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Infrastructure embankments –
condition appraisal and remedial treatment

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Infrastructure embankments – condition appraisal and remedial treatment

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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 report provides the infrastructure owner, the designer, the contractor and the maintenance manager with guidance on the management, condition appraisal and repair of infrastructure embankments. 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.

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

The objectives of the report are 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 embankments.

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.

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Glossary

asset management	A systematic process of maintaining, upgrading and operating physical assets for the benefit of customers. It combines engineering principles with sound business practices and economic theory and provides 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 embankment system established from inspections and used at a strategic level for risk analysis.
assessment	A tactical-level detailed investigation of embankment condition, stability analysis and business decision directed towards specific embankments.
business case	A submission based on business risk assessment used to justify the allocation of funds for a capital or maintenance project.
cant	The lateral difference in level between top of rails necessary to resist centrifugal force.
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 embankment condition (extent and causes), prioritisation and business decision.
consequence	The effect 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.
earth structures, linear assets or earthworks	An existing embankment or cutting that forms part of the geotechnical asset. LUL refers to "earth structures", BW refers 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.

field capacity The quantity of water in the soil when the infiltration capacity is satisfied and there is no vertical movement of moisture. The field capacity is usually expressed as a water content in terms of volume of water per unit volume of soil. See **soil moisture deficit**.

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).

geotechnical specialist A chartered engineer or a chartered geologist with a postgraduate qualification in geotechnical engineering or engineering geology, equivalent at least to an MSc and with three years of post-charter practice in geotechnics; or a chartered engineer or chartered geologist with five years of post-charter practice 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 could affect the performance of an embankment 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 embankments to be compared with the condition of other assets and priorities 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 an embankment's soil parameters, loads and geometry, worse than the probabilistic mean but not as 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)

preventative measure — Technique used to maintain, rather than improve, the current level of serviceability of an embankment.

piping — The movement of a stream of water and soil below or through a water-retaining canal embankment. This can start as a spring near the embankment toe and proceed upwards until the eroded hole reaches the canal bank or base, at which point failure occurs.

remedial treatment — Repair of an embankment 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 consequence of occurring, and their likely impact on the performance of the embankment.

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.

serviceability limit state — State of deformation of an embankment such that its use is affected, its durability is impaired or its maintenance requirements are substantially increased. Alternatively, such movement that may affect any supported or adjacent infrastructure, eg track, road or canal. See **ultimate limit state.**

sidelong ground — 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 on the downhill side to form a level surface.

site investigation — The assessment of the site, including preliminary study, planning and directing the ground investigation, and interpretation of the factual report.

slope length	The horizontal distance of a slope along the infrastructure route. The length of slope of an embankment is the sum of both sides and hence is roughly twice the route kilometre length of the embankment.
soil moisture deficit	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.
suction	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.
toe	The break in slope at the bottom of an embankment.
top and line	Vertical and horizontal rail position respectively.
towpath	The access route which normally exists along one or both banks of a canal, used by pedestrians and sometimes vehicles.
trackbed	Materials forming the foundation for railway sleepers.
transect	A line normal to the embankment which is geotechnically and topographically surveyed.
twist	The rate of change of cant on the two rails along the railway.
ultimate limit state	State of collapse, instability or forms of failure that may endanger property or people or cause major economic loss. See serviceability limit state.
VFM	Value for money
worst credible	The worst value of soil parameters, loads and geometry that the designer realistically believes might occur.
zone	Network Rail splits the railway network into zones on a geographical and route basis. Each zone has a managerial, contractual and technical structure.
4 foot	The space between the rails of a railway line.
6 foot	The space between one railway line and another (where the lines are the normal distance apart).
10 foot	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).

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).

Abbreviations

AADTs	average annual daily traffic flows
ALARP	as low as reasonably practicable
BW	British Waterways
DCD	data capture device
CDM	Construction (Design and Management) Regulations 1994
COSS	controller of site safety (Network Rail)
DEFRA	Department for the Environment, Food and Rural Affairs
DETR	Department of Environment, Transport and Regions
DFT	Department for Transport
DMRB	Design Manual for Roads and Bridges
DTI	Department of Trade and Industry
EA	Environment Agency
GIS	geographical information system
H&S	health and safety
HA	Highways Agency
LUL	London Underground Limited
MCHW	Manual of Contract Documents for Highway Works
PPE	personal protective equipment
PTS	personal track safety (Network Rail)
QRA	quantitative risk assessment
QUENSH	quality, environment, safety and health
RIGS	Regionally Important Geological and Geomorphical Sites
SAC	Special Area of Conservation
SE	Scottish Executive
SEPA	Scottish Environmental Protection Agency
SLRA	strategic-level risk assessment
SPA	Special Protection Area for Birds
SPIC	site person in charge
SSSI	Site of Special Scientific Interest
ST	safety on the track (LUL)
TLRA	tactical-level risk assessment

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 supporting the trafficked surface of transport infrastructure. The total length of embankment in the United Kingdom is considerably longer than that of bridges. Embankments require maintenance and the need to undertake it has become increasingly apparent as the materials within these structures age. This can lead to instability, which in turn has both economic and safety implications. Embankment instability affects the infrastructure foundation and can damage other assets located on the embankment. The purpose of this book is to increase awareness of embankments as civil engineering structures and to inform the industry of their maintenance requirements. It is a companion for CIRIA Report C591 *Infrastructure cuttings: condition appraisal and remedial treatment* by Perry *et al* (2003)

Embankments are made from materials placed on natural ground and are commonly composed of soil or rock excavated from elsewhere. Infrastructure embankments carry railway (Figure 1.1), road (Figure 1.2) and canal (Figure 1.3) traffic across low-lying natural ground to maintain the required vertical alignment (Figure 1.4). Cuttings (Figure 1.5) are constructed through high 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 1.6). Minimal excavation, haulage and filling are required, because the material on the upper slope is excavated and placed on the lower slope to bring the ground to the required level for traffic.

The change in condition of materials with time and rate of deformation of embankments are critical influences on the safe and efficient use of the transport corridor. Large slope movements or settlements lead to traffic speed restrictions or route closure, and in some critical circumstances may affect the safety of users. Smaller movements are directly associated with poor railway track or road quality. Railway, highway or canal operations depend on the integrity of the embankment for safe and efficient operation, and hence the understanding, management and longevity of embankments 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 other infrastructure owners. It is important for owners and their agents to be aware of, and to maintain and improve, the condition of their network and its performance. Specifically, this has resulted in a growing awareness of the need to maintain embankments. 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 sums involved are likely to be greater, as records are incomplete.

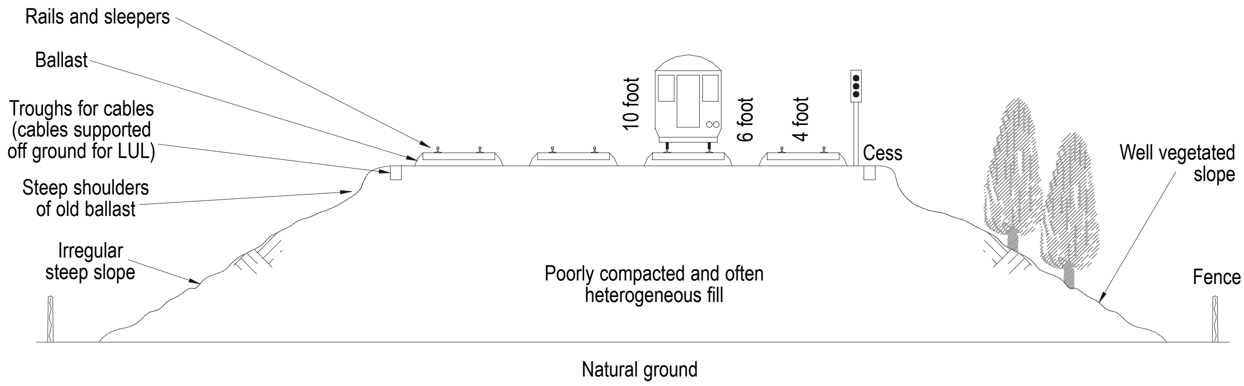

Figure 1.1 *Railway embankment. Poor compaction and steep slopes are characteristic of this type of embankment*

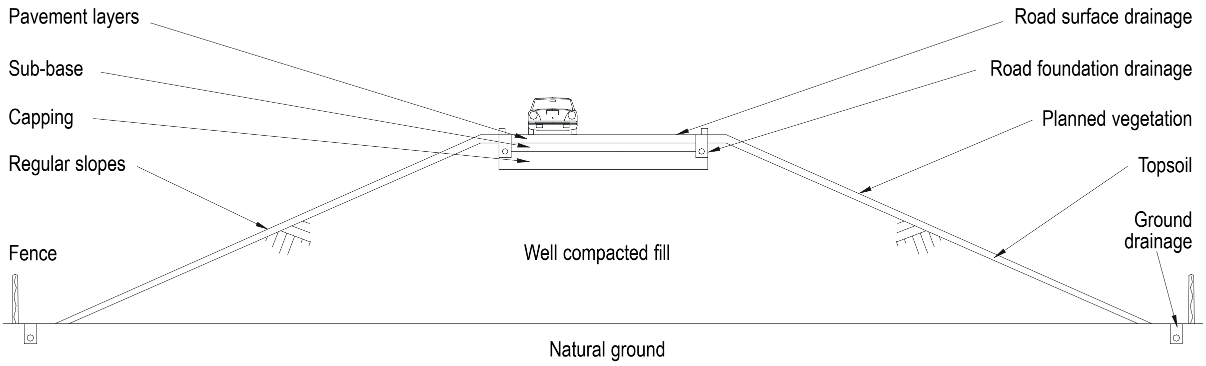

Figure 1.2 *Highway embankment. Construction and design is to modern standards with adequate compaction and flatter slopes (courtesy Adkins Photography)*

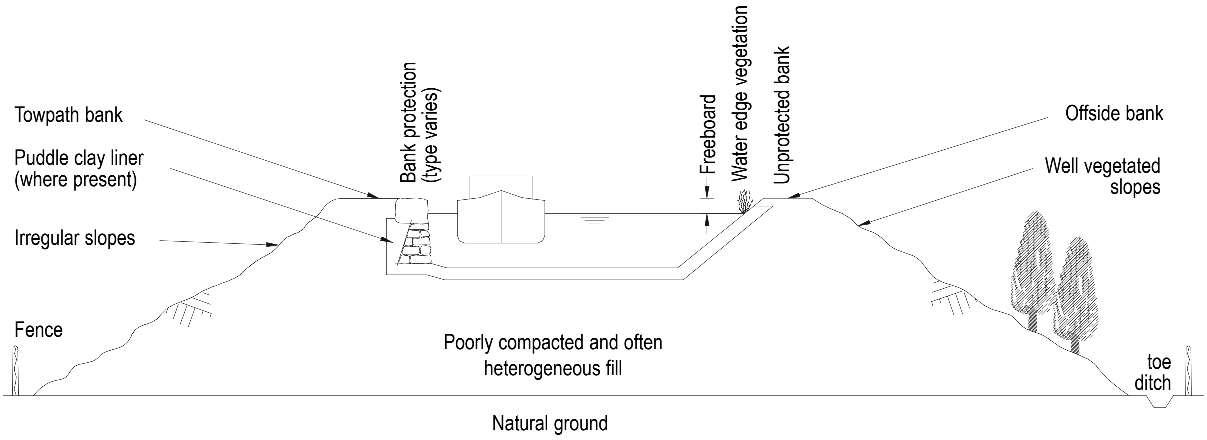

Figure 1.3 *Canal embankment. Typically, water is retained by a lining. Although traditionally puddle clay was used for this purpose, replacement often utilises modern materials (courtesy British Waterways Technical Services)*

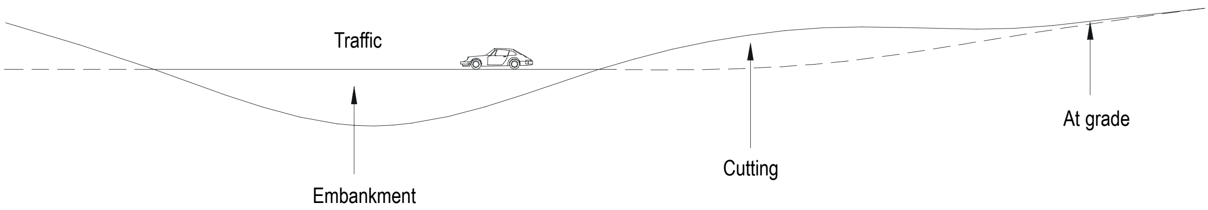

Figure 1.4 *Vertical alignment of a transport infrastructure requires construction of embankments and cuttings*

Figure 1.5 *Example of an infrastructure cutting*

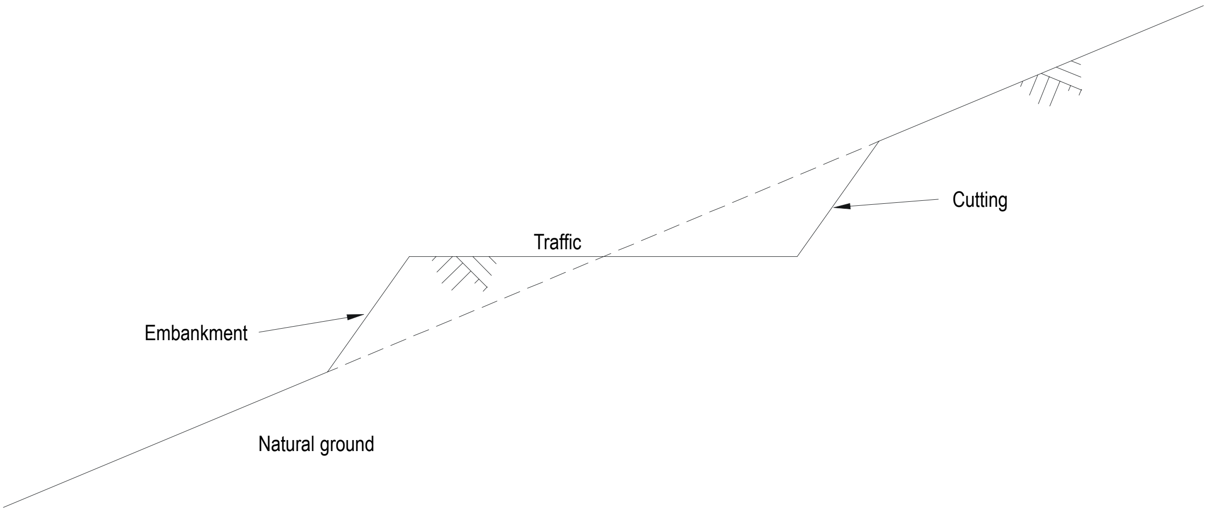

Figure 1.6 *An example of infrastructure on sidelong ground, in this case a railway with tracks supported on a repaired slope (courtesy Network Rail)*

1.2 PURPOSE AND SCOPE

This book provides guidelines on good practice for the appraisal of infrastructure embankment condition and describes the remedial treatments available. It is a companion for CIRIA publication C591 *Infrastructure cuttings: condition appraisal and remedial treatment*. However, infrastructure embankments is the lead publication.

The purpose of the book is to:

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

The book is not intended to be a detailed design guide, although the necessary broad design approach is given. It begins by introducing the appraisal and assessment of infrastructure embankments. Chapter 2 describes asset management, as it is the framework within which embankment maintenance is conducted. Embankment performance (Chapter 3) is one of the criteria against which the operation of an embankment is judged. This provides the goal for maintenance. The condition appraisal described in Chapter 4 includes inspection and assessment of the extent and type of loss of, or gain in, performance, which allows the importance of repairs to be prioritised before design and construction. Design and construction (Chapters 5 and 6) rely on an understanding of embankment condition and deformation mechanisms without which a safe repair cannot be confidently expected. Environmental considerations are of increasing importance, as is the use of data and its management to plan efficiently (Chapters 7 and 8). The report includes points for discussion on future research and draws together recommendations for future good practice.

The report does not cover in detail the maintenance of the trafficked surface of the embankment and its composite layers: ie sand blankets, ballast, sleepers and rails for railways; capping, sub-base and pavement layers for roads; or linings and bank protection for canals. Nor does the report include cuttings or embankment dams. It does cover the impact of loss of embankment performance on the trafficked surface.

1.3 APPLICATION

The book is intended for:

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

Table 1.1 lists the chapters and the principal intended readership. Although some chapters are more relevant to particular readers than others, all readers will gain an insight into the factors that govern asset management by reading the whole book.

Table 1.1 *Report structure and the principal intended readership*

Chapter		**Principal reader**			
		Client	**Geotech eng**	**Environ eng**	**Asset and main mgr**
1	Introduction	●	●	●	●
2	Asset management	●			●
3	Loss of embankment performance		●		
4	Embankment condition appraisal		●		
5	Remedial treatment and preventative techniques		●		
6	Design and application of remedial treatment and preventative measures		●		
7	Environmental considerations			●	
8	Data management systems				●
9	Areas requiring further research	●	●	●	●
10	Recommendations	●	●	●	●
11	References	●	●	●	●
A1	Health and safety and environmental legislation	●	●	●	●
A2	Specific health and safety guidance	●	●	●	●
A3	Comparison of major embankment owners' inspection procedures	●	●	●	●
A4	Geographical positioning		●		●
A5	Sources of information		●		

The four main UK infrastructure owners are:

- Network Rail, which is responsible for 16 000 route km of railway throughout England, Scotland and Wales, of which it is thought that 5000 route km are on embankment
- London Underground Limited (LUL), which maintains about 400 route km of lighter-loaded railway within and around London, of which about 60 route km are on embankment
- the Highways Agency (HA), which maintains 10 500 route km of highway in England, of which about 3500 route km are on embankment
- British Waterways (BW), which has responsibility for 3200 route km of canal in England, Wales and Scotland, of which about 1100 route km are on embankment.

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 maintains significant lengths of highway in difficult terrain
- local authorities, which maintain non-trunk roads
- the Environment Agency, the Broads Authority and other authorities, which own canals
- privately owned canals.

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

This book also applies to the following issues that are relevant to embankments:

- whole-life asset cost and future expectations of infrastructure performance
- the culture of continuous improvement
- the differences between ultimate limit state (factor of safety) and serviceability limit state (deformation)
- national practice
- geotechnical engineering and asset management
- environmental issues, with the emphasis on sustainability and maximising the use of existing fill materials in remedial works' design and construction with a sensitivity to the surrounding environment.

1.4 HISTORY AND CONSTRUCTION OF INFRASTRUCTURE EMBANKMENTS

The history of embankment development is illustrated in Figure 1.8. Most canals were constructed between 1761 and 1830, the period of "Canal Mania". Each canal was authorised by its own Act of Parliament, and between 1791 and 1795 alone, 51 canal Acts were promoted. The early canals tended to follow ground contours, being constructed largely on sidelong ground (Figure 1.7). By the 1790s, the success of canals led to greater demand for them to be more independent of terrain. As a result newer canals were constructed with embankments, cuttings and tunnels. Existing contour canals (eg the Oxford Canal) were shortened, sometimes by as much as 35 per cent, by using embankments and cuttings to carry them across valleys and through hills. Labourers ("navigators" or "navvies"), using the same techniques they were later to employ on the railway lines, constructed substantial embankments. Water was retained within the canal trough by a layer of impermeable clay known as puddle clay. The integrity of this layer was and still is crucial for the canal operation. The rate of construction slowed considerably after 1830, although some canals incorporating embankments of considerable size (eg the Shropshire Union Canal) were not completed until 1835. After this time the canal system was largely complete, totalling 6480 route km (Gascoigne, 1994).

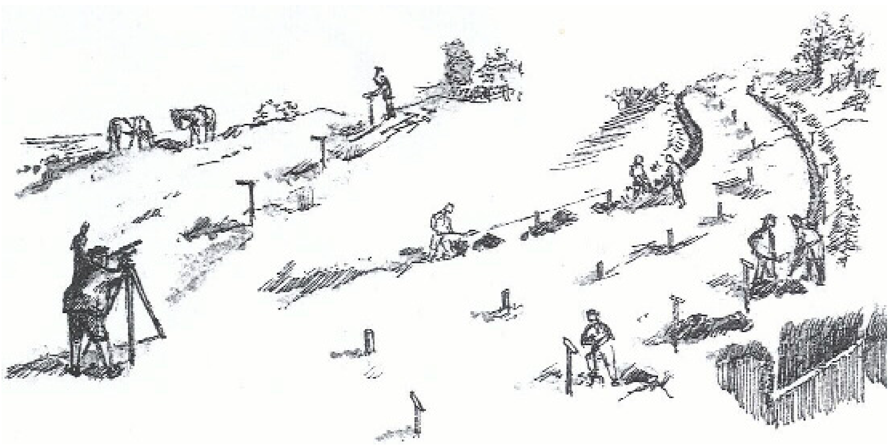

Figure 1.7 *Marking out the construction levels for a canal. First, level pegs were driven, with crosspieces indicating the depths to be dug. Opposite each one, a peg was driven to mark the centreline of the canal. Holes were then dug at each side to indicate the course and width of the canal channel. These were joined as trenches to define the canal banks and the channel excavated (Paget-Tomlinson, 1996)*

Following the advent of the railways from the mid-19th century, the use of the canal system for freight transport gradually declined. During this period, the network was reduced, largely by infilling or redevelopment, to its present size of about 4000 route km (includes the principal owner's (BW) canals and privately owned canals). Canals are now used primarily for leisure purposes, although some cargo is still carried.

circa 1760's	Early contour canals
circa 1800's	Canal construction peak
1835	Canal construction largely completed
1841	Great Western Railway construction complete
circa 1850's	Railway construction peak
circa 1860	London Underground embankment construction started
circa 1900	Manchester Ship Canal
1933	Proctor publishes paper on compaction
circa 1948	London Underground embankments completed
circa 1950	Large self propelled scrapers become common
1958	M6 Preston By-Pass open
1959	M1 Motorway Watford to Crick open
1986	M25 Motorway fully open
1998	A34 Newbury By-Pass open
2003 (expected opening date at time of printing)	Channel Tunnel Rail Link (south)

Figure 1.8 *Timeline of embankment construction in the UK*

The railway network in the UK was mostly built in the mid-19th century. Soil cuttings were excavated by pick and shovel, and rock cuttings were blasted using gunpowder. Horse-drawn wagons transported the material to fill areas where the soil or rock was end- or side tipped to form poorly compacted embankments (Wiseman, 1888; Skempton, 1996). Between 1834 and 1841, nine main line railways were built in England, totalling 1060 km with some 54 000 000 m^3 of excavation. This was a remarkable quantity feat, and was not achieved again on works of a comparable nature until the introduction of modern earthmoving plant on the first motorway contract, more than a century later. Materials used were locally won and varied considerably, matching the variation in geology. As a result embankments were made up of a variety of materials ranging from rock to clay. The variation has increased with time as extra ballast and some capping materials have been added to maintain track level and to repair past failures.

Some of the later LUL railways were constructed with steam navvies – steam-driven excavators that replaced much of the hand-dug work. Materials were transported using steam locomotives and side- or end-tipped to form embankments (Figure 1.9). The material was tipped as excavated, although occasionally, where weak clay was encountered, it was mixed with coal and burnt to bake the clay. Most embankments were made from clay, although throughout the network materials varied frequently, from gravel and cobbles to clay. Since construction, these embankments have also been topped with ash and sand. They should therefore be considered to be of a heterogeneous nature. More than 90 per cent of the LUL system was constructed between 1860 and 1948 using these methods. A significant proportion of the system was constructed for mainline railways and subsequently reused for the lighter LUL railway above ground.

Figure 1.9 *LUL Edgware extension construction in 1922 showing side-tipping trucks depositing clay onto the slope of an embankment as part of the filling process (courtesy London Transport Museum)*

Nearly all railway embankments were constructed of relatively uncompacted material. Before the 1930s, little or no compaction was possible as the construction plant had not been developed and the process of compaction was poorly understood. Also, the embankment slope angle was based on short-term angles of repose attained during construction. These would be considered oversteep in modern practice. Large settlements commonly occurred soon after construction, and some continue to the present day. Slope failures sometimes occurred during and after construction and some remain a major hazard.

Highway embankments are generally of more recent construction than canals and railways, although some highways are located on embankments built for horse and cart traffic in the late 19th century. Many of these roads were constructed on sidelong ground in hilly rural areas, and may have substantial embankments on the downslope side. The first major highway with substantial lengths of continuous embankment – and the first in the UK built to motorway standard – was the Preston By-Pass, which opened on 4 December 1958. It now forms part of the M6 motorway. The first interurban motorway was the M1 Watford to Crick (Figure 1.10) opened on 2 November 1959.

The low gradients of these new high-speed roads required a major development in the use of the embankment. Prior to this there was very little embankment construction for roads, as they tended to follow the natural ground level. With the introduction of modern road design standards, gradients of roads reduced and average journey times decreased. Some major roads (eg A1 trunk road) were upgraded and new roads and motorways (eg M1 and M4 motorways) were constructed with more embankments and larger quantities of materials. The construction was undertaken more quickly, and with less embankment instability due to the development of new construction plant (Figure 1.11) and the greater understanding of the discipline of geotechnical engineering. In some specific highway embankments, the engineered fills can be heterogeneous, for example, layering of granular materials between wet cohesive ones (Williams and Williams, 1960).

1.5 PERFORMANCE ISSUES

The legacy of these construction methods is reflected in the performance of embankments and hence in the degree of current maintenance. Railway and canal embankments often failed during, or soon after, construction (large settlements also occurred) (Gregory, 1844) due to the poor material compaction. Loss of vertical alignment due to failure and settlement were typically repaired by filling and raising the track or canal to its required level. However, settlements, and occasionally failures, have continued to the present day. Highways suffer less from settlement due to their better compaction and generally less steep slopes, but slope failures still occur. In recent years, the need to maintain embankments 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 embankments; and Holland and Andrews (1998) for canals.

Some embankments 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 book considers the performance requirements for infrastructure embankments, as this ultimately instigates the business case for embankment assessment and repair. In the past, the solution for poor embankment performance has been a reactive one, but there is a growing awareness of the need to be proactive. These themes are inherent in this book and are covered in detail.

Figure 1.10 *"Cutting the first sod": removal of topsoil in preparation for embankment construction on the M1 south of Luton-Watford Gap Dunchurch Special Road Scheme (March 1958) (courtesy Owen Williams Ltd)*

Figure 1.11 *Use of modern and efficient compaction plant on a recent highway embankment (courtesy Bomag (GB) Ltd)*