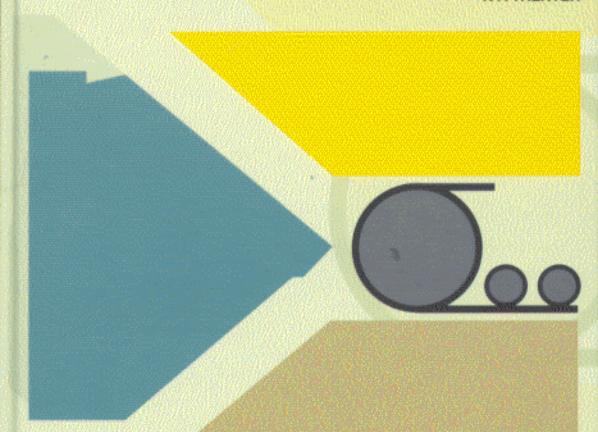
Earthworks: aguide



Contents

| Acknowledgements Preface | | | |
|--------------------------|-----|--|-------------|
| 1. | Ear | thworks: an historical perspective | 1 |
| | 1.1 | Highways | 1 |
| | | Railways | 1 2 4 |
| | 1.3 | Canals and reservoirs | 4 |
| | | Design developments | 6 |
| 2. | The | compaction process | 9 |
| | 2.1 | Introduction | 9 |
| | 2.2 | Phase relationships | 9 |
| | | Optimum water content and maximum dry density | 11 |
| | 2.4 | Effect of compactive effort | 11 |
| | | Effect of initial fill water content | 13 |
| | 2.6 | Compaction of fill with over-size particles | 14 |
| | | 2.6.1 Effect on dry density | 14 |
| | | Elimination method | 14 |
| | | Adjusted maximum dry density method | 14 |
| | | Substitution method | 15 |
| | | 2.6.2 Effect on water content | 16 |
| | 2.7 | Use of correlations to obtain compaction data | 16 |
| | 2.8 | Paez plotting method for compaction test results | 17 |
| 3. | Som | ne characteristics of clay (cohesive) fill | 19 |
| | 3.1 | Introduction | 19 |
| | 3.2 | Description and classification | 19 |
| | | 3.2.1 General | 19 |
| | | 3.2.2 Description | 22 |
| | | 3.2.3 Classification | 23 |
| | 3.3 | Properties | 24 |

| | | 3.3.1 | Plasticity and water content | 24 |
|----|-----|--------|---|----|
| | | | Undrained shear strength | 26 |
| | | | Factors affecting the undrained strength of clay fill | 26 |
| | | | High plasticity clay | 26 |
| | | | Low plasticity clay | 26 |
| | | | Strength correlations | 27 |
| | 3.4 | Behav | iour of clay fill: temporary works | 29 |
| | | 3.4.1 | General | 29 |
| | | 3.4.2 | Trafficability (instability) | 29 |
| | | 3.4.3 | Under-compaction | 31 |
| | | | Mattressing | 31 |
| | | 3.4.5 | Compaction induced shear surfaces | 31 |
| | 3.5 | Behav | riour of clay fill: permanent works | 32 |
| | | 3.5.1 | Heave and settlement | 32 |
| | | 3.5.2 | Chemical attack by sulphur-bearing minerals | 33 |
| | | | General | 33 |
| | | | Attack of buried construction materials | 35 |
| | | | Expansive reaction of finished earthworks | 35 |
| | | | Volume reduction of finished earthworks | 36 |
| | | | Attack of limestone | 36 |
| | | 3.5.3 | Frost-heave susceptibility | 37 |
| | 3.6 | Clay f | fill as landfill liner | 37 |
| | | | Required properties | 37 |
| | | 3.6.2 | Aspects of liner construction | 39 |
| 4. | Som | e char | acteristics of granular and weak rock fill | 41 |
| | 4.1 | Introd | lucition | 41 |
| | 4.2 | | iption and classification | 41 |
| | | | General | 41 |
| | | 4.2.2 | Description | 41 |
| | | | Classification | 42 |
| | 4.3 | Prope | rties | 44 |
| | | | Particle size distribution | 44 |
| | | | Effect of large particle sizes | 45 |
| | | | Shear strength | 46 |
| | 4.4 | Behav | viour of granular and some weak rock fills: | |
| | | | rary works | 48 |
| | | | General | 48 |
| | | 4.4.2 | Construction settlement | 49 |
| | 4.5 | Behav | viour of granular and more weak rock fills: | |
| | | | nent works | 51 |
| | | - | General | 51 |
| | | 4.5.2 | Creep settlement | 51 |

| | | | Collapse settlement | 52 |
|----|------|---------|---|-----------------|
| | | | Erosion | 53 |
| | | 4.5.5 | Frost heave susceptibility | 54 |
| 5. | Som | e chara | cteristics of other natural deposits | 55 |
| | 5.1 | Mercia | Mudstone | 55 |
| | 5.2 | | l deposits | 55 |
| | | | General | 55 |
| | | 5.2.2 | Construction problems with tills | 58 |
| | 5.3 | Chalk | | 58 |
| | | | General | 58 |
| | | | Chalk specification in the UK | 58 |
| | | | Construction problems | 61 |
| | | 5.3.4 | Frost-heave susceptibility | 62 |
| 6. | Som | e prope | rties of industrial fill | 63 |
| | 6.1 | Introdu | uction | 63 |
| | 6.2 | Collier | y discard (minestone) | 63 [\] |
| | | 6.2.1 | General | 63 |
| | | 6.2.2 | Use of colliery discard as fill | 66 |
| | | 6.2.3 | Frost-heave susceptibility and chemical attack of buried construction materials | 68 |
| | 6.3 | Pulveri | ised fuel ash | 68 |
| | 0.5 | | General | 68 |
| | | | Use of pulverized fuel ash as fill | 69 |
| | | 6.3.3 | Frost-heave susceptibility and chemical attack of | 0) |
| | | 0.5.5 | buried construction materials | 70 |
| | 6.4 | Other | waste materials | 71 |
| | 0.7 | | General | 71 |
| | | | Slate waste | 71 |
| | | | China clay pit waste | 71 |
| | | | Flourspar and tin mine waste | 73 |
| | | | Steel and blastfurnace slags | 73 |
| | | | Spent oil shale | 74 |
| | | 6.4.7 | Incinerator waste | 74 |
| | | | Spent railway ballast | 74 |
| | | | Road planings | 74 |
| | | | Demolition waste | 74 |
| | 6.5 | | ction qualities of industrial fills | 75 |
| 7. | Note | on ear | thworks specifications | 77 |
| | 7.1 | Introdu | - | 77 |
| | | | | |

| | 72 | Metho | d specification | 77 |
|----|-------------|---------|--|-----|
| | | | roduct specification | 78 |
| | | | mance specification | 78 |
| | | | types of specification | 79 |
| 8. | Desi | gn, con | struction control and monitoring | 81 |
| | 8.1 | Introd | | 81 |
| | 8.2 | Invest | igations for earthworks | 82 |
| | 8. <i>3</i> | Prelin | ninary design considerations | 83 |
| | | 8.3.1 | Fill suitability | 83 |
| | | | Unsuitable fill_ | 83 |
| | | | Suitable fill | 84 |
| | | | Hierarchy of fills | 84 |
| | | 8.3.2 | | 85 |
| | | 8.3.3 | Nature of structure and compactive effort required | 86 |
| | | 8.3.4 | Initial water content | 88 |
| | | | General | 88 |
| | | | Collapse settlement | 88 |
| | | | Heave | 88 |
| | | 8.3.5 | <u> -</u> | 89 |
| | 8.4 | | n and control testing | 89 |
| | | 8.4.1 | General | 89 |
| | | 8.4.2 | Setting design and control limits | 91 |
| | | 8.4.3 | Compaction test | 92 |
| | | | Air voids | 92 |
| | | | Dry density | 92 |
| | | 8.4.4 | Undrained shear strength test | 94 |
| | | | Stability of embankment fill | 94 |
| | | | Placement control | 94 |
| | | | Clay fill foundations | 95 |
| | | | Methods of testing and sampling | 95 |
| | | 8.4.5 | Moisture Condition Value test | 96 |
| | | 8.4.6 | California Bearing Ratio test | 97 |
| | | 8.4.7 | Permeability test | 98 |
| | | 8.4.8 | Relationship testing | 100 |
| | 8.5 | Comp | action trials | 102 |
| | | 8.5.1 | General | 102 |
| | | 8.5.2 | Method of approach | 102 |
| | 8.6 | | ol test frequency | 103 |
| | 8.7 | Earth | works monitoring | 104 |
| | | 8.7.1 | General | 104 |
| | | 8.7.2 | Surface levelling station (monument) | 105 |
| | | 072 | Sattlement plate (rod extensometer) | 106 |

| | | 8.7.5 | Magnetic extensometer USBR settlement gauge Piezometer | 107 108 108 |
|-----|-------|----------|--|-------------------|
| 9. | Exca | vation | | 111 |
| | 9.1 | Introdu | action | 111 |
| | 9.2 | | cavation | 111 |
| | | | Impact of groundwater and weather | 111 |
| | | | Misidentification of rockhead in glacial terrains | 112 |
| | 9.3 | | ion of rock | 112 |
| | | - | General | 112 |
| | | 9.3.2 | 'Rock' in contract documents | 113 |
| | 9.4 | Rock e. | xcavation | 115 |
| | | 9.4.1 | General | 115 |
| | | 9.4.2 | Use of excavation schemes | 116 |
| | | 9.4.3 | Pre-treatment by ripping | _118 |
| | | | Size and power of plant | 118 |
| | | | Method of working | 118 |
| | | | Nature of orientation of discontinuities | 118 |
| | | | Strength of intact rock | 119 |
| | 9.5 | Bulking | g and shrinkage | 119 |
| 10. | Place | ement a | and compaction of fill | 121 |
| | 10.1 | Introdu | uction | 121 |
| | 10.2 | Prepare | ation of site | 121 |
| | 10.3 | Fill dep | position | 122 |
| | 10.4 | Factors | s influencing compaction | 122 |
| | | 10.4.1 | General | 122 |
| | | | Compaction plant | 123 |
| | | | Layer thickness | 123 |
| | | | Water content | 123 |
| | | | Number of passes | 124 |
| | | | Influence of fill type on choice of compaction plant | |
| | 10.5 | | nditioning | 130 |
| | | | General | 130 |
| | | | Lime stabilization | 130 |
| | | | Mechanical conditioning | 132 |
| | | | Stockpiling | 132 |
| | | | Aeration | .133 |
| | | | Consolidation by drainage | 133 |
| | 10.6 | | problems | 134 |
| | | | Load bearing fill | 134 |
| | | 10.6.2 | Fill at multi-purpose sites | 135 |

| | | 10.6.3 | Stresses from compacted fill on retaining walls | 136 |
|-----|------|----------|---|-----|
| | | | Granular fill | 136 |
| | | | Clay fill | 137 |
| | | 10.6.4 | Deep hydraulic fill | 138 |
| | | | Investigations at former quarry and open-cast sites | 138 |
| | | | Investigations of solution features | 140 |
| 11. | Cuts | : some | design and construction considerations | 143 |
| | 11.1 | Introdu | uction | 143 |
| | 11.2 | Cuts in | soil: methods of approach | 143 |
| | 11.3 | Stabilit | ty analysis: long term conditions | 144 |
| | | 11.3.1 | General | 144 |
| | | 11.3.2 | Strength properties (effective stress) | 145 |
| | | | Peak strength | 145 |
| | | | Critical state strength | 147 |
| | | | Residual strength | 148 |
| | | | Selection of design strength | 148 |
| | | 11.3.3 | Groundwater and pore pressures | 149 |
| | | | General | 149 |
| | | | Special problems with clay soil | 151 |
| | | 11.3.4 | Analysis | 152 |
| | | | General | 152 |
| | | | Infinite slope | 152 |
| | | | Circular arc | 154 |
| | | | Non-circular | 154 |
| | | | Wedge analysis | 155 |
| | | 11.3.5 | Some results based on British motorway experience | 155 |
| | 11.4 | | ty analysis: short term condition | 156 |
| | | | General | 156 |
| | | 11.4.2 | Strength properties (total stress) | 157 |
| | | | Analysis of cut slopes | 158 |
| | 11.5 | | of shallow depth features on stability | 158 |
| | | 11.5.1 | General | 158 |
| | | 11.5.2 | Glacially induced soil fabric | 159 |
| | | | Solifluction deposits and shear surfaces | 159 |
| | | | Other shallow depth features | 159 |
| | 11.6 | | age and frost-heave | 160 |
| | | | General | 160 |
| | | | Cut-off drains | 160 |
| | | 11.6.3 | Surface water interceptor drains | 161 |
| | | | Counterfort and slope drains | 161 |
| | | | Herringbone drains | 162 |
| | | | Some experience in British conditions | 162 |
| | | | | |

| | 11.7 | Cuts in | | 163 |
|-----|------|----------|---|------|
| | | 11.7.1 | General | 163 |
| | | 11.7.2 | Stereonets and classifications | 163 |
| | | | Stereonets | 163 |
| | | | Classifications | 165 |
| | | | Measuring discontinuity data | 165 |
| | | | Drainage aspects | 167 |
| | | 11.7.4 | Cuts in weathered or fissured rock | 168 |
| | 11.8 | Stabiliz | zation of cut slopes | 168 |
| | | 11.8.1 | General | 168 |
| | | 11.8.2 | Soil nails, anchors and mini-piles | 169 |
| | | 11.8.3 | Reinforced earth applications | 171 |
| 12. | Emb | ankme | nts: some design and construction considerations | 173 |
| | | Introdu | | 173 |
| | | | d of approach | 173 |
| | 12.3 | Stabilit | ty analysis: long term condition | 17/4 |
| | | | General | 174 |
| | | 12.3.2 | Strength properties | 176 |
| | | | Embankment fill | 176 |
| | | | Foundation | 178 |
| | | | Mobilization of fill and foundation strengths | 179 |
| | | 12.3.3 | Groundwater and pore pressure conditions | 180 |
| | | | Pore pressure in embankment fill | 180 |
| | | | Pore pressure or groundwater in foundation | 181 |
| | | 12.3.4 | Analysis | 181 |
| | | | Embankment fill | 181 |
| | | • | Embankment fill and foundation | 182 |
| | | | Some results based on British motorway experience | 182 |
| | 12.4 | Stabilit | y analysis: short term condition | 183 |
| | | 12.4.1 | General | 183 |
| | | 12.4.2 | Strength properties | 184 |
| | | | Embankment fill | 184 |
| | | | Foundation | 184 |
| | | 12.4.3 | Analysis | 184 |
| | | | Embankment fill | 184 |
| | | | Embankment fill and foundation | 184 |
| | | 12.4.4 | The short term condition in terms of effective stress | 185 |
| | 12.5 | Settlem | | 186 |
| | | 12.5.1 | General | 186 |
| | | 12.5.2 | Primary settlement | 186 |
| | | | Secondary compression | 188 |
| | | | Negative skin friction at structure locations | 120 |

| | 12.6 | | of shallow depth features on stability | 189 |
|-----|-------|----------|--|-----|
| | | | General | 189 |
| | | | Solifluction deposits and ancient failure surfaces | 189 |
| | | 12.6.3 | Soft compressible soil | 190 |
| | | | General | 190 |
| | | | Pre-loading and surcharging | 190 |
| | | | Drainage | 191 |
| | | | Structural elements | 191 |
| | | | Excavation and replacement | 192 |
| | | | Lightweight fill | 192 |
| | 12.7 | | uction aspects | 192 |
| | | | Foundation excavation | 192 |
| | | | Non-uniform compaction and 'over-building' | 193 |
| | 12.8 | | ige aspects | 194 |
| | | | Carriageway | 194 |
| | | 12.8.2 | Foundation | 194 |
| 13. | Facto | or of sa | fety of cuts and embankments | 197 |
| | 13.1 | Genera | al | 197 |
| | | | Definitions | 197 |
| | | | Category of data and effect on factor of safety | 198 |
| | | | Technical category | 199 |
| | | | Ground and groundwater conditions | 199 |
| | | | Laboratory and in situ tests | 199 |
| | | | Nature of stability analysis | 199 |
| | | 13.1.4 | Safety, environmental and economic category | 200 |
| | | | Temporary works (short term) and permanent | |
| | | | works (long term) conditions | 201 |
| | 13.2 | Possib | le approach to factor of safety selection | 203 |
| | | 13.2.1 | | 203 |
| | | | Embankments | 204 |
| | | | Embankment fill | 204 |
| | | | Foundation | 205 |
| | 13.3 | Use of | instrumentation and the observational method | 206 |
| | | | General | 206 |
| | | | Temporary works | 206 |
| | | | Permanent works | 207 |
| 14. | Note | on site | e safety considerations | 209 |
| | 14 1 | Genera | al . | 209 |
| | | | ntion and references | 210 |
| | | _ | nuction site safety: outline procedures | 210 |

| | | Contents | xi |
|-------------|---|----------|-----|
| References | | | 213 |
| Appendix 1. | End product specification for engineered fill | | |
| | supporting low rise structures (Trenter and | | |
| | Charles, 1996) | | 225 |
| Appendix 2. | Brief description of some earthmoving and | • | |
| | compaction plant (P C Horner, 1988) | | 233 |
| Appendix 3. | Examples of planning and construction for | | |
| •• | earthworks projects (P C Horner, 1988) | | 239 |
| Appendix 4. | | | 247 |
| Index | | | 257 |