

# **UPLIFT CAPACITY OF HELICAL PILES ON RESIDUAL SOIL**

Herath Mudiyansele Ubhaya Sandaruwan Herath

198337K

Dissertation submitted in partial fulfillment of the requirements for the degree  
Master of Engineering in Geotechnical Engineering

Department of Civil Engineering  
Faculty of Engineering

University of Moratuwa  
Sri Lanka

March 2024

## DECLARATION

I declare that this is my own work and this dissertation does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text. I retain the right to use this content in whole or part in future works (such as articles or books).

Signature:

Date:

The above candidate has carried out research for the Master of Engineering in Geotechnical Engineering dissertation under my supervision. I confirm that the declaration made above by the student is true and correct.

Prof. L.I.N. De Silva

05/03/2024

.....

## **ACKNOWLEDGEMENT**

I would like to express my sincere appreciation and gratitude to my supervisor Prof. L.I.N. De Silva for the continuous support given for the research and also for his patience, motivation, enthusiasm, and immense knowledge. His guidance helped me at all the time of research and writing of this dissertation.

I am sincerely thankful to Eng. Ravi Silva; former Project Manager (Green Power Development & Energy Efficiency Improvement Investment Programme Tranche 1, Part 2) of a Transmission Infrastructure Capacity Enhancement Project in Ceylon Electricity Board and Eng. R.S.W. Wagarachchi; former Deputy General Manager (Civil Works and Buildings Branch) in Ceylon Electricity Board for the support and encouragement extended to me to complete this M.Sc. successfully.

Further, I must thank all the lecturers engaged in the M.Sc./P.G. Diploma in Geotechnical Engineering course for the wealth of knowledge they imparted and not forgetting all other staff of University of Moratuwa for their contribution to make this M.Sc. programme a success.

Also, I must thank all my colleagues who have helped me in many ways to make this Post Graduate programme a success.

Last but not least, I would also like to thank all my colleagues, friends and my family who have helped me in many ways to make this Post Graduate programme a success.

H.M.U.S.Herath

## **ABSTRACT**

Utilizing helical piles in foundation construction associated with compressive, tensile and lateral loads of power transmission towers are increasingly used by many countries all over the world. Lesser installation time, lesser manpower, lesser involvement of machinery and ability to use just after installation, can be identified as certain reasons for the popularity for helical piles compared to other foundation types. Further, helical piles which are more versatile and environmentally friendly, can be removed, reused and recycled as and when necessary.

The installation torque required to install helical piles correlates with their load-bearing capacity, resistance to uplift forces, and ability to withstand lateral loads. In this research, ultimate uplift values of helical piles were calculated and the correlation between installation torque and uplift capacity of helical piles in residual soil were investigated. Residual soil subsurface was selected for this research, since such terrains are more common in Sri Lanka.

Accordingly, three transmission tower locations (AP14, AP27 & AP47) consisting of residual soil, along Monaragala-Wellawaya power transmission line were selected and three helical piles were driven with measured depth and torque values. Also, three uplift load tests were conducted measuring the load and the deflection. For these tests, SS175 lead w/200 mm, 250 mm & 300 mm helices and RS3500.300 (88.9 mm diameter x 7.6 mm wall) extensions were used manufactured by CHANCE under Hubbell Power Systems, inc. USA were used.

The findings reveal that the correlation ( $K_t$ ) between installation torque and uplift capacity of helical piles on residual soil is  $29 \text{ m}^{-1}$ . The FEM analysis was conducted with the help of PLAXIS 3D software, and the results were validated through the aforementioned tests. Accordingly, PLAXIS 3D FEM can be used to calculate the uplift capacity of helical piles on residual soil, and the mechanism of failure of helical piles on residual soil during uplift was identified as cylindrical shear. Furthermore, it is revealed that there is a certain association between SPT N and the installation Torque of helical piles on residual soil.

# CONTENTS

	Page
DECLARATION OF THE CANDIDATE AND SUPERVISORS.....	i
ACKNOWLEDGEMENTS .....	ii
ABSTRACT.....	iii
LIST OF FIGURES .....	vii
LIST OF TABLES .....	ix
LIST OF ABBREVIATIONS .....	x
LIST OF APPENDICES .....	xi
CHAPTER 1 .....	1
1. INTRODUCTION .....	1
1.1 Background .....	1
1.2 Significance of the Research.....	5
1.3 Scope of the Study .....	6
1.4 Objectives.....	7
1.5 Methodology .....	8
1.5.1 Literature Survey on helical pile foundation system. ....	8
1.5.2 Obtain installation Torque data and Uplift test data. ....	9
1.5.3 Calculation of Effective Torque Values using field test data. ....	9
1.5.4 Calculation of Ultimate Uplift Capacities of helical piles using field test data. ....	9
1.5.5 Investigating a correlation between installation torque and uplift capacity. .....	9
1.5.6 Calculation of Uplift capacities of Helical Piles using Manual Calculations.....	10
1.5.7 Calculation of Uplift capacities of Helical Piles using Numerical Modelling. ....	10
1.5.8 Determining the Mechanism of Failure of helical piles during uplift.....	10
1.5.9 Applicability of using Helical piles as a Geotechnical Investigation Tool. .....	10
1.5.10 Discussion and Conclusion. ....	10
CHAPTER 2 .....	11
2. LITERATURE REVIEW.....	11
2.1 History of Helical Piles .....	11
2.2 Technical Advancements of Helical Piles.....	12
2.3 Performance of Helical Piles.....	12

2.4 Helical Piles in Transmission Tower Foundation Industry.....	13
2.5 Methods of Calculating Uplift Capacities of Helical Piles .....	14
2.5.1 Uplift Capacity Method by Mooney et al. (1985) using Individual Plate Bearing .....	15
2.5.2 Uplift Capacity Method by Mooney et al. (1985) using Cylindrical Shear .....	16
2.5.3 Net Ultimate Uplift Capacity in Sand Outlined by Mitsch and Clemence (1985) .....	17
2.5.4 Net Ultimate Uplift Capacity in Clay Outlined by Mooney et al. (1985) and Das & Kumar (2013) .....	20
2.5.5 Uplift Capacity of Helical Piles by Torque Based Method .....	23
2.5.6 Uplift Capacity of Helical Piles using In-situ Test Method .....	25
2.5.7 Uplift Capacity of Helical Piles using Finite Element Method.....	25
CHAPTER 3 .....	28
3. UPLIFT CAPACITY OF HELICAL PILES ON RESIDUAL SOIL .....	28
3.1 Collection of Data for Installation Torque and Uplift Tests from the Field ....	28
3.1.1 Installation of Helical Piles in the Field .....	28
3.1.2 Uplift Test Methodology for Installed Helical Piles in the Field.....	30
3.2 Assessing Effective Torque Values using Field Test Data .....	34
3.3 Calculation of Ultimate Uplift Capacities of Helical Piles using Field Test Data .....	34
3.3.1 Calculation of Ultimate Uplift Capacities .....	34
3.4 Investigating a Correlation between Uplift Capacity and Installation Torque	36
3.5 Calculation of Uplift Capacities of Helical Piles using Manual Calculations .	37
3.5.1 Soil Properties Derived from Borehole Logs.....	38
3.5.2 Calculation of Uplift Capacity using the Method Proposed by Mooney et al.(1985) for Individual Plate Bearing and Cylindrical Shear.....	39
3.5.3 Calculation of Uplift Capacity using the Method Proposed by Mitsch and Clemence for Shallow Anchor Condition and Deep Anchor Condition in Sand .....	41
3.5.4 Calculation of Uplift Capacity using the Method Proposed by M. Das and S. Kumar for Shallow Anchor Condition and Deep Anchor Condition in Clay	42
3.6 Calculation of Ultimate Uplift Capacity of Helical Piles using Finite Element Modeling. ....	44
3.6.1 Validation of PLAXIS 3D Model .....	44
3.6.2 Development of Finite Element Model for the Analysis .....	47
3.6.3 Output Results of Finite Element Model .....	48

3.7 Applicability of using Helical Piles as a Geotechnical Investigation Tool.....	52
CHAPTER 4 .....	55
4. DISCUSSION .....	55
4.1 Interpretation of Results.....	55
4.1.1 Correlation between Uplift Capacity and Installation Torque of Helical Piles .....	55
4.1.2 Uplift Capacities of Helical Piles using Manual Calculations .....	55
4.1.3 Uplift Capacities of Helical Piles using Finite Element Method. ....	57
4.1.4 Failure Mechanism of Helical Piles during Uplift on Residual Soil.....	59
4.1.5 Applicability of using Helical Piles as a Geotechnical Investigation Tool .....	61
4.2 Comparison of Results with Previous Studies .....	62
4.2.1 Axial Testing and Numerical Modelling of Square Shaft Helical Piles under Compressive and Tensile Loading.....	62
4.2.2 Relationship between installation torque and uplift capacity of deep helical piles in sand.- .....	63
4.3 Termination Criteria used in Driving Helical Piles .....	63
The termination criteria used in driving helical piles at site (Wellaway to Monaragala) typically involved reaching a certain depth or achieving a specified torque resistance. This is to ensure that the helical pile is securely embedded in the soil and can support the intended load. The followings are the three termination criteria used at site. It is necessary to fulfill all these criteria to terminate a helical pile. ....	63
4.3.1 Ultimate Capacity of the Helical Pile.....	64
4.3.2 Torque Rating of the Helical Pile .....	64
4.3.3 Minimum Depth of the Helical Pile.....	64
4.4 Limitations of using Helical Piles .....	65
4.4.1 Limited Load Capacity in Certain Soils.....	65
4.4.2 Soil Conditions Limitations .....	65
4.4.3 Driving Equipment Limitations .....	65
4.4.4 Corrosion Concerns.....	66
4.4.5 Lateral Capacity Limitations.....	66
CHAPTER 5 .....	67
5. CONCLUSION .....	67
5.1 Main Findings of the Research .....	67
5.2 Suggestions for Future Research.....	67

## LIST OF FIGURES

Figure 1.1: Some Types of Lattice Transmission Towers (saVRee)	01
Figure 1.2: Typical Helical Pile with Three Helices (HELI-PILE, 2011)	02
Figure 1.3: Some Applications of Helical Piles (OJSC Metallist /James P Hambleton)	03
Figure 1.4: Helical Pile Installation	04
Figure 1.5: SS and RS type Helical Piles and Connections (Hughes Construction)	05
Figure 1.6: Locations of the Field Tests	08
Figure 2.1: Early method of driving a helical pile, Lutenegeger(2011)	11
Figure 2.2: Maplin Sands lighthouse, Lutenegeger(2011)	11
Figure 2.3: A transmission tower on helical pile foundation	14
Figure 2.4: Individual Plate Breakout in Uplift, Lutenegeger, 2009	15
Figure 2.5 Cylindrical Shear in Uplift, Lutenegeger, 2009	16
Figure 2.6 Uplift Capacity Factor, $N_{cu}$ by Mooney et al.(1985)	16
Figure 2.7: Failure profile in sand around a multi-helix pile for shallow anchor condition (Das & Kumar, 2013)	17
Figure 2.8: Failure profile in sand nearby a multi-helix anchor for deep anchor condition (Das & Kumar, 2013)	18
Figure 2.9: Variation of $(H_1/D_1)_{cr}$ with soil friction angle $\phi$ (Das & Kumar, 2013)	19
Figure 2.10 : Idealized failure profile in sand for shallow anchor condition	19
Figure 2.11 Idealized failure profile in sand for deep anchor condition	20
Figure 2.12 Idealized failure profile in clay for deep anchor condition	21
Figure 2.13 Variation of $F_c$ Vs $(H_1/D_1)/(H_1/D_1)_{cr}$	21
Figure 2.14 Idealized failure profile in clay for shallow anchor condition	22
Figure 2.15 Idealized failure profile in clay for deep anchor condition	23
Figure 3.1: Torque Motor & Excavator	28
Figure 3.2 : Typical Uplift Test Arrangement (Ravi Sundaram, 2020)	30
Figure 3.3: Uplift Load setup at AP14	31
Figure 3.4: Uplift Load setup at AP27	32



Figure 3.5: Uplift Load setup at AP47	33
Figure 3.6: Load Vs Deflection, AP 14	34
Figure 3.7: Load Vs Deflection, AP 27	35
Figure 3.8: Load Vs Deflection, AP47	35
Figure 3.9: Effective Torque Vs Ultimate Uplift	36
Figure 3.10: Load Vs Deflection, AP14	45
Figure 3.11: Load Vs Deflection, AP27	45
Figure 3.12: Load Vs Deflection, AP47	46
Figure 3.13: Connectivity Plot after Meshing, AP14	47
Figure 3.14: Connectivity Plot after Meshing, AP27	48
Figure 3.15: Connectivity Plot after Meshing, AP47	48
Figure 3.16: Load Vs Displacement, AP14 PLAXIS	49
Figure 3.17: Displacement Profile at 406.29 kN, AP14	49
Figure 3.18: Load Vs Displacement, AP27 PLAXIS	50
Figure 3.19: Displacement Profile at 317.1 kN, AP 27	50
Figure 3.20: Load Vs Displacement, AP47 PLAXIS	51
Figure 3.21: Displacement Profile at 376.51 kN, AP47	51
Figure 3.22: Torque values and SPT values, AP 14	52
Figure 3.23: Torque values and SPT values, AP 27	53
Figure 3.24: Torque values and SPT values, AP 47	53
Figure 3.25: SPT N Vs Torque at AP14, AP27 and AP47	54
Figure 4.1: Comparison of Load Vs Displacement Curves, AP14	57
Figure 4.2: Comparison of Load Vs Displacement Curves, AP27	58
Figure 4.3: Comparison of Load Vs Displacement Curves, AP47	58
Figure 4.4: Vertical Displacement, 3D Profile and Cross Section, AP14	60
Figure 4.5: Vertical Displacement, 3D Profile and Cross Section, AP27	60
Figure 4.6: Vertical Displacement, 3D Profile and Cross Section, AP47	61
Figure 4.7: Driving a Raking Helical Pile with a Grillage	66

## LIST OF TABLES

Table 3.1: Torque Values with Depth at AP14	29
Table 3.2: Torque Values with Depth at AP27	29
Table 3.3: Torque Values with Depth at AP47	29
Table 3.4: Load and Deflection Values with the Graph at AP14	31
Table 3.5: Load and Deflection Values with the Graph at AP27	32
Table 3.6: Load and Deflection Values with the Graph at AP47	33
Table 3.7: Effective Torque Values of Test Piles	34
Table 3.8: Load Vs (PL/AE) Values, AP14	34
Table 3.9: Load Vs (PL/AE) Values, AP27	35
Table 3.10: Load Vs (PL/AE) Values, AP47	35
Table 3.11: Values Obtained for Correlation	36
Table 3.12: Properties of Soil, AP 14	38
Table 3.13: Properties of Soil, AP27	38
Table 3.14: Properties of Soil, AP 47	38
Table 3.15: Sample Calculation, AP14	40
Table 3.16: Summary of Results	40
Table 3.17: Sample Calculation, AP14	42
Table 3.18: Summary of Results	42
Table 3.19: Sample Calculation, AP14	43
Table 3.20: Summary of Results	43
Table 3.21: Results of Uplift Values	46
Table 4.1: Summary of Results	56
Table 4.2: Deviation of Manually Calculated Uplift Values with Field Values	56
Table 4.3: Deviation of Uplift Values	58

## LIST OF ABBREVIATIONS

AP	Angle Point
SS	Square Section
RS	Round Section
33kV	33,000.00 Volt
AC	Acceptance Criteria
ICC-ES	International Code Council – Evaluation Service
ACSE	American Society of Civil Engineers
PLAXIS	Plasticity Axi-Symetry
3D	Three Dimensional
FEM	Finite Element Model
ASTM	American Society for Testing and Materials
SPT	Standard Penetration Test

## **LIST OF APPENDICES**

Appendix 01 : Borehole Log at AP 14

Appendix 02 : Borehole Log at AP 27

Appendix 03 : Borehole Log at AP 47