1	Justin Eugene Burgoon, 2007 [28].....	71
2.6.2	Gregory Paul Turco, 2007 [29].....	72
2.6.3	Bijan O. Aalami, 2011 [30].....	74

2.6.4	Bijan O. Aalami, 1995 [31].....	75
2.6.5	Zuher abou-saleh, 2007 [32].....	75
2.6.6	Haider M. Abdul, 2011 [33]	76
2.6.7	Way Seng Chia, Franck McCollough and Ned H, Burns, 1986 [34].....	77
CHAPTER 3: THEORETICAL INVESTIGATION		78
3.1	Introduction.....	78
3.2	Case study description	78
3.3	Super structure analysis and design	82
3.4	Geotechnical investigations	83
3.4.1	Introduction.....	83
3.4.2	Soil Parameters	83
3.4.3	Procedure for estimating acceptable K_s value.....	83
3.4.4	Modeling of the subgrade	84
3.4.5	Adopted analytical program (GGU-Settle).....	84
3.4.5.1	Introduction.....	84
3.4.5.2	Program capabilities and features	84
3.4.5.3	Case study modeling.....	85
3.5	Post-tensioned raft foundation analysis and design	87
3.5.1	Introduction.....	87
3.5.2	Design assumptions, philosophy, theory and criteria adopted.....	87
3.5.2.1	Design loads.....	87
3.5.2.2	Load combinations.....	87
3.5.2.3	Adopted materials properties	88
3.5.2.4	Post tension losses calculation	89
3.5.2.5	Maximum tendon spacing.....	90
3.5.3	Modeling of the post tensioned raft foundation.....	90

3.5.3.1 Introduction.....	90
3.5.3.2 Post tensioning system design process	91
3.5.3.3 Adopted analytical programs (SAFE 12).....	92
3.5.3.4 Modeling configurations.....	92
CHAPTER 4: CASE STUDY RESULTS AND DISCUSSION	105
4.1 Introduction.....	101
4.2 Design procedure	101
4.2.1 Serviceability check.....	101
4.2.2 Ultimate limit state check	121
4.3 Comparison between post-tensioned and conventional RC raft foundations	126
4.4 Design codes comparison	131
4.5 Software comparison	138
4.5.1 Structural geometry.....	138
4.5.2 Mesh Plan.....	139
4.5.3 Modulus of subgrade reaction.....	139
4.5.4 Tendons layout.....	140
4.5.5 Soil pressure.....	141
4.5.6 Settlement	141
4.5.7 Final service stresses.....	142
4.5.8 Flexural strength reinforcement.....	144
CHAPTER 5: PARAMETRIC STUDY.....	163
5.1 Variation of raft thickness.....	148
5.1.1 Raft thickness versus concrete volume	148
5.1.2 Raft thickness versus post-tension material weight.....	148
5.1.3 Raft thickness versus soil pressure and settlement	150

5.1.4	Raft thickness versus ultimate bending moment	153
5.1.5	Raft thickness versus PT balancing moment	156
5.1.6	Raft thickness versus service tensile stresses.....	158
5.1.7	Raft thickness versus initial tensile stresses (at transfer).....	160
5.1.8	Raft thickness versus punching shear	162
5.1.9	Raft thickness versus the post tensioning losses.....	163
5.2	Precompression stress	168
5.3	Variation of number of storeys (Superstructure load)	169
5.3.1	Number of storeys versus soil pressure and settlement	170
5.3.2	Number of storeys versus ultimate bending moment	173
5.3.3	Number of storeys versus PT balancing moment	175
5.3.4	Number of storeys versus service tensile stresses.....	176
5.3.5	Number of storeys versus initial tensile stresses (at transfer).....	177
5.4	Variation of span length.....	178
5.4.1	Span length versus soil pressure and settlement.....	179
5.4.2	Span length versus ultimate bending moment	182
5.4.3	Span length versus PT balancing moment	185
5.4.4	Span length versus service tensile stresses	187
5.4.5	Span length versus initial tensile stresses (at transfer).....	189
CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS.....		208
6.1	Conclusions.....	191
6.2	Recommendations.....	192
6.3	Suggestion of future work.....	194
REFERENCES		195

APPENDIX A: SUPER-STRUCTURE ANALYSES AND DESIGN	199
APPENDIX B: DESIGN OF PT RAFT ACCORDING TO BS8110-97.....	216
APPENDIX C: DESIGN OF PT RAFT ACCORDING TO ECP 203-2007.....	245
APPENDIX D: DESIGN OF RC RAFT (ACI 318-11).....	266
APPENDIX E: LOSSES CALCULATION AND SOFTWARE VAREFECTION....	284
ARABIC ABSTRACT	295

LIST OF FIGURES

Figure 2.1: Section and plan illustrate the common raft foundation types [11]	7
Figure 2.2: Bearing Pressure Distribution and Settlement for Rigid Method (a) Normal Loads (b) Eccentric or Moment Loads. [15]	9
Figure 2.3: Bearing Pressure Distribution and Settlement for Non-rigid Method. [15]	10
Figure 2.4: Modeling of soil structure interaction using Winkler method [10]	10
Figure 2.5: Bearing pressure – Settlement relationship [10]	11
Figure 2.6: Settlement of uniformly loaded raft on uniform soil, (a) Per Winkler assumption (b) Actual [10]	12
Figure 2.7: Modeling of soil structure interaction using coupled springs [10]	12
Figure 2.8: General shear failure [10]	15
Figure 2.9: Punching shear failure [10]	15
Figure 2.10: Local shear failure [10]	16
Figure 2.11: Illustration the prestressing types	19
Figure 2.12: Post tensioning procedure	20
Figure 2.13: Standard unbonded tendon anchor and encapsulated anchor [Freyssinet Catalog]	21
Figure 2.14: Standard anchor for bonded system [Freyssinet Catalog]	22
Figure 2.15: Tendons layouts [21]	27
Figure 2.16: Two-way layout of both banded and distributed tendons in the site	28
Figure 2.17: Two-way layout of both banded and distributed tendons in the site	28
Figure 2.18: Plan and section of foundation for CN tower shown tendons layout [20]	29
Figure 2.19: Typical reinforcement detail and tendons profile	30
Figure 2.20: Illustrate the stresses in post tension raft foundation	33
Figure 2.21: Stress and strain distribution caused by increasing moment [35]	35
Figure 2.22: Variation of ϕ with net tensile strain in extreme tension steel [5]	37
Figure 2.23: Ultimate moment conditions and rectangular stresses block [35]	38
Figure 2.24: a) Stress distribution b) Strain distribution and c) Equivalent block distribution [38]	39
Figure 2.25: Strain distribution at three stages of loading [17]	39
Figure 2.26: Conventional approach: (a) Analysis of superstructure assuming rigid foundation, (b) Reactions from superstructure analysis applied to flexible foundation.	45

Figure 2.27: Subgrade reaction and settlement as a function of soil and foundation stiffness [8].....	46
Figure 2.28: Unit slab element subjected to a constant normal pressure σ , and a shear stress τ [8].....	47
Figure 2.29: Test curves for a 125 mm thick concrete slab cast on polyethylene sheeting [8].....	48
Figure 2.30: Test curve from a direct shear test on a loose sand [8]	48
Figure 2.31: Idealized shear-displacement relationships [8]	49
Figure 2.32: Effect of prestressing on soil pressure distribution [8]:	50
Figure 2.33: Effect of prestressing on punching resistance	51
Figure 2.34: Principle and mechanics of stage post tensioning showing stress values at corresponding construction steps [20]	57
Figure 2.35: Level of prestressing force after each losses stage.....	58
Figure 2.36: Force profile due to anchorage slip losses [9]	59
Figure 2.37: Wobble friction loss [9].....	61
Figure 2.38: Evaluation of tendon profile curvature [9]	63
Figure 2.39: Effect of subgrade resistance on the concrete stresses [34]	66
Figure 2.40: Hider's research case study [33]	76
 Figure 3.1: Section building elevation at section A-A.....	79
Figure 3.2: Illustrates the foundation plan	80
Figure 3.3: Illustrates the typical floor general arrangement.....	81
Figure 3.4: Schematic illustration of the iterative process to determine acceptable K_s values.....	83
Figure 3.5: Illustrate the initial steps and input data for GGU-Settle	86
Figure 3.6: Schematic of post-tensioning system and process	81
Figure 3.7: 3D Structural modeling for post tensioned raft foundation.....	92
Figure 3.8: Subgrade reaction modulus values (1000 kN/m^3).....	93
Figure 3.9: Automatic finite element mesh.....	94
Figure 3.10: Illustrates the tendon layout and the profile in X-Dir.	95
Figure 3.11: Illustrates the tendon layout and the profile in Y-Dir.	96
Figure 3.12: 3D tendons layout and profile in both directions	96
Figure 3.13: Illustrates the design strip in X-Dir	97
Figure 3.14: Illustrates the design strip in Y-Dir	98
Figure 3.15: The joint local degrees of freedom [18]	99