

## Table of Contents

<b>INTRODUCTION .....</b>	<b>1</b>
<b>Selection of Quality Control Methods .....</b>	<b>3</b>
<b>Costs of In Situ Quality Control Methods .....</b>	<b>3</b>
<b>Time-Related Issues in Quality Control.....</b>	<b>5</b>
Time-Dependent Strength Gain of Densified Soil .....	5
Curing Time for Grouted or Chemically Treated Soil.....	6
Availability of Equipment.....	6
Time for Acquiring Data and Identifying Non-conformance .....	6
<b>Solutions to Time-Related Problems .....</b>	<b>9</b>
Advantages and Limitations of a Test Section.....	9
Advantages and Limitations of In Situ Testing.....	9
<b>IN SITU VERIFICATION TESTS.....</b>	<b>10</b>
<b>STANDARD PENETRATION TEST (SPT).....</b>	<b>13</b>
Application of SPT for Quality Control .....	13
References Documenting the SPT for Quality Control.....	14
Advantages of SPT .....	15
Limitations of SPT .....	15
Cost Considerations for SPT .....	16
Time Considerations for SPT .....	16
<b>CONE PENETRATION TEST (CPT).....</b>	<b>16</b>
Application of CPT for Quality Control .....	18
References Documenting the CPT for Quality Control.....	18

Advantages of CPT ..... 20

Limitations of CPT ..... 20

Cost Considerations for CPT ..... 20

Time Considerations for CPT ..... 21

**BECKER PENETRATION TEST (BPT)..... 21**

Application of BPT for Quality Control ..... 21

References Documenting the BPT for Quality Control..... 22

Advantages of BPT ..... 22

Limitations of BPT ..... 24

Cost Considerations for BPT ..... 24

**PRESSUREMETER TEST (PMT) ..... 24**

Application of PMT for Quality Control..... 25

References Documenting the PMT for Quality Control ..... 25

Advantages of PMT ..... 26

Limitations of PMT..... 26

Cost Considerations for PMT ..... 27

Time Considerations for PMT..... 27

**DILATOMETER TEST (DMT)..... 28**

Application of DMT for Quality Control ..... 28

References Documenting the DMT for Quality Control..... 29

Advantages of DMT ..... 29

Limitations of DMT ..... 30

Cost Considerations for DMT ..... 30

Time Considerations for DMT ..... 30

<b>SEISMIC TESTING .....</b>	<b>30</b>
Down-Hole Test/Up-hole Test .....	31
Cross-hole Method.....	31
Application of Seismic Testing for Quality Control .....	34
References Documenting Seismic Testing for Quality Control.....	34
Advantages of Seismic Testing .....	35
Limitations of Seismic Testing .....	35
Cost Considerations for Seismic Testing .....	36
Time Considerations for Seismic Testing .....	36
<b>SPECTRAL ANALYSIS OF SURFACE WAVES (SASW).....</b>	<b>36</b>
Application of SASW for Quality Control .....	38
References Documenting SASW for Quality Control .....	38
Advantages of SASW .....	39
Limitations of SASW .....	39
Cost Considerations for SASW .....	40
Time Considerations for SASW .....	40
<b>ACOUSTIC EMISSION TESTING .....</b>	<b>40</b>
Application of Acoustic Emission Testing for Quality Control .....	40
References Documenting Acoustic Emission Testing for Quality Control.....	41
Advantages of Acoustic Emission Testing .....	41
Limitations of Acoustic Emission Testing .....	42
<b>LOAD TESTING .....</b>	<b>42</b>
Application of Load Tests for Quality Control .....	43
References Documenting Load Testing for Quality Control .....	44

Advantages of Load Tests .....	45
Limitations of Load Tests .....	45
Cost Considerations for Load Tests .....	45
<b>QUALITY CONTROL SPECIFICATIONS FOR VARIOUS GROUND IMPROVEMENT TECHNIQUES .....</b>	<b>46</b>
<b>DEEP DYNAMIC COMPACTION.....</b>	<b>46</b>
Method Specifications .....	47
End-result Specifications .....	47
Time Considerations .....	47
<b>VIBRO-COMPACTION.....</b>	<b>48</b>
Method Specifications .....	49
End-result Specifications .....	50
Time Considerations .....	50
<b>EXPLOSIVE COMPACTION.....</b>	<b>50</b>
Method Specifications .....	51
End-result Specifications .....	51
Time Considerations .....	51
<b>GROUTING METHODS .....</b>	<b>52</b>
<b>COMPACTION GROUTING .....</b>	<b>53</b>
Method Specifications .....	57
End-result Specifications .....	57
Time Considerations .....	58
<b>HYDROFRACTURE GROUTING .....</b>	<b>58</b>
Method Specifications .....	59

End-result Specifications .....	59
Time Considerations .....	59
<b>PERMEATION GROUTING .....</b>	<b>60</b>
Method Specifications .....	60
End-result Specifications .....	61
Time Considerations .....	61
<b>JET GROUTING .....</b>	<b>62</b>
Method Specifications .....	62
End-result Specifications .....	63
Time Considerations .....	64
<b>DEEP MIXING .....</b>	<b>64</b>
Method Specifications .....	65
End-result Specifications .....	65
Time Considerations .....	67
<b>LIME AND LIME/CEMENT COLUMNS .....</b>	<b>67</b>
Method Specifications .....	68
End-result Specifications .....	68
Time Considerations .....	70
<b>STONE COLUMNS .....</b>	<b>71</b>
Method Specifications .....	71
End-result Specifications .....	72
Time Considerations .....	74
<b>PRECOMPRESSION .....</b>	<b>74</b>
Method Specifications .....	75

End-result Specifications .....	76
Time Considerations .....	76
<b>REFERENCES BY AUTHOR .....</b>	<b>77</b>
<b>REFERENCES BY IN SITU TEST .....</b>	<b>90</b>
<b>STANDARD PENETRATION TEST.....</b>	<b>90</b>
<b>CONE PENETRATION TEST.....</b>	<b>96</b>
<b>BECKER PENETRATION TEST .....</b>	<b>102</b>
<b>PRESSUREMETER TEST .....</b>	<b>102</b>
<b>DILATOMETER TEST .....</b>	<b>106</b>
<b>SEISMIC TESTING.....</b>	<b>108</b>
<b>SPECTRAL ANALYSIS OF SURFACE WAVES .....</b>	<b>110</b>
<b>ACOUSTIC EMISSION TESTING .....</b>	<b>111</b>
<b>LOAD TESTING .....</b>	<b>112</b>
<b>REFERENCES BY GROUND IMPROVEMENT</b>	
<b>TECHNIQUE .....</b>	<b>115</b>
<b>DEEP DYNAMIC COMPACTION.....</b>	<b>115</b>
<b>VIBRO-COMPACTION.....</b>	<b>118</b>
<b>EXPLOSIVE COMPACTION.....</b>	<b>121</b>
<b>COMPACTION GROUTING.....</b>	<b>122</b>
<b>HYDROFRACTURE GROUTING .....</b>	<b>125</b>
<b>PERMEATION GROUTING .....</b>	<b>126</b>
<b>JET GROUTING .....</b>	<b>127</b>
<b>DEEP MIXING .....</b>	<b>129</b>

<b>LIME AND LIME/CEMENT COLUMNS .....</b>	<b>129</b>
<b>STONE COLUMNS .....</b>	<b>130</b>
<b>PRECOMPRESSION .....</b>	<b>133</b>
<b>APPENDIX A – UNIT CONVERSIONS .....</b>	<b>134</b>
<b>Conversion Factors for Length.....</b>	<b>135</b>
<b>Conversion Factors for Force .....</b>	<b>136</b>
<b>Conversion Factors for Stress .....</b>	<b>137</b>
<b>Conversion Factors for Unit Weight.....</b>	<b>138</b>
<b>Conversion Factors for Coefficient of Consolidation .....</b>	<b>139</b>

## **List of Figures**

Figure 1. Typical Strength Gain for Soilcrete™ .....	7
Figure 2. Schematic Diagram of Becker Sampling Operation .....	23
Figure 3. Principles of the Seismic CPT .....	32
Figure 4. Schematic Diagram of Cross-hole Seismic Testing .....	33
Figure 5. Schematic Diagram of SASW Testing.....	37
Figure 6. Lime Column Penetrometer .....	69

## **List of Tables**

Table 1. Quality Control/Quality Assurance Responsibilities .....	2
Table 2. In Situ Verification Test Costs from 2000 Survey .....	4
Table 3. Summary of Time Considerations for Various In Situ Tests .....	8
Table 4. Applicability of In Situ Tests Used for Quality Control of Ground Improvement, Based on Published Experience .....	11
Table 5. Cost Range of SPT with Borehole Depth .....	17
Table 6. Applicability of Verification Methods by Grouting Method .....	53
Table 7. Applicability of Verification Methods by Grouting Purpose .....	54
Table 8. Applicability of Grouting Verification Methods by Soil Type.....	55
Table 9. QC/QA Testing for Deep Mix Columns .....	66
Table 10. Suitability for Testing Stone Columns .....	73