

UNIVERSITI TEKNOLOGI MALAYSIA

BORANG PENGESAHAN STATUS TESIS^u

JUDUL: THE PROBLEMS IN THE APPLICATION OF THE MICROPILE FOUNDATION SYSTEM IN MALAYSIA

SESI PENGAJIAN: 2006/2007

Saya, HALIMMI BIN HASHIM mengaku membenarkan tesis Sarjana ini disimpan di Perpustakaan Universiti Teknologi Malaysia dengan syarat-syarat kegunaan seperti berikut:

1. Tesis adalah hakmilik Universiti Teknologi Malaysia.
2. Perpustakaan Universiti Teknologi Malaysia dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. **Sila tandakan (√)

SULIT

(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)

TERHAD

(Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)

TIDAK TERHAD

Disahkan oleh



(TANDATANGAN PENULIS)



(TANDATANGAN PENYELIA)

Alamat Tetap:

107, Jalan Ampang Hilir, 55000 Kuala Lumpur,
Wilayah Persekutuan Kuala Lumpur

Prof. Madya Dr. Mohamad Ibrahim Bin
Mohamad

Nama Penyelia

Tarikh: 10hb Mei 2007

Tarikh: 10hb Mei 2007

CATATAN: * Potong yang tidak berkenaan.

** Jika tesis ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab dan tempoh tesis ini perlu dikelaskan sebagai SULIT atau TERHAD.

^u Tesis dimaksudkan sebagai tesis bagi Ijazah Doktor Falsafah dan Sarjana secara penyelidikan, atau disertasi bagi pengajian secara kerja kursus dan penyelidikan, atau Laporan Projek Sarjana Muda (PSM).

“I/We* hereby declare that I/we* have read this project report and in my/our* opinion this project report is sufficient in terms of scope and quality for the award of the degree of Master of Science (Construction Management)”

Signature : 

Name of Supervisor : Prof. Madya Dr. Mohamad Ibrahim Bin Mohamad

Date : 10th May 2007

**THE PROBLEMS IN THE APPLICATION OF THE MICROPILE
FOUNDATION SYSTEM IN MALAYSIA**

HALIMMI BIN HASHIM

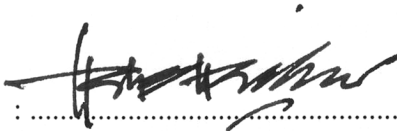
A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Science (Construction Management)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

MAY, 2007

I declare that this project report entitled "**THE PROBLEMS IN THE APPLICATION OF THE MICROPILE FOUNDATION SYSTEM IN MALAYSIA**" is the result of my own research except as cited in the references. The project report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature



:

Name

: HALIMMI BIN HASHIM

Date

: 10th May 2007

This project report is dedicated to my early mentors, Ir. Hope Thevaraj and Dato' Ir. Syed Muhammad Shahabudin to whom I am professionally inspired, to my precious mother and father and both my parents in-law. And most of all I devote this, to my wife Aida Nazlene and my children Tahira, Yasar and Qayyum.

ACKNOWLEDGEMENT

As in most undertaking, many people have contributed to the preparation of this project report. The contributions of some others, among them peers, academicians, and practitioners however, have not been similarly acknowledged and I hasten here to express my appreciation to them also.

The encouragement, guidance, criticisms and friendship of Associate Professor Dr. Mohamad Ibrahim Bin Mohamad has driven this study to its completion through his continued guidance, support and interest. Deserving of special mention are two classmates/colleagues of mine: Ir. Salehin Hj. Salleh and Ir. Ng Choo Geon who has mutually shared frustrations and tribulations, as well as the occasional shots of joy and exhilaration and for their support in needy times. Special note is also made of the contributions of Ir. Dr. Gue See Sew, Past President of The Institution of Engineers, Malaysia, for his inspirations and suggestions; Ir. Moy Weng Yeow, Director of Cygal Geotechnics Sdn Bhd, for sharing his extensive experiences in Foundation Engineering and Deep Piled Foundations; and to Ir. Dr. Mohd. Asbi Bin Othman, and Ir. Tan Ah Chai for their invaluable friendship.

Lastly, many other people, knowingly or otherwise, have also contributed to the knowledge and experience to make this report possible. Such individuals include faculty members of The Faculty of Civil Engineering, Universiti Teknologi Malaysia (UTM) Master of Science (Construction Management) off-shore programme, fellow post-graduate students, professional colleagues, friends and family members. To them also I express my deepest appreciation.

ABSTRACT

The micropiling concept is relatively young. The system which evolved in Europe in the 1950s, introduced to the United Kingdom in 1962 and to North America a decade later in 1973 was first applied in Malaysia in the early 1980s. The concept as a foundation system in Malaysia has gained acceptability in difficult ground condition and treacherous limestone areas. However, the current micropile design and construction practices in Malaysia is very fragmented, unguided and are generally independently reliant on the experience and knowledge of the specialist contractor or designer only. The aim of this study is to review the current practice of micropile system in Malaysia with regard to the limitations and problems of its application and identifying the improvement proposal. Literature reviews, industry observations and expert consultations were carried out to investigate the present and past practices in North America, Europe and Malaysia. The studies were sub-divided into different categories of the micropile practices differentiated by planning and design Practices, and construction practices. The Expert Panel Survey on a target group of experts had confirmed the deficiencies and problems identifying a state of lacking and fragmentation in certain aspects of the micropile practices in the country. This subsequently reinforced the need by the Industry Survey to determine and validate areas of weaknesses and obtain ratings on proposed change factors for the improvement of practice standards. The study showed that there is in general a gap existing between the level of analytical understanding and that of performance knowledge and construction excellence. It further confirmed the need to regularise and to standardise the industry, and to educate. While ways, methods and some industry improvement factors to drive positive changes were tested and determined, it was also found that the degree for improvement that is required varies among the component aspects of its current planning, design and construction practices.

ABSTRAK

Penggunaan konsep cerucuk mikro adalah agak baru. Sistem ini diwujudkan di Eropah pada awal tahun 1950an. Ia mula diperkenalkan di United Kingdom pada tahun 1962 dan di Amerika Utara satu dekad kemudian. Di Malaysia sistem cerucuk Mikro ini mula digunakan pada awal tahun 1980an. Sistem cerucuk ini diterima di Malaysia sebagai penyelesaian terhadap masalah kerja asas di kawasan substruktur yang sukar dan kawasan batu kapur. Walaupun sistem ini sudah diterima pakai tetapi masih belum wujud satu garis panduan piawai yang lengkap untuk dirujuk dalam amalan rekabentuk dan pembinaannya. Sistem rekabentuk cerucuk mikro pada masa ini sangat bergantung kepada pengalaman dan kepakaran individu perunding dan kontraktor. Oleh itu kajian ini telah dijalankan dengan tujuan untuk mengkaji masalah yang wujud dalam amalan rekabentuk dan pembinaan sistem cerucuk mikro ini. Diantara fokus dalam kajian ini termasuklah untuk mengkaji masalah dan kelemahan dalam aplikasi sistem cerucuk ini serta mengenalpasti kaedah yang boleh digunakan untuk membantu meningkatkan keberkesanan penggunaan sistem ini. Metodologi utama yang digunakan dalam kajian ini adalah kajian literatur, temubual dengan panel pakar yang mempunyai pengalaman luas dalam sistem cerucuk ini serta pengedaran borang soal selidik. Hasil daripada kajian di peringkat awal mendapati bahawa panel pakar telah bersetuju bahawa sememangnya wujud masalah tiada panduan dan piawai yang jelas yang dapat dirujuk dalam amalan rekabentuk dan pembinaan sistem cerucuk mikro dinegara ini. Selain dari itu, juga didapati terdapat masalah dalam menghubungkan antara kaedah analisa rekabentuk dengan prestasi sebenar yang dicapai oleh cerucuk mikro ini dalam pembinaan. Kajian ini juga telah mengenalpasti faktor yang penting untuk memperbaiki lagi amalan penggunaan sistem cerucuk mikro ini. Sebagai rumusan adalah sangat penting bagi industri pembinaan di Malaysia mengwujudkan satu sistem rekabentuk piawai yang dapat dirujuk dan dijadikan panduan oleh para perunding dan kontraktor supaya penggunaan cerucuk mikro ini lebih selaras samada untuk peringkat rekabentuk atau pun pembinaannya.

TABLE OF CONTENTS

| CHAPTER | TITLE | PAGE |
|----------|--|-------|
| | DECLARATION | ii |
| | DEDICATION | iii |
| | ACKNOWLEDGEMENTS | iv |
| | ABSTRACT | v |
| | ABSTRAK | vi |
| | TABLE OF CONTENTS | vii |
| | LIST OF TABLES | xiii |
| | LIST OF FIGURES | xvi |
| | LIST OF SYMBOLS | xx |
| | LIST OF APPENDICES | xxiii |
| 1 | INTRODUCTION | 1 |
| | 1.1 Background | 1 |
| | 1.2 Problem Statement | 2 |
| | 1.3 Objectives | 6 |
| | 1.4 Scope of the Study | 7 |
| | 1.5 Brief Research Methodology | 7 |
| | 1.6 Significance of the study | 9 |
| | 1.7 Limitations of the study | 9 |
| | 1.8 Summary | 11 |
| 2 | THE MICROPILE SYSTEM | 12 |
| | 2.1 Introduction | 12 |
| | 2.1.1 Historical Background | 13 |
| | 2.1.2 Key Benefits | 14 |
| | 2.2 The International Micropile Perspectives | 15 |
| | 2.2.1 The European Perspective | 15 |

| | | |
|----------|---|-----------|
| 2.2.2 | The American Perspective | 16 |
| 2.2.3 | The Malaysian Perspective | 17 |
| 2.3 | Design and Construction of micropile as an Integrated System | 20 |
| 2.4 | The Typical Micropile | 22 |
| 2.4.1 | The Basic Steps of the Construction of a Micropile | 23 |
| 2.4.1.1 | Step 1: Drilling | 24 |
| 2.4.1.2 | Step 2: Steel Reinforcement Placement | 24 |
| 2.4.1.3 | Step 3: Grout Injection | 25 |
| 2.4.2 | Drilled Micropile Execution | 26 |
| 2.5 | Types of Micropiles | 26 |
| 2.5.1 | Root piles | 26 |
| 2.5.2 | Tubfix micropile | 27 |
| 2.5.3 | The Gewi pile | 28 |
| 2.5.4 | Root pile with expanded base | 29 |
| 2.6 | Micropile Classification Based on Grouting Procedures | 30 |
| 2.6.1 | "Injection Répétitive et Sélective" and "Injection Globale Unitaire" | 30 |
| 2.6.1.1 | "Injection Répétitive et Sélective" | 30 |
| 2.6.1.2 | "Injection Globale Unitaire" | 30 |
| 2.6.2 | Classification accepted by the U.S. Federal Highway Administration | 31 |
| 2.6.2.1 | Based on philosophy of behaviour (Bruce et al. 1995b) | 31 |
| 2.6.2.2 | Based on Method of Grouting | 33 |
| 2.7 | Typical characteristics of a micropile as reported by different authors | 35 |
| 2.7.1 | Boring Diameters | 35 |
| 2.7.2 | Pile Length | 35 |
| 2.7.3 | Maximum Grouting Pressures | 35 |
| 2.7.4 | Service Loads | 36 |
| 2.7.5 | Typical Safe Working Capacities: Fondedile, United Kingdom | 36 |
| 3 | PILE APPLICATION, DESIGN AND CONSTRUCTION | 37 |
| 3.1 | Introduction | 37 |

| | | |
|----------|---|-----------|
| 3.2 | Pile Application | 37 |
| 3.3 | Methods of design | 39 |
| 3.3.1 | Design Requirements | 39 |
| 3.3.2 | The JKR Structural Design Concept | 44 |
| 3.3.3 | Foreign Structural Design Concepts | 46 |
| 3.3.3.1 | North American Structural Design Concepts | 46 |
| 3.3.3.2 | European Structural Design Concepts | 49 |
| 3.4 | Geotechnical design approaches | 51 |
| 3.4.1 | The Malaysian Practices | 51 |
| 3.4.1.1 | Design based on: Fixed Length (Bearing Resistance) in Rock Socket | 52 |
| 3.4.1.2 | Other geotechnical design approaches | 54 |
| 3.5 | Drilling Methods | 56 |
| 3.5.1 | Fully Lined to Rock, Rotary Percussive | 57 |
| 3.5.2 | Opened Hole, Rotary Percussive | 58 |
| 3.5.3 | Fully Opened Hole, Mud Stabilised Rotary Drill | 59 |
| 3.5.4 | Partially Lined with Temporary Casing, Mud Rotary | 60 |
| 3.6 | Borehole Flushing | 61 |
| 3.6.1 | Rotary Mud Drilling Method | 61 |
| 3.6.2 | Rotary Air-Flushed Percussive Method | 62 |
| 3.7 | Cement and Neat Cement Grout: Grouting material | 64 |
| 3.8 | Summary | 66 |
| 4 | METHODOLOGY | 67 |
| 4.1 | Introduction | 67 |
| 4.2 | Literature Review and Determination of the Research Objectives | 67 |
| 4.3 | Data collection | 68 |
| 4.4 | The Expert Panel Survey - Problem Statement Validation | 69 |
| 4.4.1 | Development of the Expert Panel Survey Questionnaire - Problem Statement Validation | 70 |
| 4.4.2 | Objective of the Expert Panel Survey - Problem Statement Validation | 72 |

| | | |
|----------|---|-----------|
| 4.4.3 | Methodology for the Expert Panel Survey - Problem Statement Validation | 73 |
| 4.4.4 | The Questionnaire: The Expert Panel Survey | 73 |
| 4.5 | The Industry Survey | 74 |
| 4.5.1 | Development of the Industry Survey Questionnaire | 75 |
| 4.5.2 | Objective of the Industry Survey | 78 |
| 4.5.3 | Methodology of the Industry Survey | 78 |
| 4.5.4 | The Questionnaire: The Industry Survey | 80 |
| 4.6 | Data Analysis | 81 |
| 4.6.1 | Frequency Analysis | 82 |
| 4.6.2 | Average Index Analysis | 82 |
| 4.6.3 | Relative Index Analysis | 84 |
| 5 | DATA ANALYSIS AND RESULTS | 87 |
| 5.1 | Introduction | 87 |
| 5.2 | The Expert Panel Survey: The Problem Statement Validation Questionnaire | 88 |
| 5.2.1 | Section A – Background of the Expert Panel | 88 |
| 5.2.2 | Restructuring the Questionnaire Items of the Expert Panel Survey - (Problem Statement Validation Questionnaire Survey) | 93 |
| 5.2.3 | Reduction of Data to Nominal Level | 98 |
| 5.2.4 | Data Analysis on the Expert Panel Survey - The Problem Statement Validation Questionnaire | 99 |
| 5.2.4.1 | Objective 1: Review of Current Practices | 100 |
| 5.2.4.2 | Objective 2: Limitations and Problems of Current Practices | 104 |
| 5.2.4.3 | Objective 3 (preliminary): Justification for changes and improvements | 109 |
| 5.3 | The Industry Survey | 112 |
| 5.3.1 | The Respondents' Background | 113 |
| 5.3.2 | Data Analysis on the Industry Survey | 115 |
| 5.3.2.1 | General Issues | 116 |

| | | |
|----------|--|-----|
| | (a) Comparative Standard of Practice against Other Piling Systems | 116 |
| | (b) Aspects of the Micropiling Practices Requiring Improvement and Upgrades | 119 |
| | (c) Reasons and Sources of Problems encountered with Micropile Practices | 122 |
| | (d) Preferred Choice of Document Formats as Practice Guides | 124 |
| | 5.3.2.2 Planning and Design | 126 |
| | (a) Micropile Structural Design | 126 |
| | (b) Micropile Geotechnical Design | 127 |
| | (c) Contracting Methods | 131 |
| | (d) Contractors' Experience and Pre- Qualification Requirement | 133 |
| | 5.3.2.3 Micropile Construction | 138 |
| 5.4 | General Comments from the Respondents | 141 |
| | 5.4.1 General Comments from the Expert Panel Survey | 141 |
| | 5.4.2 General Comments from the Industry Survey | 142 |
| 6 | DISCUSSION | 145 |
| 6.1 | Introduction | 145 |
| 6.2 | Review of Current Practices: Objective 1 | 145 |
| 6.3 | Limitations and Problems of Current Practices: Objective 2 | 152 |
| | 6.3.1 Limitations to Practices | 152 |
| | 6.3.2 Problems of Practices | 155 |
| | 6.3.3 Inquisition on Objective 3: Justification for changes and improvements | 161 |
| 6.4 | Changes and Improvements: Objective 3 | 164 |
| | 6.4.1 General Issues | 165 |
| | 6.4.1.1 Comparative Standard of Practice against Other Piling Systems | 165 |
| | 6.4.1.2 Aspects of the Micropiling Practices requiring Improvement | 167 |
| | 6.4.1.3 Reasons and Sources of Problems encountered with Micropile Practices | 169 |

| | | |
|----------|---|----------------|
| 6.4.1.4 | Preferred Choice of Document Formats as Practice Guides | 171 |
| 6.4.2 | Planning and Design | 173 |
| 6.4.2.1 | Micropile Structural Design | 173 |
| 6.4.2.2 | Micropile Geotechnical Design | 175 |
| 6.4.2.3 | Contracting Methods | 176 |
| 6.4.2.4 | Contractors' Experience and Pre- Qualification Requirement | 178 |
| 6.5 | Micropile Construction | 182 |
| 6.5.1 | Construction issues | 183 |
| 7 | CONCLUSION AND RECOMMENDATION | 187 |
| 7.1 | Introduction | 187 |
| 7.2 | Major findings | 187 |
| 7.3 | Additional proposals from the respondents | 195 |
| 7.4 | Conclusion | 196 |
| 7.5 | Recommendation for Further Studies | 197 |
| | REFERENCES | 201 |
| | APPENDICES A-B | 204-234 |

LIST OF TABLES

| TABLE NO. | TITLE | PAGE |
|------------------|---|-------------|
| 2.1 | Typical Safe Working Capacities (KN) - Fondedile, United Kingdom | 36 |
| 3.1 | Geotechnical Design (piles grouted under pressure) | 55 |
| 3.2 | Geotechnical Design (piles grouted under gravity head) | 56 |
| 3.3 | Quality limits of mixing water | 66 |
| 4.1 | The level of agreement and evaluation for average index analysis for Ordinal Data (5-point Likert Scale) | 83 |
| 4.2 | The level of agreement and evaluation for average index analysis for Ordinal Data (3-point Likert Scale) | 83 |
| 4.3 | The level of agreement and evaluation for average index analysis for Interval Data (Linear, Numeric Scale) | 84 |
| 4.4 | The level of agreement and evaluation for relative index analysis for Ordinal Data (5-point Likert Scale) | 85 |
| 4.5 | The level of agreement and evaluation for relative index analysis for Ordinal Data (3-point Likert Scale) | 85 |
| 4.6 | The level of agreement and evaluation for relative index analysis for Interval Data (Linear, Numeric Scale) | 86 |
| 5.1 | Number of respondents (Expert Panel) | 88 |
| 5.2 | Distribution of Expert Panel by nature of business/ core activity | 89 |

| | | |
|------|--|-----|
| 5.3 | Distribution of Expert Panel by positions in their organisation | 90 |
| 5.4 | Distribution of Experts based on years of experience in micropile design & construction | 91 |
| 5.5 | Frequency of experience with other types of pile design and construction among the Experts | 92 |
| 5.6 | The level of agreement and evaluation on 5 point Likert and Linear, Numeric Scales reduced to a nominal level | 98 |
| 5.7 | The level of agreement and evaluation on 3 point Likert Scale reduced to a nominal level | 97 |
| 5.8 | Problem Statements for Objective 1 - Frequency Analysis of the Review of Current Practices with the Expert Panel | 103 |
| 5.9 | Problem Statements for Objective 2 - Frequency Analysis of the Limitations and Problems of Current Practices with the Expert Panel | 106 |
| 5.10 | Objective 3 (preliminary) - Frequency Analysis for Justification for Changes and Improvement with the Expert Panel | 111 |
| 5.11 | Number of Responses to the Industry Questionnaire | 112 |
| 5.12 | Distribution of Industry Survey Respondents by nature of business/core activity | 114 |
| 5.13 | Distribution of Industry Survey respondents by positions in their organisation | 114 |
| 5.14 | Distribution of Industry Survey Respondents based on years of experience in design and construction | 115 |
| 5.15 | Comparative standard of practice against other piling systems | 118 |
| 5.16 | Aspects of the micropiling practice requiring improvement | 121 |
| 5.17 | Frequency for sources and causes of problems | 122 |
| 5.18 | Preferable choice of document formats as practice guides | 125 |
| 5.19 | (a) - Micropile Structural Design | 129 |
| | (b) - Micropile Structural Design (continued) | 130 |

| | | |
|------|--|-----|
| 5.20 | Contracting Methods as ranked by the respondents | 131 |
| 5.21 | Frequency Distribution for Contracting Methods | 132 |
| 5.22 | (a) - Contractors' experience and pre-qualification requirements | 136 |
| | (b) - Contractors' experience and pre-qualification requirements (continued) | 137 |
| 5.23 | Construction Issues | 140 |
| 6.1 | General Statements on Good Practices for Piling | 146 |
| 6.2 | Critical Problem Statements in the Review of Current Practices with the Expert Panel | 148 |
| 6.3 | Limitations to Micropiling Practices | 153 |
| 6.4 | Problems in Micropiling Practices | 157 |
| 6.5 | Cumulative Percentage Distribution for Objectives 1 and 2 | 161 |
| 6.6 | Justification for Changes and Improvement | 162 |
| 6.7 | Design Issues | 174 |
| 6.8 | Contracting Methods | 177 |
| 6.9 | Contractors' Experience and Pre-Qualification Issues | 179 |
| 6.10 | Contractors Pre-Qualification Requirement | 181 |
| 6.11 | Construction Issues | 184 |

LIST OF FIGURES

| FIGURE NO. | TITLE | PAGE |
|-------------------|--|-------------|
| 1.1 | Research Methodology Flowchart | 8 |
| 2.1 | Typical micro pile sections, left with solid bar reinforcement, right with hollow bar reinforcement or casing (FHWA, 2000) | 14 |
| 2.2 | Typical Micropile | 23 |
| 2.3 | Grout hacked & steel starter bars exposed for connection to pilecap | 23 |
| 2.4 | Typical Micropile Construction Sequence Using Casing (FHWA, 2000) | 24 |
| 2.5 | Typical post-grouting system (FHWA, 2000) | 27 |
| 2.6 | Continuously Threaded Dywidag Bar (DSI) | 28 |
| 2.7 | GEWI Pile (typical) with standard and double corrosion protected reinforcing bar | 29 |
| 2.8 | Classification by Philosophy of Behaviour (Bruce et al. 1995b) Case 1: Directly Loaded Piles (FHWA, 2000) | 32 |
| 2.9 | Classification by Philosophy of Behaviour (Bruce et al. 1995b) Case 2: Working with soil as a composite (FHWA, 2000) | 33 |
| 2.10 | Classification by Method of Grouting (Bruce et al. 1995b) | 34 |
| 3.1 | Summary of the Typical Design Behaviour and Micropile Construction type for each application | 38 |
| 3.2 | Pile Foundation Design and Construction Scope (Neoh, 2005) | 40 |

| | | |
|------|---|----|
| 3.3 | Design Aspects of a Typical Micropile. | 41 |
| 3.4 | Eccentric Overburden Drilling Bits | 57 |
| 3.5 | Typical Longitudinal Section of a Down-the-Hole Hammer | 58 |
| 3.6 | DTH-Drilling Bits | 59 |
| 3.7 | Down-the-Hole Hammers with Bit Attached | 59 |
| 3.8 | Rotary Tricones (T.C.I. – Tungsten Carbide Inserts) and Mill Tooth Rock Roller Bits | 59 |
| 3.9 | The Marsh Funnel | 60 |
| 3.10 | Gardner-Denver Triplex Mud Pumo 215 to 2000 HP (160 to 1490 kW) | 62 |
| 3.11 | Air Flushed Percussive Drilling | 62 |
| 3.12 | 1200 CFM Portable Air Compressors | 63 |
| 3.13 | Air Velocity Chart (Sandvik Mission Down-the-Hole Hammers) | 64 |
| 3.14 | Effect of Water Content on Neat Cement Grout Compressive Strength and Flow Properties (Barley and Woodward, 1992) | 65 |
| 4.1 | Five ordinal measures of agreement of the Likert scale | 70 |
| 4.2 | Three ordinal measures of agreement the of Likert scale | 71 |
| 4.3 | Three relative measures of the Comparative Scale (Alreck and Settle, 1995) | 75 |
| 4.4 | Three ordinal measures of agreement of the Likert Scale (Alreck and Settle, 1995) | 76 |
| 4.5 | Multiple Choice Items – multiple response scale (Alreck and Settle, 1995) | 76 |
| 4.6 | Five interval measures of agreement of the Linear, Numeric Scale (Alreck and Settle, 1995) | 77 |
| 4.7 | Forced Ranking Scale (Alreck and Settle, 1995) | 77 |
| 5.1 | Distribution of Expert Panel by nature of business/ core activity | 89 |

| | | |
|------|--|-----|
| 5.2 | Distribution of Experts based on position in company by percentage | 90 |
| 5.3 | Distribution of Experts based on years of experience with micropile design & construction | 91 |
| 5.4 | Frequency of Experts' competency with other types of pile design and construction | 92 |
| 5.5 | Regrouping the Expert Panel survey questionnaire items by topics | 94 |
| 5.6 | Percentage of the Responses to the Industry Survey questionnaire | 113 |
| 5.7 | Percentage of the Industry Survey respondents by Business Activity | 113 |
| 5.8 | Distribution of Industry Survey Respondents by nature of business/core activity | 114 |
| 5.9 | Distribution of Industry Survey Respondents based on years of experience in design and construction | 115 |
| 5.10 | Percentage bar charts for sources and causes of problems in micropiling practices (Multiple Response Scale) | 123 |
| 6.1 | Summary of Frequency Analysis on Objectives 1 and 2: Dissatisfaction Levels and the Need for Improvement Changes | 164 |
| 6.2 | Mean Comparative Score of Aspects of Micropile Practice Compared to others Piling Systems on a 3-point Comparative Scale | 166 |
| 6.3 | Likert Scale Item Bar Chart Mean Score for Aspects of Micropile Practice Requiring Improvements and Upgrades | 168 |
| 6.4 | Percentage Distribution of Multiple Responses on Sources and Causes of problems in Micropiling | 170 |
| 6.5 | Linear, Numeric Scale Item Bar Chart of Mean Ratings of Preference for Documentation Format for Practice Guide | 172 |
| 6.6 | Linear, Numeric Scale Item Bar Chart of the Mean Score for Methods of Deriving the Micropile Structural Design Formulae | 175 |

| | | |
|-----|--|-----|
| 6.7 | Forced Ranking Stacked Column Chart of the Percentage Ranking each Contracting Method at each rank 1, 2, 3 and 4 | 178 |
| 6.8 | Linear, Numeric Scale Item Bar Chart of the Mean Rating for Pre-Qualification Methods | 182 |

LIST OF SYMBOLS

| | | |
|--------------------------|---|---|
| A | - | Surface area of rock/grout bond |
| A_c | - | Nett grout x-sectional area |
| A_g | - | Gross x-sectional area of the micropile |
| A_s | - | Steel core or reinforcement x-sectional area |
| A_p | - | Area at bottom of the pile based on a diameter <i>D</i> (if the construction procedure produces an increase in diameter) |
| c | - | Cohesion or strength intercept of the assumed straight line Mohr envelope |
| c_a | - | Adhesion between pile and soil independent of the normal stress acting on the shaft |
| C_u | - | Average undrained shear strength over the bond length |
| D, d | - | Gross diameter of the micropile |
| D_s | - | Diameter of rock socket |
| E_{grout} | - | Modulus of elasticity, grout |
| E_{rock} | - | Modulus of elasticity, rock |
| f_s | - | Unit skin friction/ unit shaft resistance |
| f | - | Allowable rock/grout bond strength |
| f_y | - | Yield stress of steel core or reinforcement |
| f_{cu} | - | Grout characteristic strength |
| FS | - | Factor of Safety |
| I | - | Dimensionless coefficient based on the nominal diameter of the micropile (drilling diameter) |
| k_p | - | Coefficient for point bearing which depends on soil type |
| k_{sp} | - | Empirical bearing capacity factor based on the spacing of the discontinuities of the rock |
| K | - | Coefficient representing the average interaction between the micropile and the soil for the whole length (pile-soil adherence: based on soil consistency) |
| K_o | - | Coefficient of at rest lateral pressure |
| K_s | - | Coefficient of skin pressure |
| K_p | - | Coefficient of passive earth pressure [= tan ² (45+ φ/2)] |
| L | - | Bond length in soil only |

| | | |
|------------|---|---|
| L_s | - | Pile rock socket length |
| L_T | - | Total length of pile |
| n | - | Factor which is affected by η |
| N | - | Standard Penetration Test (SPT) value/300mm penetration |
| N_c^* | - | Dimensionless bearing capacity factors as a function of the soil friction angle ϕ |
| N_s | - | Dimensionless bearing capacity factors as a function of the soil rigidity index I_r |
| ϕ | - | Angle of shearing resistance granular soil |
| ϕ' | - | Effective angle of shearing resistance granular soil |
| ϕ_r | - | Angle of shearing resistance of the rock mass |
| p_i | - | Grouting pressure |
| p_l | - | Limit pressure of the soil pressure of soil at the bottom of the pile found with the Ménard pressuremeter test |
| q_p | - | Unit point resistance/unit base resistance |
| q_u | - | Unconfined compressive strength of rock |
| q_s | - | The normal stress acting on the foundation shaft which is conventionally related to the effective vertical stress q_v [$= K_s \cdot q_v$] |
| q_{sl} | - | Lateral friction which depend on p_l and on the type of soil; values can be obtained from graphs of q_s vs p_l |
| q_v | - | Effective vertical stress |
| Q_p | - | Pile end bearing capacity |
| Q_s | - | Pile total shaft friction |
| Q_a | - | Allowable load or design working load |
| Q_u | - | Pile ultimate structural capacity |
| Q_L | - | Ultimate geotechnical capacity |
| QP_L | - | Limit point bearing capacity |
| QS_L | - | Limit side resistance |
| $\tan d$ | - | Coefficient of friction between soil and shaft [$= \tan \phi'$ for piles of normal roughness] |
| t_{ult} | - | Ultimate rock skin friction/rock-grout bond value |
| T | - | Pile grout bond with granular soil |
| $T_{ult.}$ | - | Ultimate bearing capacity |
| α | - | Pile/soil adhesion factor which varies between 0.6 and 0.8 for micropile design |
| σ_o | - | Mean normal effective ground stress related to the effective vertical stress [$= 1/3 (1+2K_o)q_v$] |

σ_r - Failure radial stress

¶

- drilling technique (rotary percussive with water flush),
- depth of overburden,
- fixed anchor diameter,
- grouting pressure in the range 30 to 1000 kPa ,
- in situ stress field, and
- dilation characteristics of the soil

LIST OF APPENDICES

| APPENDIX | TITLE | PAGE |
|-----------------|---|-------------|
| A | STRUCTURED QUESTIONNAIRES TO THE EXPERT PANEL - Expert Panel Survey | 204 |
| A1 | STRUCTURED QUESTIONNAIRES TO THE EXPERT PANEL - Questionnaire Results (in accordance with the exact format issued to respondents) | 212 |
| A2 | FREQUENCY ANALYSIS ON STRUCTURED QUESTIONNAIRES RESPONSES FROM THE EXPERT PANEL | 217 |
| B | STRUCTURED QUESTIONNAIRE FOR THE INDUSTRY SURVEY - The Industry Survey | 221 |
| B1 | RESPONDENTS' RATINGS ON THE QUESTIONNAIRE ITEMS - The Industry Survey | 230 |

*"Lives of great men all remind us. We can make our lives sublime and departing
leave behind us footsteps on the sands of time..."*
Henry Wadsworth Longfellow

CHAPTER 1

INTRODUCTION

1.1 Background

Unlike piling systems such as pre-cast reinforced concrete or spun concrete piles which has long been established and guided by well defined practice codes, the micropile is in contrast a non-proprietary system which is largely the responsibility of the Engineer to design and specify. The dearth of documented guidelines, rules or conduct definition in its practice has placed its applications in this country on a pedestal that is subjective and arbitrary and dependent largely on the designer's own and independent past experiences and perception of the system, and paired by the unregulated and liberal choices of construction methods by the contractor. Neoh (1996) had commented that the current micropile design and construction practice is considered to be very empirical and are generally reliant on the experience and knowledge of the micropile specialist contractor for calculation and specification. Empiricism is in fact the philosophy by which geotechnical engineering is practiced worldwide. While micropile practices are not expected to be of any exception, it is without an acknowledged and established empirical rule, unlike others. Currently, reliable designs are based on sound judgment and experience rather than the truth, a situation that does not bode well for the industry.

The concept of the micropile system as a deep foundation system in Malaysia has gained acceptability in difficult ground and treacherous limestone areas in contrast to the traditional steel piles or bored piles. This is said to be mainly due to technical superiority in respect of fast installation while providing reliable capacity. It has grown since the early 1980s amidst the absence of a commonly accepted industry practice guideline which could serve as a benchmark for both regulation of

good practice as well as an authority in cases of disputes and litigations. The lack of common ground on acceptable practices has also resulted in an array of problems, some technical and the others professional, arising from arguable and inconsistent opinions and criteria in application.

The Partnership for Advancing Technology in Housing (PATH) in 2002 stated that as for most technologies, considerations of practice regulations are addressed after the technology is already in the marketplace. Similarly, this applies to micropile. In Malaysia, only Jabatan Kerja Raya (JKR) has been known to have formulated a brief design and practice notes intended for in-house use only. The system has enjoyed technology deployment for over 20 years.

Taking a technology from idea through development and deployment to market acceptance is complex and requires many activities. The use of micropile has seen the reverse of these where there was technology acceptance prior to research and development, therefore giving rise to the approach of “predict and control”. The practice needs to be better defined, documented and regulated, in order to ensure that acceptable industry standards are achieved, kept sustainable and evolving.

1.2 Problem Statement

Neoh (1996), stated that the choice of the formula used in piling and foundation designs depends on the designers' individual preference and experiences and that the resulting computations must be checked by senior geotechnical engineers who must have several years of experiences to ensure that designs are reasonable. Problems arise when designers lack the design experience and knowledge, amounting to working beyond an area of competency against the Board of Engineers Malaysia, Code of Ethics (Revision 2002). The unchecked design is further exacerbated by contractors who are neither engineers nor possessing the necessary engineering and skills to notice design flaws. Thereon, there persist the errors of ignorance and inexperience creeping through the stages of planning, design and procurement and construction phases until these errors are arrested and identified at an advanced stage, sometimes at substantial cost and delays.

Micropiles have been universally accepted as the least understood of all the piling systems, and even so called 'senior geotechnical engineers' lacks the level of knowledge to be effective technical adjudicators. The United States Federal Highway Administration (2000) reported that most United States' public agencies and consulting engineers presently have little or no knowledge regarding micropiles and their application. At the moment, excellent piling supervisors or contractors are equally as crucial as expert pile designers for the successful implementation of micropile works. The understanding of all piling principles is requisite to expert pile designers and supervisors. An ignorant piling supervisor or contractor can turn a sound pile design into a nightmare, but an experienced supervisor or contractor can prevent poorly conceived pile design from becoming a disaster (Neoh, 1996). British Standards Institution, BS 8004 recommends that a competent person, properly qualified and experienced, should be appointed to supervise piling operations. This person should be capable of recognising and assessing any errors or potential danger as they arise that may require a change in design and/or construction technique.

The implementation of the micropile technology in Malaysia, have existed on a platform roughened by the lack of practical design and construction guidelines. In place of a time consuming learning curve, 'guidelines' could help to 'smoothen' out the prevalent overall 'roughness' of knowledge in a much shorter period. Since the early 1980's when Malaysia first adopted this foundation concept, there is still no dedicated and documented design guidelines, procedures or codes for micropile use and practice in Malaysia despite the ambiguities and anomalies among designers.

The absence of standards and the lack of analytical knowledge in its design, characteristics and nature of behaviour and performance, has resulted in the use of:

- Standardised, repetitive and extravagant designs appearing in Tenders.
- Multitudes of unlikely design variants and material usage contradicting the requirements of various relevant codes, and
- The use of patchy or sometimes non-existent material specifications.

Todate most Malaysian Engineers still has a superficial knowledge of an appropriate practice philosophy that lead to practitioners widely opting to practice by:

- the duplication of designs and construction specifications inappropriate to site and sub-soil condition;
- the reproduction of higher capacity existing/previous designs and the adoption of these designs for lower capacity need;
- over designed details and over specification (erring on the safe side);
- under designed details and under specification (total lack of knowledge and experience);
- a lack of the knowledge of construction material properties required resulting in the, usage of wrong materials inappropriate to construction techniques and pile dimension (constructability issue);
- inability to predict and forecast expected performance and results of their designs and specifications; and
- misconception of the system's capability (by MLT or otherwise) due to the absence of any understanding of its limitations.

The minimalism approach in design has at times resulted in very wasteful designs where at times the cost of piling could have been reduced by 40%. Full trust on the capability of the system without any consideration of its limitations has compounded the problem.

Design adjustments are required to counter the effects of level of stresses that are in addition governed by serviceability limits (pile length differentials), Maximum slenderness ratio (maximum elastic compression), low slenderness ratio (excessive pile stresses) and negative skin friction (additional loads). Unless better knowledge

and understanding is acquired, uncertainties will prevail and very safe decisions will continue to be taken based on experience only which is most likely to have excessive tendencies, costing more than what is necessary. The lack of both design and performance behaviour knowledge of the system for over 20 years, has forced the micropile design to continue to be based on the approach of “predict and control” as an industry norm.

The main issues confronting the Malaysian micropile practice were:

- Competent knowledge and understanding confined only to a very few.
- Proliferation of differing concepts and design philosophies.
- Absence of local research and interest in academia.
- No set standards and guidelines as yet for practice.

The source of this state of backwardness could be traced to the comments by Neoh (1996) of Institut Latihan dan Penyelidikan Kerja Raya Malaysia, that the present day micropile design and construction practice still remains empirical due to the lack of research data. The state of affairs could be generalised as follows:

1. Local and current micropile design and construction practice is considered to be very empirical.
2. Reliable designs made from design decisions based on judgement and experience rather than the truth.
3. Inept practice by designers – often requires intervention
4. Generally reliant on the experience and knowledge of the micropile specialist contractor's. When ‘cheap’ and non-specialist sub-contractors are paired with ‘inept’ designs, disaster occurs.

5. Lack of scientific knowledge prevents optimised designs and construction – uneconomical.
6. Faulty judgement and lack of experience results in construction problems and cost overruns as a documented “truth” has yet to exist.
7. No dedicated standards exist. No defined practice method/s; requirements are derived from many different codes and standards.
8. Too many design methods in use (designs are independent and subjective).
9. Construction methods vary and are driven by commercial interest – not technical or cost considerations.

The United States Federal Highway Administration in its FHWA Publication No: FHWA-RC-BAL-04-0015 stated that the implementation of micropile technology on U.S. transportation projects has been hindered by the lack of practical design and construction guidelines, a situation seemingly familiar to Malaysia.

1.3 Objectives

This aim of this study is to review and expose current concepts, methods and weaknesses of local micropiling practices by probing queries into aspects of the practices and revealing its actual status and condition. It was also aimed at identifying the level of weaknesses of the various aspects of the practices, the critical areas and thereon the determination and suggestion of change factors for improvements. The information gained by the study could lead towards further efforts for an overall improvement of the state-of-practice for micropiles, identify the virtues as well as limitations in order to arrive to a benchmark representing best practices and good standards, technologically and economically.

The objectives of this study are as follows:

- (i) To evaluate and perform a review of current Malaysian Practices in the use of the micropile piling system.
- (ii) To determine the problems and limitations of current practices.
- (iii) To identify possible changes for improvement to practice standards (design and construction) for micropile foundation.

1.4 Scope of the Study

Each of the numerous participants in the process of planning, (concept and technological, economic and feasibility studies), designing, (preliminary and detailed engineering), financing, (procurement), constructing and, operating physical facilities (start-up, operation, utilisation) has a different perspective on overall project management for construction (Hendrickson, 1998). The focus of attention for this study is not on all of the components of a project life cycle, but to identify strengths, weaknesses, problems and limitations in the steps and activities employed in direct application of the micropile system, namely in the stages for

- i. planning and design practices i.e. (conceptual, technological, economic and feasibility studies) and designing i.e. (preliminary and detailed engineering), and
- ii. construction operation practices (drilling, reinforcing, grouting, pile finishing).

1.5 Brief Research Methodology

The methodology used in conducting this study were through identification of the problem structure from literature search, industry observations and consultations with experts, followed by an expert panel structured questionnaire survey with local professionals of proven expertise in micropile design and

construction to largely establish a general overview of the state-of-practice of the micropile technology and verify current problems and limitations facing the practices. The study was finally capped by an industry survey through structured questionnaires directed to a wider spectrum of respondents comprising users and practitioners of the system. The industry survey was intended at gaining some direction for changes and improvement to current practices in order to address the problems and limitations associated with micropile practices.

The overall sequence of research process undertaken for the study is shown in figure 1.1.

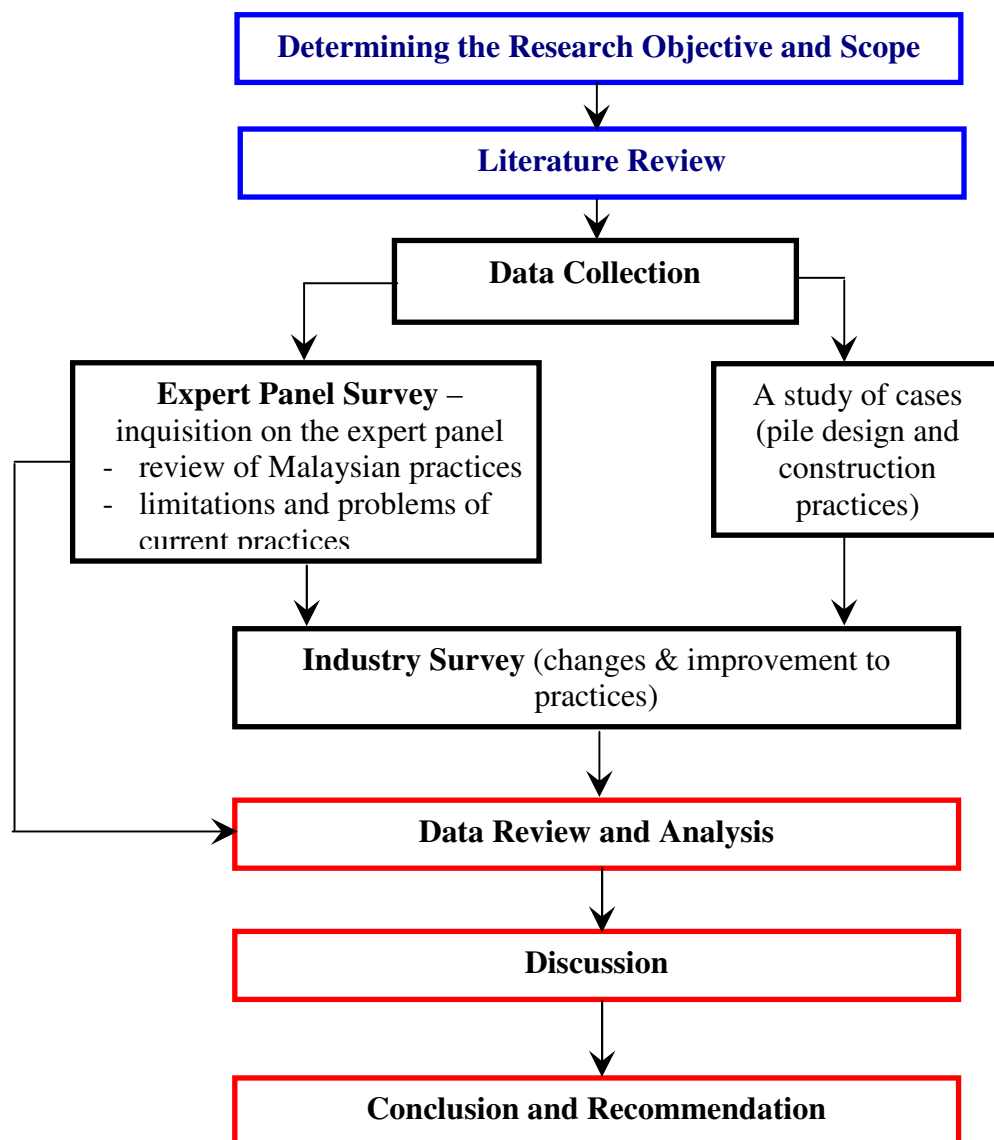


Figure 1.1 - Research Methodology Flowchart

1.6 Significance of the study

In Malaysia, micropiles have been used mainly as elements for structural foundation support to resist static and lateral loading conditions, and as in-situ reinforcements for slope and excavation stability. Many of these applications have been for transportation, building structures and as slope failures permanent remedies.

The lack of standardisation in practice, to date has resulted in a less than professional manner with which micropiles has been applied in Malaysia. A loosely defined set of rules is detrimental to professionalism and ethics. The JKR has drawn their own guidelines for in-house guidance based on their own review of case studies of past projects (Neoh, 1994). However, this may be regarded as still being very general and lacks the depths of knowledge to be justified as a standard.

The importance and significance of this study is to gain a better insight into the present day micropile foundation practices. Information obtained can be utilised to help alleviate the problems of weaknesses and anomalies of approaches and concepts. In addition, the study design can be implemented as a part of a future extended study whereby the limitations and uncertainties in the current state-of-the-practice need to be evaluated with greater rigour and further research needs be identified. Eventually, the product of the efforts should be a national and industry regulated manual of design and construction guidelines directed for use by practicing engineers, government agencies, geotechnical and structural engineers.

1.7 Limitations of the study

The limitations for the study relates mainly to issues pertaining to human factor and time constraints. The scope of this study had to be restricted to issues of general practices only without touching on finer details of the aspects of the practices which could be a huge insurmountable task given the amount of design and construction elements linked to the design and construction of micropiles.

Limitations to the study come in the form of:

- a. Limited number of respondents available
- b. Apprehension in answering survey questions
- c. Numerical analysis - depths of research and scientific studies required

Most practicing engineers and technicians, however, are aware of the nature and attributes of the micropile. However, very few are aware of the technicalities and principles behind its design and fewer still are the number of engineers who are conversant with the design principles, material usage, construction processes, and the relationship of these to the eventual performance and behaviours of the micropiles. There is another group of people involved with the technology whose knowledge is confined to the drilling and installation of the micropile only. These are the works contractors or sub-contractors who are non-engineers or professionals from other disciplines who lacks the knowledge of engineering principles. Often, they have dangerously conceived engineering perceptions on the workings of the micropile.

This section illustrates a situation where the number of qualified respondents for this study would be limited. In ensuring that all survey results have 'quality and validity', only respondents fulfilling all of the criteria such as experience in micropiles, formal tertiary technical education and are engineers, geologist or quantity surveyors, has some micropile design knowledge and at least some micropile construction knowledge were invited to participate in the study.

Excluded from participation in this study were the many works contractors or sub-contractors who are knowingly just specifications and shop drawing observers. They lack the engineering training to allow critical thinking to be applied on engineering issues for survey and study reliability and validity.

One observation made is the tendency to treat the survey questionnaires as a test of competency by the respondents, hence apprehension and delays in response. With an overwhelming majority of respondents with work experiences more than 15 years, most are weary of protecting their professional reputation and places strong emphasis in trying to answer 'correctly'.