

Contents

| | |
|---|-------------|
| List of Tables | xi |
| List of Figures | xiii |
| Preface | xxi |
| 1 Introduction | 1 |
| 1.1 Background | 1 |
| 1.2 Source of Alkali Contamination | 2 |
| 1.3 Field Incidents of Alkali Contamination | 3 |
| 1.4 Impact of Alkali Contamination | 5 |
| 1.5 Mitigation Techniques | 7 |
| 1.6 Motivation of Study | 8 |
| 1.7 Research Objectives | 9 |
| 1.8 Thesis Outline | 9 |
| 2 Literature Review | 11 |
| 2.1 General | 11 |
| 2.2 Alkali-Induced Heaving | 11 |
| 2.3 Mineralogical Alterations in Alkali Interacted Soil | 13 |
| 2.4 Geotechnical Properties of Alkali Interacted Soil | 15 |
| 2.5 Heaving Suppression Technique | 16 |
| 2.5.1 Application of Salt Solutions | 16 |
| 2.5.2 Application of Waste Materials | 17 |
| 2.6 Soil Stabilisation Technique | 18 |
| 2.6.1 Mechanical Stabilisation | 19 |

| | | |
|----------|---|-----------|
| 2.6.2 | Chemical Stabilisation | 20 |
| 2.6.2.1 | Stabilisation using Ground Granulated Blast-Furnace Slag (GGBFS) | 21 |
| 2.6.2.2 | Stabilization using Alccofine | 24 |
| 2.6.2.3 | Stabilization using other Inorganic Chemicals | 27 |
| 2.7 | Stabilization of Soil using Bio-Chemicals | 30 |
| 2.8 | Electrokinetic (EK) Technique | 33 |
| 2.9 | Summary | 51 |
| 3 | Materials and Methods | 53 |
| 3.1 | General | 53 |
| 3.2 | Material Selection | 53 |
| 3.2.1 | Soil | 53 |
| 3.2.2 | Geotechnical Tests | 54 |
| 3.2.2.1 | Particle Size Distribution | 54 |
| 3.2.2.2 | Atterberg Limits | 55 |
| 3.2.2.3 | Specific Gravity | 55 |
| 3.2.2.4 | Compaction Characteristics | 56 |
| 3.2.2.5 | Unconfined Compressive Strength | 56 |
| 3.2.2.6 | Triaxial Test | 57 |
| 3.2.3 | Ground Granulated Blast-Furnace Slag (GGBFS) | 58 |
| 3.2.4 | Alccofine | 59 |
| 3.2.5 | Chemical Stabilizer | 61 |
| 3.2.5.1 | Enzyme-Induced Carbonate Precipitation (EICP) | 61 |
| 3.2.5.2 | Sodium Silicate | 62 |
| 3.2.5.3 | Sodium Carbonate | 63 |
| 3.2.5.4 | Calcium Chloride | 64 |
| 3.2.6 | Alkali Solution | 64 |
| 3.2.7 | Sample Preparation | 64 |
| 3.2.8 | Mineralogical Studies | 65 |
| 3.2.9 | Morphological Studies | 65 |
| 3.2.10 | Electrokinetic Model Set-up | 66 |

| | | |
|----------|--|-----------|
| 3.2.10.1 | Rectangular Model Tank Equipped with ElectroKinetics | 66 |
| 3.2.10.2 | Circular Model Tank Equipped with ElectroKinetics | 67 |
| 3.2.10.3 | Electrodes used in Large Scale Models | 69 |
| 3.2.10.4 | Bench Scale ElectroKinetic Model | 72 |
| 3.2.10.5 | Electrodes used in Bench Scale Model | 72 |
| 3.2.10.6 | Voltage Sensors | 73 |
| 3.2.10.7 | DC Supplier | 74 |
| 3.2.10.8 | Motorized Stirrer | 74 |
| 3.3 | Research Methodology Adopted | 74 |
| 3.4 | Summary | 77 |
| 4 | Assessment of Alkali-Induced Heaving through Electrokinetics | 79 |
| 4.1 | General | 79 |
| 4.2 | Effect of Alkali Concentration on Soil | 80 |
| 4.2.1 | Particle Size Analysis | 80 |
| 4.2.2 | Atterberg Limits | 80 |
| 4.2.3 | Specific Gravity | 81 |
| 4.2.4 | Compaction Characteristics | 82 |
| 4.2.5 | Heaving Analysis | 82 |
| 4.2.6 | Heaving Pressure | 84 |
| 4.2.7 | Unconfined Compressive Strength | 85 |
| 4.2.8 | Shear Strength Parameters | 86 |
| 4.2.9 | Zeta Potential | 86 |
| 4.2.10 | Dielectric Constant | 87 |
| 4.2.11 | X-ray fluorescence analysis | 87 |
| 4.2.12 | Mineralogical Analysis | 89 |
| 4.2.13 | Micro Structural Analysis | 90 |
| 4.3 | Alkali-Induced Soil Heaving in Large Scale Model through Electrokinetics | 91 |
| 4.3.1 | Rectangular Model Equipped with Electrokinetics | 93 |
| 4.3.2 | Circular Model Equipped with Electrokinetics | 93 |
| 4.3.3 | Sample Preparation | 93 |
| 4.3.4 | Electrokinetic Mechanism | 94 |

| | | |
|----------|---|------------|
| 4.3.5 | Comparison of Rectangular and Circular Model Equipped with EK | 95 |
| 4.3.5.1 | Surface Heaving | 95 |
| 4.3.5.2 | Heaving Pressure in Large Scale Models | 98 |
| 4.3.5.3 | Variation of Electric Potential | 98 |
| 4.3.5.4 | Variation of Temperature | 100 |
| 4.3.5.5 | Variation of EO Flow | 101 |
| 4.3.5.6 | Unconfined Compressive Strength | 101 |
| 4.3.5.7 | Shear Strength Parameters | 104 |
| 4.4 | Summary | 107 |
| 5 | Stabilization using Industrial Waste Materials | 109 |
| 5.1 | General | 109 |
| 5.2 | Specimen Preparation | 110 |
| 5.3 | Experimental Results and Discussion | 111 |
| 5.3.1 | Particle Size Analysis | 112 |
| 5.3.2 | Atterberg Limits | 112 |
| 5.3.3 | Specific Gravity | 114 |
| 5.3.4 | Compaction Characteristics | 116 |
| 5.3.5 | Heaving Analysis | 120 |
| 5.3.6 | Unconfined Compressive Strength | 122 |
| 5.3.7 | Shear Strength Parameters | 126 |
| 5.3.8 | Mineralogical Studies | 130 |
| 5.3.9 | Microstructural studies | 131 |
| 5.4 | Bench Scale Study through Electrokinetics | 134 |
| 5.4.1 | Alkali Interacted Soil | 134 |
| 5.4.2 | Model Chamber | 134 |
| 5.4.3 | Sample Preparation for Bench-Scale Model Study | 134 |
| 5.4.4 | Experimental Results of the Electrokinetic Bench-Scale Study | 135 |
| 5.4.4.1 | Variation in Voltage During EK Test | 135 |
| 5.4.4.2 | Variation in pH of Electrolytic Solution During EK Test | 135 |
| 5.4.4.3 | Variation in Electroosmotic Flow During EK Test | 138 |
| 5.4.4.4 | Unconfined Compressive Strength Studies | 138 |

| | | |
|----------|--|------------|
| 5.5 | Summary | 140 |
| 6 | Chemical Stabilization using Bench Scale Model through Electrokinetics | 143 |
| 6.1 | General | 143 |
| 6.2 | Test Procedure and Conditions | 144 |
| 6.2.1 | Test Procedure and Conditions | 144 |
| 6.2.2 | Electrokinetic Mechanism and Procedure | 146 |
| 6.2.3 | Quantification of Precipitated Calcite (Acid Leaching test) | 147 |
| 6.3 | Monitoring of Data During EK Test | 148 |
| 6.3.1 | Variation of pH of Electrolytes and Soil | 149 |
| 6.3.2 | Variation in Electric Potential | 153 |
| 6.3.3 | Variation in Electroosmotic Flow During EK Process | 157 |
| 6.4 | Results of Geotechnical Testing After EK Treatment | 159 |
| 6.4.1 | Variation of Atterberg Limits of Post EK Treated Soil | 159 |
| 6.4.2 | Variation in Unconfined Compressive Strength of Alkali Interacted Soil after EK Treatment | 164 |
| 6.4.3 | Variation in Shear Strength Parameters of Alkali Interacted Soil after EK Treatment | 168 |
| 6.4.4 | Variation in Coefficient of Compression of Alkali Interacted Soil after EK Treatment | 173 |
| 6.4.5 | Heaving Analysis on Soil Stabilised with Chemicals | 176 |
| 6.4.6 | Effect of EK Treatment with Chemicals on Mineral Composition of Alkali Interacted Soil | 179 |
| 6.4.7 | Microstructural Study of Alkali Interacted Soil after EK Treatment with Different Chemicals | 183 |
| 6.5 | Summary | 185 |
| 7 | CONCLUSIONS AND FUTURE SCOPE | 187 |
| 7.1 | Summary and Conclusion | 187 |
| 7.2 | Limitations and Scope for Future Work | 191 |
| 7.2.1 | Limitations | 191 |
| 7.2.2 | Scope for Future Work | 191 |

