Infrastructure cuttings
condition appraisal and remedial treatment

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Keywords
Ground engineering, ground improvement, ground investigation and characterisation, transport infrastructure

Reader interest
Owners; asset and maintenance managers; geotechnical engineers; environmental engineers involved in infrastructure cutting management

Classification
AVAILABLEY Unrestricted
CONTENT Enabling document
STATUS Committee guided
USER Maintenance, geotechnical, environmental and civil engineers

British Library Cataloguing in Publication Data
A catalogue record is available for this book from the British Library.

Published by CIRIA, Classic House, 174–180 Old Street, London EC1V 9BP.

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Note
Recent UK Government reorganisation has meant that DETR responsibilities have been moved variously to the Department of Trade and Industry (DTI), the Office of the Deputy Prime Minister (ODPM), the Department for Environment, Food and Rural Affairs (DEFRA) and the Department for Transport (DfT). References made to government agencies in this publication should be read in this context.

For clarification, readers should contact the Department of Trade and Industry.
Summary

This book provides the infrastructure owner, the designer, the contractor and the maintenance manager with guidance on the management, condition appraisal and repair of infrastructure cuttings. It is based on a detailed review of published literature and infrastructure owner’s procedures, consultation with experts and practitioners within the field, and case studies demonstrating good practice. It has been prepared as a companion to CIRIA publication C592 *Infrastructure embankments: condition appraisal and remedial treatment* (2003) and makes extensive cross-reference to that book.

Cuttings perform an important function in the efficient operation of an infrastructure network, whether it is rail, highway or waterway, and it is essential that they be recognised accordingly within the asset management policy. Typically cuttings form 30 per cent of all transport infrastructure.

This book aims to:

- present good practice
- provide a guide for routine use
- recommend maintenance strategies for best value for money
- facilitate knowledge sharing.

The report addresses technical issues in design, repair and maintenance and is published as an enabling document to promote the managerial and engineering requirements of infrastructure cuttings.

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**Health and safety**

Construction activities, particularly those on construction sites, have significant health and safety implications. These can be the result of the activities themselves or can arise from the nature of the materials and the chemicals used in construction. This report gives some coverage to relevant health and safety issues. However, other published guidance on specific health and safety issues in construction should be consulted as necessary to ensure up-to-date legislation is applied and appreciated, especially the requirements of national legislation and those of infrastructure owners.
Acknowledgements

Research contractor
This Report, part of CIRIA’s ground engineering programme, was produced as a result of Research Project 657 “Infrastructure cuttings: condition appraisal and remedial treatment”, which was carried out under contract to CIRIA by Mott MacDonald in partnership with Cementation Foundations Skansa and the TRL Ltd.

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Project funders
This project was funded by:
British Waterways, London Underground Limited,
Highways Agency, Network Rail,
Her Majesty’s Railway Inspectorate, CIRIA’s Core Programme Sponsors.

Photographs
Unattributed photographs have kindly been provided by the author’s organisations.
Contents

Summary ........................................................................................................... 3
Acknowledgements ......................................................................................... 4
Glossary ............................................................................................................. 12
Abbreviations .................................................................................................... 15

1 INTRODUCTION ......................................................................................... 17
1.1 Background ............................................................................................... 17
1.2 Purpose and scope .................................................................................... 19
1.3 Application ................................................................................................ 20
1.4 History and construction of infrastructure cuttings ................................. 22
1.5 Performance issues ................................................................................... 24

2 ASSET MANAGEMENT ............................................................................. 25
2.1 Statutory and regulatory health and safety and environmental obligations .................................................. 26
2.2 Consequences of loss of performance ....................................................... 28
  2.2.1 Historical situation ............................................................................. 28
  2.2.2 Safety in operation ............................................................................ 28
  2.2.3 Synergy with other assets .................................................................. 28
  2.2.4 Disruption and customer dissatisfaction ............................................ 28
  2.2.5 Costs of failure and repair ................................................................ 28
2.3 Whole-life asset costs ............................................................................. 29
  2.3.1 Whole-life costing ............................................................................. 29
  2.3.2 Design life .......................................................................................... 29
  2.3.3 Performance requirements ................................................................ 29
2.4 Risk assessment ....................................................................................... 30
  2.4.1 The need for risk assessment ............................................................. 30
  2.4.2 Risk assessment procedure ............................................................... 30
  2.4.3 Strategic-level risk assessment (SLRA) .............................................. 30
  2.4.4 Tactical-level risk assessment (TLRA) ................................................. 34
2.5 Environmental asset management ............................................................ 35
2.6 Business case ............................................................................................ 35

3 LOSS OF CUTTING PERFORMANCE ...................................................... 37
3.1 Performance requirements ....................................................................... 37
  3.1.1 Ultimate limit state ............................................................................ 37
  3.1.2 Serviceability limit state ................................................................... 37
  3.1.3 Commentary ...................................................................................... 38
3.2 Soil slopes .................................................................................................. 39
  3.2.1 Soil properties .................................................................................... 39
  3.2.2 Pore water pressures ....................................................................... 40
  3.2.3 Drainage ............................................................................................ 41
  3.2.4 Changes in performance ................................................................... 41
3.2.5 Failures ................................................. 44
3.2.6 Particular stability aspects relating to canals .............. 49
3.3 Rock slopes .............................................. 50
  3.3.1 Rock properties ........................................... 52
  3.3.2 Ultimate limit state failure ................................ 52
  3.3.3 Serviceability limit state failure ......................... 55
  3.3.4 Factors affecting performance ............................. 55
  3.3.5 Rock type ............................................. 55
  3.3.6 Presence of discontinuities ................................ 56
  3.3.7 Original slope design .................................... 56
  3.3.8 Construction technique .................................. 57
  3.3.9 Groundwater ........................................... 57
  3.3.10 Climatic conditions .................................... 57
  3.3.11 Vegetation ............................................. 58
3.4 Scale of the problem ......................................... 58
  3.4.1 Cost of remedial measures ................................ 58
  3.4.2 Frequency of failure ..................................... 58
  3.4.3 Future performance ....................................... 59

4 CUTTING CONDITION APPRAISAL ............................... 61
  4.1 Inspection .................................................. 61
    4.1.1 Health and safety ........................................ 62
    4.1.2 Information required ..................................... 62
  4.2 Assessment .................................................. 63
  4.3 Site investigation for soil slopes ......................... 63
  4.4 Site investigation for rock slopes ....................... 65
    4.4.1 Information required ..................................... 65
    4.4.2 Preliminary study ......................................... 66
    4.4.3 Design of ground investigation ............................ 67
    4.4.4 Design of instrumentation and monitoring ............. 68
    4.4.5 Exploration and sampling ................................ 69
    4.4.6 Laboratory testing ........................................ 71
  4.5 Stability study and business case ........................ 71
    4.5.1 Rock strength parameters ................................. 73
    4.5.2 Water pressure in rock ................................... 74
  4.6 Loadings .................................................... 74
  4.7 Reporting and prioritisation ................................ 74

5 REMEDIAL TREATMENT AND PREVENTATIVE TECHNIQUES ... 77
  5.1 Construction safety issues ................................... 80
  5.2 Reconstruction methods ....................................... 81
    5.2.1 Regrading and toe berms .................................. 83
    5.2.2 Strengthened and stabilised fills ......................... 84
    5.2.3 Granular replacement ...................................... 84
  5.3 Retaining structures .......................................... 85
    5.3.1 Gravity retaining walls and gabions ..................... 85
5.3.2 Piles ................................................................. 86
5.3.3 Ground anchors and raking mini piles used to support retaining walls ........................................... 88

5.4 Failure prevention methods ................................................. 88
5.4.1 Soil nailing .......................................................... 89
5.4.2 Ground anchors, bolts and dowels ................................. 90
5.4.3 Dentition and buttressing ........................................... 92
5.4.4 Dowel piles .......................................................... 92
5.4.5 Mass concrete retaining walls ..................................... 93

5.5 Failure containment and protection methods ............................... 93
5.5.1 Scaling and removal of loose blocks ............................... 93
5.5.2 Netting and meshing ............................................... 93
5.5.3 Catch fences ......................................................... 95
5.5.4 Benching, ditches and rock traps ................................. 96
5.5.5 Rock fall shelters .................................................. 96
5.5.6 Alarm and warning systems ....................................... 97

5.6 Drainage ........................................................................ 97
5.6.1 Slope drainage ....................................................... 98
5.6.2 Surface drainage ..................................................... 99

5.7 Surface protection .......................................................... 100
5.7.1 Membranes .......................................................... 100
5.7.2 Vegetation ............................................................ 101

5.8 Routine maintenance methods ............................................ 101

6 DESIGN AND APPLICATION OF REMEDIAL TREATMENT AND PREVENTATIVE MEASURES .................................................. 103

6.1 Design methodology ......................................................... 103
6.2 Collection of available information ...................................... 103
6.3 Understanding the mechanisms involved ............................... 106
6.4 Design requirements ....................................................... 106
6.4.1 Health and safety in design ......................................... 106
6.4.2 Design life, factor of safety and geotechnical parameters ...... 106
6.4.3 Groundwater ........................................................ 107
6.5 Design approach .......................................................... 107
6.5.1 Limit equilibrium ..................................................... 109
6.5.2 Numerical analysis ................................................... 109
6.6 Construction considerations ............................................... 109
6.6.1 Access ................................................................. 110
6.6.2 Boundaries .......................................................... 110
6.6.3 Excavation and filling processes .................................. 110
6.6.4 Drilling and grouting processes .................................... 110
6.6.5 Services and utilities ................................................ 111
6.6.6 Ground movements ................................................ 111
6.6.7 Materials ............................................................. 111
6.6.8 Size and weight of equipment ...................................... 111
6.6.9 Cost and maintenance .............................................. 111
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.7</td>
<td>Implementation of design</td>
<td>111</td>
</tr>
<tr>
<td>6.8</td>
<td>Post-construction assessment and design verification</td>
<td>112</td>
</tr>
<tr>
<td>6.8.1</td>
<td>Monitoring</td>
<td>112</td>
</tr>
<tr>
<td>6.8.2</td>
<td>Back analysis</td>
<td>112</td>
</tr>
<tr>
<td>6.8.3</td>
<td>Feedback and continuous improvement</td>
<td>113</td>
</tr>
<tr>
<td>6.9</td>
<td>Applications</td>
<td>113</td>
</tr>
<tr>
<td>7</td>
<td>ENVIRONMENTAL CONSIDERATIONS</td>
<td>133</td>
</tr>
<tr>
<td>7.1</td>
<td>Sustainable development</td>
<td>134</td>
</tr>
<tr>
<td>7.2</td>
<td>Environmental policies of infrastructure owners</td>
<td>134</td>
</tr>
<tr>
<td>7.3</td>
<td>Protection of controlled waters</td>
<td>135</td>
</tr>
<tr>
<td>7.4</td>
<td>Maximising the reuse of materials</td>
<td>136</td>
</tr>
<tr>
<td>7.5</td>
<td>Vegetation</td>
<td>136</td>
</tr>
<tr>
<td>7.6</td>
<td>Wildlife</td>
<td>139</td>
</tr>
<tr>
<td>7.7</td>
<td>SSSI and RIGS</td>
<td>140</td>
</tr>
<tr>
<td>7.8</td>
<td>Heritage</td>
<td>140</td>
</tr>
<tr>
<td>8</td>
<td>AREAS REQUIRING FURTHER RESEARCH</td>
<td>141</td>
</tr>
<tr>
<td>8.1</td>
<td>Asset Management</td>
<td>141</td>
</tr>
<tr>
<td>8.2</td>
<td>Loss of cutting performance and cutting condition appraisal</td>
<td>141</td>
</tr>
<tr>
<td>8.3</td>
<td>Remedial treatment and preventative techniques and their design</td>
<td>141</td>
</tr>
<tr>
<td>8.4</td>
<td>Environmental considerations</td>
<td>142</td>
</tr>
<tr>
<td>9</td>
<td>RECOMMENDATIONS</td>
<td>143</td>
</tr>
<tr>
<td>9.1</td>
<td>Asset management</td>
<td>143</td>
</tr>
<tr>
<td>9.2</td>
<td>Loss of performance</td>
<td>143</td>
</tr>
<tr>
<td>9.3</td>
<td>Condition appraisal</td>
<td>143</td>
</tr>
<tr>
<td>9.4</td>
<td>Remedial and preventative techniques</td>
<td>144</td>
</tr>
<tr>
<td>9.5</td>
<td>Design and application of remedial and preventative measures</td>
<td>144</td>
</tr>
<tr>
<td>9.6</td>
<td>Environmental considerations</td>
<td>144</td>
</tr>
<tr>
<td>9.7</td>
<td>Further research</td>
<td>145</td>
</tr>
<tr>
<td>10</td>
<td>REFERENCES</td>
<td>147</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

Figure 1.1 Vertical alignment of a transport infrastructure requires construction of embankments and cuttings ..................................................... 17
Figure 1.2 Side-long ground requires filling and cutting on hill sides to provide a platform for traffic ............................................................ 17
Figure 1.3 Steep sided railway cutting at Hooley with a shallow failure of gravels washing out over chalk ...................................................... 18
Figure 1.4 Highway cutting in clay showing flatter modern slope ............... 18
Figure 1.5 Canal cutting with towpath and extensive vegetation ............... 18
Figure 1.6 Railway embankment .......................................................... 19
Figure 1.7 Cutting at Edgware on the London Underground Northern Line being constructed by steam shovel in March 1924 ......................... 22
Figure 1.8 Scrapers were used frequently in the past on most of the motorway system ............................................................... 22
Figure 1.9 Backactors are used with dump trucks on most modern earthmoving schemes due to their ability to traverse a wide range of soil conditions 23
Figure 1.10 Articulated dumptrucks have the ability to maintain maximum traction with the ground ..................................................... 23
Figure 1.11 Ripper on a dozer being used for breaking up weaker or highly fractured rocks ................................................................. 24
Figure 2.1 The asset management cycle ................................................ 26
Figure 2.2 Strategic and tactical risk assessment procedures ..................... 31
Figure 2.3 Comparison of consequences and risk of failure .................... 32
Figure 2.4 The aftermath of a train striking a rock .................................. 33
Figure 2.5 The continuous improvement cycle ...................................... 36
Figure 3.1 Examples of rupture surfaces for shallow and deep cutting failures ... 44
Figure 3.2 Deep failure of a Gault cutting on the M25 motorway ............ 45
Figure 3.3 Deep failure of canal cutting causing blocked waterway and loss of draft ................................................................. 45
Figure 3.4 Highway cutting in clay showing flatter modern slope but still subject to shallow failure ....................................................... 46
Figure 3.5 Shallow failure of a canal cutting caused by weathering, damaging off-side of canal ....................................................... 46
Figure 3.6 Comparison of Plasticity Index and Angle of Friction ............... 48
Figure 3.7 Rock fall leading to traffic disruption for over 24 hours ........... 51
Figure 3.8 Samphire Hoe natural chalk sea-cliff. Signal wire cautions train drivers of chalk fall .......................................................... 53
Figure 3.9 Planar failure on a dominant discontinuity set in rock ............ 53
Figure 3.10 Wedge failure on a combination of discontinuities in rock ...... 54
Figure 3.11 Toppling failure on an alternative combination of discontinuities in rock ................................................................. 57
Figure 3.12 Influence of discontinuity orientation on stability of opposite slopes of a cutting in rock ....................................................... 57
Figure 4.1 Geomorphological map for use in condition assessment ............ 72
Figure 4.2 Hemispherical projection of a discontinuity in a rock slope ....... 76
Figure 4.3 The 1915 slip at Folkestone Warren .................................... 82
LIST OF TABLES

Table 1.1 Report structure and the principal intended readership

Table 2.1 Example of a simple strategic level risk matrix to categorise level of risk and to identify actions to be taken

Table 5.1 Summary of remedial treatment and preventative techniques for cuttings

Table 5.2 Principal advantages and limitations of remedial treatment and preventative techniques for cuttings

Table 6.1 Typical applications of remedial techniques

LIST OF BOXES

Box 3.1 Soil shear strength

Box 3.2 Rock mechanics principles for slope stability

Box 4.1 Management of a major area of coastal land instability at Folkestone Warren

Box 6.1 There is a lack of detailed understanding of soil cutting deformation mechanisms

Box 6.2 Rock slope stabilisation works on a highway

Box 6.3 Use of rock fill to stabilise Loch shore and the need to realign railway

Box 6.4 Use of dowel piles in a cutting destabilised by a pre-existing shear plane

Box 6.5 Stabilisation works at Stanmore Cutting

Box 6.6 Stabilisation works at Olive Mount Cutting

Box 6.7 Stabilisation works for West Brompton to Fulham

Box 6.8 Stabilisation works for Kenyon Cutting

Box 6.9 Slope stabilisation / Repair Works – A1 Morpeth

Box 6.10 Emergency works on a canal at Little Leigh, Trent and Mersey Canal

Box 6.11 Stabilisation of a canal cutting at Holly Hill, Oxford Canal

Box 6.12 Stabilisation of a canal cutting at Newbold, Oxford Canal

Box 6.13 Stabilisation of a canal cutting at Cheddleton, Caldon Canal
Glossary

**asset management** A systematic process of maintaining, upgrading and operating physical assets for the benefit of customers, combining engineering principles with sound business practices and economic theory, and providing tools to facilitate a more organised and logical approach to decision making.

**asset register** A detailed account of the physical extent and properties of an infrastructure cutting system established from inspections and used at a strategic level for risk analysis.

**assessment** A tactical level detailed investigation of cutting condition, stability analysis and business decision directed toward specific cuttings.

**business case** A submission made based on business risk assessment used to justify the allocation of funds for a capital or maintenance project.

**cess** The space adjacent to a railway line but not the space between railway lines.

**cess heave** Instability of a clay layer underlying the cess, due to loading and softening of clay by percolating water.

**condition appraisal** The process of inspection and assessment for understanding cutting condition (extent and causes), prioritisation and business decision.

**consequence** The impact of a hazard occurring, categorised in terms of loss of life, personal injury, property damage or financial loss.

**controlled waters** These include groundwater, inland freshwaters (including rivers and watercourses), coastal waters and territorial waters.

**crest** The break in slope at the top of a cutting.

**earth structures, linear assets or earthworks** An existing embankment or cutting, which forms part of the geotechnical asset. LUL refer to ‘earth structures’, BW refer to linear assets while Network Rail and HA refer to ‘earthworks’.

**engineering geologist** A chartered geologist with at least one year of postgraduate experience in geotechnics and a postgraduate qualification in geotechnical engineering or engineering geology, equivalent at least to an MSc; or a chartered geologist with at least three years of postgraduate experience in geotechnics (Site Investigation Steering Group, 1993).

**feature** A characteristic of a slope.

**freeboard** The distance between water level and the top of the canal bank, or the bank protection, whichever is the lesser.

**geotechnical adviser** A chartered engineer or a chartered geologist with five years of practice as a geotechnical specialist (Site Investigation Steering Group, 1993).
geotechnical engineer  A chartered engineer with at least one year of postgraduate experience in geotechnics and a postgraduate qualification in geotechnical engineering or engineering geology, equivalent at least to an MSc; or a chartered engineer with at least three years of postgraduate experience in geotechnics (Site Investigation Steering Group, 1993).

ground investigation  The sub-surface field investigation, with the associated sample testing and factual reporting. (See site investigation.)

hazard  An event, process or mechanism that may affect the performance of a cutting and prevent performance objectives from being met.

inspection  The strategic level consideration of whole routes or a network to provide an asset register of condition and hence an estimate of costs for future years. It allows the condition of cuttings to be compared with the condition of other assets, and priorities to be set. Areas of the route or network are identified that require more detailed assessment for both operational and safety reasons.

moderately conservative  A cautious estimate of the value of soil parameters, loads and geometry of a cutting, worse than the probabilistic mean but not so severe as a worst credible parameter value. Sometimes termed a conservative best estimate.

offside  The bank of a canal opposite the towpath bank (where only one towpath exists).

remedial treatment  Repair of a cutting to improve the current level of serviceability where there has been a loss of performance.

risk  The combination of the probability and consequences of a hazard occurring.

risk assessment  A structured process of identifying hazards, their probability and the consequence of them occurring, and their likely impact on the performance of the cutting.

risk mitigation  Measures taken to either remove a hazard or to minimise the likelihood or consequences of it occurring to an acceptable level including; monitoring, increased maintenance and remedial action.

risk register  A list of the risks arising from relevant hazards and the costs and benefits of mitigating them.

route kilometre  The length of transport infrastructure along a route.

rupture surface  The detachment surface on which differential movement occurs.

sectional appendices  Network Rail regional handbooks on safety and description of railway lines, eg line speed.
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tr>
<td>Serviceability limit state</td>
<td>State of deformation of a cutting such that its use is affected, its durability is impaired or its maintenance requirements are substantially increased. (See ultimate limit state.)</td>
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<td>Sidelong ground</td>
<td>Where a railway, road or canal has been constructed along the side of a hill, so that the natural ground slopes down steeply across the infrastructure. Often the infrastructure will have been constructed by excavating material from the uphill side and placing it on the downhill side to form a level surface.</td>
</tr>
<tr>
<td>Site investigation</td>
<td>The assessment of the site, including preliminary study, planning and directing the ground investigation, and interpretation of the factual report.</td>
</tr>
<tr>
<td>Slope length</td>
<td>The horizontal distance of a slope along the infrastructure route. The length of slope of a cutting is the sum of both sides and hence is roughly twice the route kilometre length of the cutting.</td>
</tr>
<tr>
<td>Soil moisture deficit</td>
<td>The cumulative reduction in the quantity of soil water below the field capacity. Calculated over the whole profile, the soil moisture deficit is dependent on rainfall, evaporation, wind speed, soil type and the type of vegetation. It is also dependent on the amount of water that runs down and off a slope.</td>
</tr>
<tr>
<td>Suction</td>
<td>A measure of the stress required to move moisture in a soil that lies above the natural water table. Measured as negative pore water pressure.</td>
</tr>
<tr>
<td>Toe</td>
<td>The break in slope at the bottom of a cutting.</td>
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<tr>
<td>Towpath</td>
<td>The access route that normally exists along one or both banks of a canal, used by pedestrians and sometimes vehicles.</td>
</tr>
<tr>
<td>Trackbed</td>
<td>Materials that form the foundation for railway sleepers.</td>
</tr>
<tr>
<td>Transect</td>
<td>A line normal to the cutting that is geotechnically and topographically surveyed.</td>
</tr>
<tr>
<td>Ultimate limit state</td>
<td>State of collapse, instability or forms of failure that may endanger property or people, or cause major economic loss. Such movement would affect any adjacent infrastructure, eg track, road or canal (See serviceability limit state.)</td>
</tr>
<tr>
<td>Worst credible</td>
<td>The worst value of soil parameters, loads and geometry that the designer could realistically believe might occur.</td>
</tr>
<tr>
<td>Zone</td>
<td>Network Rail split the railway network into zones on a geographical and route basis. Each zone has a managerial, contractual and technical structure.</td>
</tr>
<tr>
<td>4 foot</td>
<td>The space between the rails of a railway line.</td>
</tr>
<tr>
<td>6 foot</td>
<td>The space between one railway line and another (where the lines are the normal distance apart).</td>
</tr>
<tr>
<td>10 foot</td>
<td>The space between one railway line and another (where there is a wide space between a pair of lines and where there are three lines or more in total).</td>
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</tbody>
</table>

For further definitions and information, the reader is referred to technical dictionaries including: *Penguin Dictionary of Civil Engineering* (Scott, 1991) and *Dictionary of Geotechnical Engineering* (Somerville and Paul, 1983).
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALARP</td>
<td>as low as reasonably practicable</td>
</tr>
<tr>
<td>BW</td>
<td>British Waterways</td>
</tr>
<tr>
<td>CDM</td>
<td>Construction (Design and Management) Regulations 1994</td>
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<tr>
<td>COSS</td>
<td>controller of site safety (Network Rail)</td>
</tr>
<tr>
<td>DEFRA</td>
<td>Department for Environment, Food and Rural Affairs</td>
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<tr>
<td>DETR</td>
<td>Department of Environment, Transport and Regions</td>
</tr>
<tr>
<td>DMRB</td>
<td>Design Manual for Roads and Bridges</td>
</tr>
<tr>
<td>EA</td>
<td>Environment Agency</td>
</tr>
<tr>
<td>H and S</td>
<td>health and safety</td>
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<tr>
<td>HA</td>
<td>Highways Agency</td>
</tr>
<tr>
<td>ISRM</td>
<td>International Society of Rock Mechanics</td>
</tr>
<tr>
<td>LUL</td>
<td>London Underground Limited</td>
</tr>
<tr>
<td>MCHW</td>
<td>Manual of Contract Documents for Highway Works</td>
</tr>
<tr>
<td>PPE</td>
<td>personal protective equipment</td>
</tr>
<tr>
<td>PTS</td>
<td>personal track safety (Network Rail)</td>
</tr>
<tr>
<td>QRA</td>
<td>quantitative risk assessment</td>
</tr>
<tr>
<td>QUENSH</td>
<td>quality, environment, safety and health</td>
</tr>
<tr>
<td>RIGS</td>
<td>regionally important geological and geomorphological sites</td>
</tr>
<tr>
<td>SAC</td>
<td>special area of conservation</td>
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<tr>
<td>SEPA</td>
<td>Scottish Environmental Protection Agency</td>
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<tr>
<td>SLRA</td>
<td>strategic-level risk assessment</td>
</tr>
<tr>
<td>SPA</td>
<td>special protection area for birds</td>
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<tr>
<td>SPIC</td>
<td>site person in charge</td>
</tr>
<tr>
<td>SSSI</td>
<td>site of special scientific interest</td>
</tr>
<tr>
<td>ST</td>
<td>safety on the track (LUL)</td>
</tr>
<tr>
<td>TLRA</td>
<td>tactical-level risk assessment</td>
</tr>
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1 Introduction

1.1 BACKGROUND

Embankments and cuttings form civil engineering structures known as earth structures, linear assets or earthworks. They are an important means of physically forming the trafficked surface of transport infrastructure. Cuttings require maintenance, and the need to undertake it has become increasingly apparent as the materials within these structures age. This can lead to instability, with both economic and safety implications. Cutting instability affects the trafficked surface with immediate safety implications for users and costs for owners. Cutting instability can also damage other assets located on, above and adjacent to the cutting. This guide is a companion for CIRIA publication C592 Infrastructure embankments: condition appraisal and remedial treatment (2nd edn), Perry et al (2003). These guides aim to increase awareness of cuttings and embankments as civil engineering structures and inform the industry of their maintenance requirements.

Infrastructure cuttings are excavations in existing ground, with side slopes and a trafficked surface. Infrastructure cuttings provide passage for rail (Figure 1.3), road (Figure 1.4) and canal (Figure 1.5) traffic across natural ground to maintain the required vertical alignment (Figure 1.1). Embankments (Figure 1.6) are constructed across low-lying natural ground to maintain vertical alignment. Where the transport infrastructure follows the contours of the land, sidelong ground, it is supported by a combination of cutting and embankment (Figure 1.2). Minimum amounts of excavation, haulage and filling are required as the material on the upper slope is excavated, and placed on the lower slope to bring the ground to the required level for traffic.

Figure 1.1 Vertical alignment of a transport infrastructure requires construction of embankments and cuttings

Figure 1.2 Sidelong ground requires filling and cutting on hill sides to provide a platform for traffic
Figure 1.3  Steep sided railway cutting at Hooley with a shallow failure of gravels washing out over chalk (courtesy Network Rail)

Figure 1.4  Highway cutting in clay showing flatter modern slope

Figure 1.5  Canal cutting with towpath and extensive vegetation
The change in condition of materials with time and the ensuing rate of deformation of cuttings, are critical influences on the safe and efficient use of the transport corridor. Large soil slope movements and rock falls lead to traffic speed restrictions or route closure, and can directly affect the safety of users. Smaller movements of the cutting subgrade are directly associated with poor railway track or road quality. Railway, highway or canal operations depend on the integrity of the cutting for safe and efficient operation, and hence the understanding, management and longevity of cuttings are of concern to the owners and operators of transport links.

The cost-benefit of new infrastructure development has always included a financial assessment. However, the present day demand for timeliness and reliability from existing transport networks has led to the introduction of financial penalties (railways) and increased public pressure on infrastructure owners. It is important for owners and their agents to be aware of, maintain and improve the condition of their network and its performance. Specifically, this has resulted in a growing awareness of the need to maintain cuttings. As a result, the amounts spent on appraisal and repair are increasing nationally each year. In 1998/1999, at least £50 000 000 was spent on earth structure maintenance. However, the actual sum is likely to be greater, as records are incomplete.

1.2 PURPOSE AND SCOPE

This report provides guidelines on good practice for the appraisal of infrastructure cutting condition and describes many of the remedial treatments available. Frequent cross-reference is made to CIRIA publication C592. This is to reduce duplication, to provide a pair of companion documents for earthwork asset management and to ensure compatibility of information.

This report aims to:

- present best practice
- provide a guide for routine use
- recommend maintenance strategies for best value for money
- facilitate knowledge sharing between infrastructure types.

The report is not intended to be a detailed design guide, although from necessity a relatively broad approach is given.
Chapter 1 begins with an introduction to the appraisal and assessment of infrastructure cuttings. Chapter 2 describes asset management: this is the framework within which cutting maintenance is conducted. Cutting performance (Chapter 3) is one of the criteria against which the operation of a cutting is judged and provides the goals for maintenance. Condition appraisal is described in Chapter 4. This includes inspection and assessment of the deterioration or improvement in asset condition to allow the importance of repairs to be prioritised before their design and construction. Design and construction (Chapters 5 and 6) rely on an understanding of cutting condition and deformation mechanisms, without this understanding you cannot confidently expect a safe and appropriate repair. Environmental considerations, and their efficient management, are of increasing importance and are discussed in Chapter 7. Finally the report includes points for discussion on future research to provide a way forward for development and draws together recommendations for future good practice.

This publication does not cover maintenance or assessment of the trafficked surface of the cutting and its composite layers: ie sand blankets, ballast, sleepers and rails for railways; capping, sub-base, pavement layers for roads; or linings and bank protection for canals. Nor does the report cover structural assessment, and their design and construction.

It does cover the impact of cutting loss of performance on the trafficked surface, retained slopes (where the slope is the major component) and natural ground instability adjacent to and above the transport infrastructure. As well as operational cuttings, this report may also be used for when disused railway lines, roads and canal tracks are being reinstated.

**1.3 APPLICATION**

The publication is intended for:

- clients who are transport infrastructure owners
- geotechnical and environmental engineers (such as environmental scientists or ecologists with engineering experience)
- asset and maintenance managers, who may not necessarily be engineers.

To help the reader, Table 1.1 lists the chapters and the principal intended readership. Although some chapters are more relevant than others, all will gain an insight into the factors that govern asset management by reading the whole report.
The four main UK infrastructure owners are:

- Network Rail – responsible for 16 000 route km of railway throughout England, Scotland and Wales, of which it is thought that about 5 000 route km are in cutting
- London Underground Limited (LUL) – maintain about 400 route km of lighter loaded railway within and around London, of which about 60 route km are in cutting
- the Highways Agency (HA) – maintain 10 500 route km of highway in England, of which about 3500 route km are in cutting
- British Waterways (BW) – responsible for 3200 route km of canal in England, Wales and Scotland, of which about 1100 route km are in cutting.

Others responsible for infrastructure include:

- private railway line owners, eg Heritage Railways
- the Scottish Executive, the National Assembly for Wales and the Department for Regional Development, which maintain significant lengths of highway in difficult terrain
- local authorities who maintain non-trunk roads
- the Environment Agency, the Broads Authority and other authorities that own canals
- privately owned canals.

This report is relevant to any rail, road or canal cutting. References to documents and procedures have, however, been restricted to those of the major owners.

This report also applies to the following issues that are relevant to cuttings:

- whole-life asset cost and future expectations of infrastructure performance
- the culture of ‘continuous improvement’
- the differences between ultimate limit state and serviceability limit state
- national practice
- geotechnical engineering and asset management
- environmental issues with the emphasis on sustainability and maximising the use of existing fill materials in remedial treatment, with a sensitivity to the surrounding environment.
1.4 HISTORY AND CONSTRUCTION OF INFRASTRUCTURE CUTTINGS

Section 1.4 of CIRIA C592 presents a concise history of the construction of infrastructure earth structures. The main differences to highlight here are that the use of compaction is not an issue but methods of excavation are.

Canal soil cuttings were built principally in the late eighteenth and early nineteenth centuries by excavation with shovel, pick and horse-drawn cart, and required a considerable work force (Gregory, 1844). The same methods were employed for railway cuttings later in the mid-nineteenth century until the beginning of the twentieth century when steam shovels began to be used (Figure 1.7). Highway cuttings, although using similar techniques as canals and railways for contemporary roads, were initially principally constructed using scrapers (Figure 1.8). However in the last twenty years, almost exclusive use is made of backactors (Figure 1.9) and articulated dumptrucks (Figure 1.10) with their greater tolerance of varying ground conditions and hence higher productivity.

Figure 1.7 Cutting at Edgware on the London Underground Northern Line being constructed by steam shovel in March 1924 (courtesy London’s Transport Museum)

Figure 1.8 Scrapers were used frequently in the past on most of the motorway system (courtesy Caterpillar Ltd)
Figure 1.9 Backactors are used with dump trucks on most modern earthmoving schemes due to their ability to traverse a wide range of soil conditions (courtesy Caterpillar Ltd)

Figure 1.10 Articulated dump trucks have the ability to maintain maximum traction with the ground (courtesy Caterpillar Ltd)

The key point is that the final form of the soil cutting is the same in all cases. However, there is a major difference in the age of the different infrastructure cuttings. Firstly, like most old embankments, the older cutting slopes are much steeper than younger ones. They were constructed in this way because the knowledge of slope instability was not developed and the effort required to remove larger amounts of material was greater. Secondly as slopes become older and more exposed, their strength reduces and their moisture content rises leading to increasing slope instability.

The excavation of hard rock cuttings for canals and railways was by gunpowder. Later cuttings used nitroglycerine as this provided a more controlled environment for bulk blasting. Modern highway rock cuttings are excavated using presplit and bulk blasting techniques, hydraulic powered breakers and by rippers mounted on dozers (Figure 1.11).
1.5 PERFORMANCE ISSUES

The legacy of these construction methods is reflected in the performance of cuttings and hence in the degree of current maintenance. Railway and canal embankments often failed during, or soon after, construction (Gregory, 1844) due to the presence of pre-existing shear planes or release of groundwater and associated erosion. Repair usually involved removal of material, realignment, or in some circumstances installation of timber shear dowels. Movements may still be continuing to the present day. Highways suffer in the same way, although modern design techniques reduce or better manage the risk. In recent years, the need to maintain cuttings to avoid disruption to the traffic has been more widely recognised, and has led to a number of publications. These include: Perry et al. (1999) for railways; McGinnity et al. (1998) for LUL; Perry (1989) for modern highway cuttings; and Holland and Andrews (1998) for canals.

Some cuttings are of historical interest or Sites of Special Scientific Interest (SSSI). Both can have an impact on the investigation and works to be undertaken.

This report considers the performance requirements for infrastructure cuttings, as this ultimately governs whether a business case for assessment and repair is required. In the past, the solution for poor cutting performance has been a reactive one, but there is now a growing awareness of the need to be proactive. These two themes are inherent in this report and are covered in detail.