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Drystone retaining walls and their modifications – condition appraisal and remedial treatment

Prepared under contract to CIRIA by Dr Myles O'Reilly and Mott MacDonald Ltd

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Foreword

Much of the UK's transport infrastructure passes very close to, or is supported by, many thousands of kilometres of masonry retaining walls. Most of these structures – for that is indeed what they are – stand up without the benefit of detailed design and modern construction methods and materials.

Often built centuries ago, these walls use traditional methods and local stone and work only from a composite interaction with the backfill material behind them. Whether empirical rules were ever devised, or whether it was due to an innate understanding of the materials, is unknown. Whatever the case, they continue to stand despite increases in traffic live loads far beyond anything that could have been anticipated at the time of their construction. Conventional analysis would often suggest that such walls should not be standing and that is the key reason for this research programme and this guide.

The need for research arose from the national bridge assessment and strengthening programme in the 1990s, which was later extended to other highway structures. Bridge engineers, responsible for the structures on their network, could see the need for a quantitative as well as qualitative guidance. This was considered by the Bridge Owners Forum who then persuaded the UK Bridges Board to promote and prioritise the research programme with help in kind as well as financial support from its members – the Department for Transport, Network Rail, the DRD(NI) Roads Service and the County Surveyors Society (CSS).

I welcome this publication and the advice and guidance it offers. I am sure it will be a useful reference for many years for structures managers and engineers throughout the UK.

Richard Fish, BSc CEng FICE FiStructE FIHT

Chair of UK Bridges Board and CSS Bridges Group 2005–2008

Executive summary

Drystone retaining walls are commonplace on the UK transport infrastructure in areas where building stone is readily available. The indications are that since 1920, only a handful of such retaining structures have been built on the transport network. The vast majority of these structures that now exist began life over 90 years ago. Over the years many drystone retaining walls have been modified by various measures to increase their lives, and these modified structures are considered within this publication. Although now an historic form of construction, the numbers of drystone and modified drystone retaining walls are such that their complete replacement with modern retaining walls would be prohibitively expensive, more risky and would be in conflict with the concept of sustainability. The need is to promote and develop methods of preserving this valuable stock of retaining structures. The process involved and the basic information needed in achieving this desirable state of affairs is the subject of this publication.

This publication provides infrastructure owners, consulting engineers, contractors and maintenance managers with guidance on the management, condition appraisal, maintenance and repair of drystone retaining walls. It is based on a detailed review of published literature and infrastructure owners' procedures, consultation with experts and practitioners within the field.

The purpose of this publication is to:

- present good practice
- provide a guide for routine management
- recommend assessment, maintenance and repair strategies to give value for money
- help knowledge sharing.

This publication is divided into ten chapters, each including information and guidance on particular aspects of drystone retaining walls, followed by appendices with detailed information for practitioners including case studies demonstrating good practice.

Health and safety

Construction activities, particularly 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 publication 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

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Dr Perry is a geotechnical director with Mott MacDonald. He is a geotechnical advisor with over 20 years' experience of geotechnical design, construction and maintenance. He is a recognised national and international expert in earthworks and a leading figure in research and development in the geotechnics field.

Steering group

Following CIRIA's usual practice, the research project was guided by a steering group that comprised:

Brian Bell*	Network Rail
Dr Ken Brady	Network Rail
Edward Bunting	Department for Transport
John Clarke*	BRB (Residuary) Ltd
Graham Hollett**	Derbyshire County Council
Rod Howe*	British Waterways
Jim Johnson	Arup
Neil Garton Jones	Gwynedd County Council
Alex Kidd	Highways Agency
Richard Kromolicki	Tameside Metropolitan Borough Council
Hazel McDonald	Transport Scotland
Bill Middleton	Mouchel
Paul O'Neill	Dew Construction
Prof William Powrie	University of Southampton
Tudor Roberts*	Welsh Assembly Government
Richard Todd	City of Bradford Metropolitan District Council
Jon Tuson	Formerly Oldham Metropolitan Borough Council

Dr Peter Walker	University of Bath
Jon Walters	Cornwall County Council
Ronnie Wilson (chair)*	DRDNI Roads Service

*Bridge Owners' Forum representatives

** County Surveyors Society representative

CIRIA managers

The project manager for this research was Philip Charles, and the project director was Chris Chiverrell

Project funders

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County Surveyors Society

Department for Transport

DRD(NI) Roads Service

Network Rail

The project team would also like to thank Professor William Powrie of the University of Southampton for providing the calculations for Appendix A5.

Contents

Glossary

Appraisal	Includes the range of activities involved with the evaluation of a drystone retaining wall's condition and performance (ie the gathering of existing data, inspection, investigation and structural assessment).
Asset management	A systematic process of maintaining, upgrading and operating physical assets for the benefit of customers, which combines engineering principles with sound business practices and economic theory. Provides tools to help a more organised and logical approach to decision making.
Asset register	A detailed account of the physical extent and properties of a drystone retaining wall system established from inspections and used at a strategic level for risk analysis.
Assessment	Here used specifically to imply the evaluation of a drystone retaining wall's structural capacity and performance. Typically using one of many prescribed methods and possibly making use of proprietary software applications.
Backfill (or backing/fill/infill)	Material (usually low quality fill) used to give support behind a structure.
Drystone wall	Stone wall constructed without mortar.
Ground investigation	The subsurface field investigation, with the associated sample testing and factual reporting.
Inspection	A visually-based examination of the drystone retaining wall, which may be supported by other simple methods of evaluation.
Investigation	An enquiry into one or more specific aspects of a drystone retaining wall's structure, its environment, performance or behaviour. It typically uses techniques of measurement, testing or sampling of relevant parameters that go beyond the normal scope of visual inspection.
Knappings	Pieces off the stone within a drystone retaining wall that is being dressed.
Maintenance	All the operations necessary to maintain a wall in a serviceable condition until the end of its life. It comprises routine maintenance (routine work carried out with the aim of preventing or controlling deterioration, including inspection and monitoring activities) and essential maintenance (rehabilitation works required to address specific inadequacies in function and performance, eg strengthening).
Mortar	Mix of one or more inorganic binders, aggregates, water and sometimes additions and/or admixtures for bedding, jointing and pointing of masonry.

Masonry	The work of a mason, strictly referring to work in stone, but commonly used to refer generally to work in either brick or building stone.
Masonry wall	A masonry wall is a structure built from individual block units laid in and bound together by mortar.
Performance	Operation and/or functionality of a drystone retaining wall or element thereof, in relation to the requirements of owners/operators/users.
Pointing	The filling and finishing of mortar on the outer face of a joint where the bedding mortar has been raked back from the masonry face or left recessed from it in construction.
Remedial treatment	Repair of wall 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 possible effect on the performance of the asset.
Rupture surface	The detachment surface on which differential movement occurs.
Thrust line	The locus of the positions of the centroid of the compressive force within the wall. The point on a given section where if you transfer the stresses, there is no bending moment but only axial force.
Weep hole	A drainage hole through a wall.

Acronyms and abbreviations

AONB	Areas of Outstanding Natural Beauty
BRE	Building Research Establishment
BSI	British Standards Institution
BW	British Waterways
CDM	Construction (Design and Management) Regulations
CSS	County Surveyors Society
Defra	Department for Environment, Food and Rural Affairs
DfT	Department for Transport
DMRB	Design Manual for Roads and Bridges
DRD (NI) Roads Service	Department for Regional Development (N. Ireland) Roads Service
EDM	Electronic distance measurement
EPSRC	Engineering and Physical Sciences Research Council
GIS	Geographical information system
GPR	Ground penetrating radar
HA	Highways Agency
LCA	Life cycle analysis
MCHW1	Manual of Contract Documents for Highway Works
PFA	Pulverised fuel ash
SAC	Special Area for Conservation
SHW	Specification for Highway Works
SMS	Structures management system
SNCO	Statutory Nature Conservation Organisation
SO	Special Order
SPA	Special Protection Area
SSSI	Site of Special Scientific Interest
STGO	Special Types General Order
TRL	Transport Research Laboratory
UDEC	Universal distinct element code
WLC	Whole-life costing

1 Introduction and background

1.1 Background

Drystone earth retaining structures were commonplace on the transport infrastructure in the hillier and mountainous areas of the United Kingdom where durable rock is abundant and is easy to obtain. Most of them were constructed in the 19th and early 20th centuries. Drystone is a method of placing blocks of stone without mortar between them to form structures the stability of which depends on the weight and arrangement of the blocks of stone and on the friction and interlock between them. This guide deals with earth retaining structures originally constructed in this way including those that were later modified, typically by pointing, when showing signs of deterioration.

Many of these drystone retaining walls and their modifications are still in use today and predominantly they are on roads although there are several hundreds of such structures on railways and canals. They remain true to line and level 100 years or more after their construction, have not required any substantial maintenance in the interim and currently do not show any signs of instability. With annual maintenance and renewal costs averaging about 0.75 per cent of the replacement cost for such structures on trunk roads (O'Reilly *et al*, 1999) it is clear that many of these retaining walls have a considerable residual lifetime remaining. However, failures do occur and occasionally the stability of these retaining walls is being compromised.

Structures can begin to deteriorate as soon as they have been constructed due to naturally occurring phenomena: the rate at which they deteriorate will depend on the durability of the materials of which they are composed and the conditions they are subjected to. On the transport network drystone retaining walls are subjected to other debilitating factors as well. Vehicular loading occurs daily, but vehicle impact less frequently. The activities of public utilities (ie water, gas, electricity, telecommunications) and nearby developers as well as highway maintenance and road works including the application of de-icing salts, vandalism and any other activity that alters the existing state of affairs can all contribute to structural decay over time. Vibrations from any source can be a particular problem. Drystone retaining walls near railways may be less exposed to some of these factors but in many cases the loading conditions can be more onerous. It is important that management systems are in place to ensure that these risks are as low as is reasonably practicable, that the examination and assessment regimes represent good practice and that the methods of repair, refurbishment and replacement are cost-effective.

According to a census of highway structures in the UK undertaken in 1987 by the Department of Transport there were about 5400 km of retaining and supporting walls on roads in the 36 authorities that responded. Simple proportioning of this data would suggest a total of about 9000 km for the whole of the UK. The census considered that 50 per cent of the retaining structures were of drystone construction, 35 per cent of other masonry and the remaining 15 per cent concrete. Network Rail owns around 17 000 retaining walls and many of these are of drystone construction in upland areas. There are also similar earth retaining structures on canals.

The more recent survey on trunk roads in five local authorities in England and Wales (O'Reilly *et al*, 1999) suggested that the overall proportion of unmodified drystone retaining walls is likely to be less than 50 per cent. Indications that the figure of 15 per cent from the 1987 survey for the proportion of concrete retaining walls for trunks roads was a good estimate. That survey also showed that the replacement cost of such retaining structures averaged £1.16m per kilometre so that the replacement value of the stock of retaining structures on the UK's roads of which about 85 per cent are of drystone or other masonry faced retaining walls, was about £10bn at that time.

In these circumstances the case for a regime of inspection, maintenance and renewal of drystone and other masonry faced retaining structures is compelling and equally applicable to all transport infrastructure (road, rail and waterways). It is important for those responsible for transport infrastructure and their agents to realise the full potential of these existing assets, minimise their use of scarce resources and ensure the facilities they provide are satisfactory and safe for those who use them.

1.2 Purpose and scope of work

This publication provides guidance on good practice for inspection, maintenance, repair and replacement of drystone and modified drystone retaining walls. Their history of performance in service is examined and methods are provided with the objective of enabling them to achieve satisfactory performance in the long-term. Such methods have been pursued with success by the authorities responsible for trunk roads in the UK. They have found that the stock of drystone retaining walls can be maintained and reviewed as necessary for an annual expenditure of 0.75 per cent of their replacement cost.

This guide aims to:

- present good practice
- provide information and help with knowledge sharing
- provide an enabling document for national application
- provide the basis of an auditable, cost-effective conservation strategy.

Chapter 2 considers a management framework within which the stock of existing drystone and other masonry-faced retaining walls can be well managed and preserved. The reasons why so many drystone earth retaining structures remain stable are examined in Chapter 3 while methods of inspection and assessment are considered in Chapter 4. Condition appraisal is fundamental and provides the basis for the identification and prioritisation of the need for maintenance, repair and strengthening. Chapter 5 deals with regular maintenance, repair and renewal and the organisation of these activities. Repair techniques and their evaluation and design are covered in Chapter 6 and illustrated by several practical examples. The provision of replacement earth retaining structures, again with practical examples, is discussed in Chapter 7 while research and development is considered in Chapter 8. Finally Chapter 9 combines the various aspects of the publication and points the way forward. Further background material supporting the main text is given in the appendices.

The guide does not cover the design of new replacement retaining structures, which is dealt with in codes of practice such as EC7-1 (BSI, 1995) and BS 8002 (BSI, 1994).

1.3 Application

The publication is intended for:

- clients and administrators who are responsible for parts of the transport infrastructure
- structural and geotechnical engineers
- asset and maintenance managers.

To assist the reader Table 1.1 lists the chapters and the principal target readership. Although some chapters may be more relevant than others, all will gain an understanding and insight into the factors governing the asset conservation process from reading the whole publication.

Table 1.1 ***Report structure and principal intended readership***

Chapter		Principal reader		
		Client and administrator	*Structural and geotechnical engineer*	*Asset and maintenance manager*
1	Introduction and background	✔	✔	✔
2	Management of drystone retaining walls	✔	✔	✔
3	Understanding the stability of drystone retaining walls		✔	✔
4	The inspection and qualitative assessment of drystone retaining walls	✔	✔	✔
5	Maintenance	✔	✔	✔
6	Repairing drystone retaining walls		✔	✔
7	Replacing drystone retaining walls		✔	✔
8	Research and development	✔	✔	✔
9	Summary and recommendations	✔	✔	✔
10	References		✔	✔
	Appendices		✔	✔

The main UK transport infrastructure owners are:

- National and Local Highway Authorities: responsible for some 400 000 km of roads in England, Scotland, Wales and Northern Ireland
- Network Rail: responsible for some 16 000 route kilometres of main line railway network throughout England, Scotland and Wales
- Translink (Northern Ireland Railways): responsible for some 340 route kilometres of main line rail network
- British Waterways: responsible for 3540 km of canal in England, Scotland and Wales
- BRB (Residuary) Ltd: responsible for those sections of closed railway lines and retains ownership of about 3800 structures across England, Scotland and Wales not sold for alternative uses.

This guide is applicable to all existing drystone and modified drystone earth retaining walls and it is also relevant to some extent to other masonry faced retaining structures. References to documents and procedures have, however, been restricted to those of the major owners.

Readers are reminded that all European and National legislation, codes of practice and standards are subject to updating and change and may even be superseded over the years, and also prescriptive instructions and advice produced by authorities responsible for the transport infrastructure, health and safety etc. Any such alterations must be recognised and taken into account when using this guide.

1.4 A historical perspective

1.4.1 Drystone walling

Drystone walls are not new with some dating back to the early Stone Age, for example early traces of them have been found in the South of France (Cabanel, 1995). Building with drystone is one of the earliest skills developed by mankind and was used to build shelters, houses, fortifications, ceremonial structures and animal enclosures.

In the UK the Neolithic village of Skara Brae, in Orkney was built in drystone around 3000 BC. The drystone work there is still in good condition and was protected by being buried in sand-dunes for millennia until rediscovered around 1850 (Ritchie, 1995). The distinctive drystone circular towers tapering with height called brochs and peculiar to Scotland date from the Iron Age: the most complete example is the broch of Mousa with a diameter of 15 m and a height of 13.3 m. Again the drystone is in good shape after two thousand years or so exposed to the elements (Newton, 1995 and Ritchie, 1995).

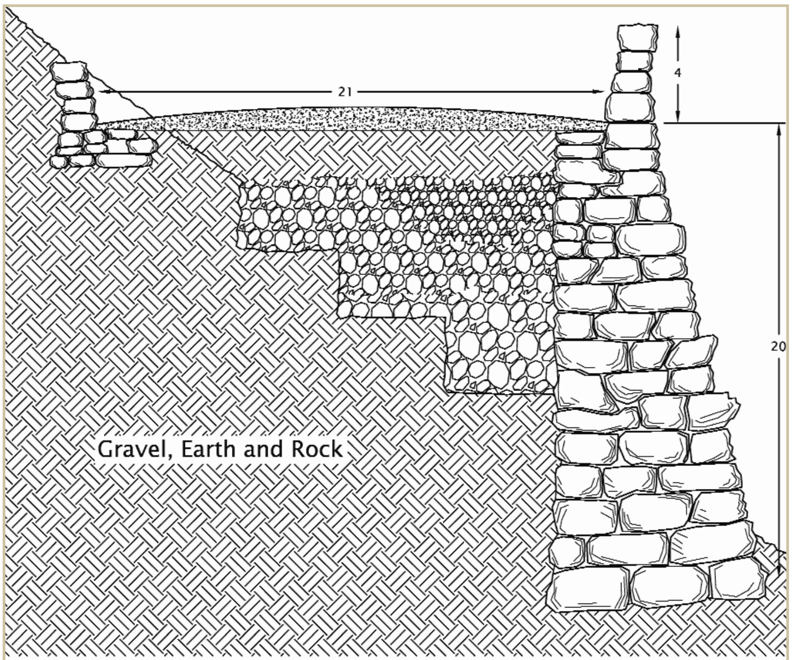
Drystone walls have long been used to enclose land. Only traces of the earliest walls remain and most of the drystone walls we see today that have created such a picturesque landscape were built from the 14th century onwards (Brooks and Adcock, 2004). The early 17th and early 18th centuries were the most productive when enclosures were promoted by large landowners through Acts of Parliament and effectively expropriated the smaller farms. These acts limited the time allowed for fencing landholdings to one to two years and meant that only the wealthy could afford to pay the labour for the work.

1.4.2 Drystone retaining walls

Other than for fortifications there would have been little need for drystone retaining walls before the 17th century. Until that time the poor condition of the roads precluded the carriage of goods over long distances other than by pack horse (Collins and Hart, 1936) so that steep gradients remained commonplace, as they had since Roman times and earlier, and posed no great impediment to travel (Belloc, 1923). The first stagecoach in Scotland was run between Edinburgh and Leith in 1600 (Aitken, 1900), with their introduction in England somewhat later. The upgrading of the road system may be traced to these events as well as to the increasing number of heavy horse-drawn wagons that necessitated the improvement of communications between towns. The turnpike system was established after the restoration of Charles II and turnpike gates were first legally erected in England in 1663 at Wadesmill, north of Ware in Hertfordshire (Wright, 1992). It was the close of that century before this new concept was accepted. Many turnpikes were sanctioned at the beginning of the 18th century, but because of local antipathy made little progress until 1760 (Parnell, 1838). However, road conditions were still deplorable in 1770. Stagecoach speeds of 5 mph were considered quite reasonable with the fastest coaches from London to Manchester having a journey time of four days (Collins and Hart, 1936). With horse-drawn cartage by road about four to 20 times more expensive than by barge, the raw materials and bulky products of the nascent Industrial Revolution, where possible, were conveyed on navigable rivers and a burgeoning canal system (Hill, 1991).

However this was to change. Much of the increasing industrialisation was located in upland districts and was closely associated with the increasing use of horse-drawn vehicles. Gradient easing on roads became increasingly important both to reduce journey times and the strain on the horses (Timmins, 2003). The practice of building retaining walls – many of them of drystone construction – to support the cuttings and embankments needed to achieve those aims became widespread in many areas. The successful construction of some 320 km of roads involving in some instances the erection of many bridges, retaining walls and culverts in Lancashire, Cheshire, Yorkshire and Derbyshire in the latter half of the 18th century (Aitkin, 1900, Kennerell, 1958 and Davies, 2006) probably marks the emergence of this phenomenon, which accelerated during the opening decades of the 19th century.

Telford (Rolt, 1985) and McAdam (Reader, 1980) are most associated with this upsurge in the building and upgrading of roads. In common with their road building colleagues both favoured easy gradients preferably less than 1 in 30 with a maximum of 1 in 20. Many of Telford's retaining walls are still in use today, those on the A5 at Nant Ffrancon in North Wales being particularly impressive examples (Davies, 2006): it would appear from Parnell (1838) that some of the retaining walls on the Holyhead Road were built of pointed drystone construction although the more important ones appear to have been of masonry set in lime mortar. By contrast, Telford appears to have specified drystone construction for retaining walls on the Highland Roads because the use of lime mortar is only mentioned for the erection of parapet walls and the pointing of their copings (Cresy, 1856 and Ford, 2007). Figure 1.1 shows a cross-section of a similar drystone retaining wall used at Carey Mountain during construction of the Antrim Coast Road during the 1830s (Commissioners of Public Works in Ireland, 1835). Aitkin (1900) states that "retaining walls are structures in masonry, laid dry or in mortar" to support roads on hillsides or where the landtake is restricted.



Note: dimensions in feet

Figure 1.1 ***Cross-section of drystone wall at Carey Mountain on the Antrim Coast Road constructed in the 1830s. Contemporary drawing***

The development of the railways from 1830 onwards had a disastrous effect on the 35000 km or so of roads administered by seven hundred Turnpike Trusts and also on the canals with passenger traffic and goods being diverted to this new, quicker and cheaper means of transport. Many main roads between the larger towns became of little importance and were neglected for the following sixty years. The number of Turnpike Trusts declined steadily with the last one being dissolved in 1895. The remaining 170 000 km or so of miscellaneous roads, streets and lanes in 1820 were still administered as they had been since the middle of the 16th century by the thousands of separate parishes and townships according to the medieval assumption of personal service and parochial obligation (Webb and Webb, 1913). Efforts to create larger, more effective organisations to manage local highways continued for the remainder of the century. County councils were given responsibility for main roads in 1888 but it was 1897 before the role of the highway parish was finally abolished: even then there were still 1900 organisations responsible for roads in England and Wales. Despite the incompetence of authorities, progress was made in the more populous urban areas where the larger local authorities assumed responsibility for highways. New roads had to be built to cope with the growing population and to act as feeders to the railways. The length of road in the UK increased from about 205 000 km in 1820 to 285 345 km in 1922 (Mitchell, 1988).

All that can be surmised from the little evidence available is that most of the drystone retaining walls on today's transport infrastructure in the UK were constructed between 1800 and 1920 either on newly constructed roads or as improvements to the existing network. Aitken (1900) states that drystone retaining walls continued to be constructed on roads during the early years of the 20th century although how long this continued is unclear. Leeming (1924) makes no reference to them in his book on road engineering where only the use of mass brickwork and reinforced concrete are mentioned for the construction of retaining walls. But at that time drystone retaining walls were still being built on the peripheries of the British Isles. For example much drystone walling was used in the construction of the 11 km long Healy Pass over the Caha Mountains between the Counties of Cork and Kerry in the southwest of Ireland, which was opened to traffic in 1931 (Ayto and Crofton, 2005).

Figure 1.2 ***Drystone retaining wall, Settle – Carlisle Railway Line (courtesy Mouchel)***

Figure 1.3 ***Drystone retaining wall, Settle – Carlisle Railway Line (courtesy Mouchel)***

Drystone retaining walls were also constructed on the canal and railway networks. Canal building after small scale beginnings (Blair, 2007) took off in the UK with the construction of the Bridgewater Canal between 1759 and 1761, and continued on a large scale until about 1840, when construction of the Birmingham and Liverpool Junction Canal (now the Shropshire Union main line) was essentially completed. The use of dry walls in the Woodseaves cutting, 1.6 km long with a maximum depth of 27 m, on the latter canal where friable rock strata alternated with bands of clay is mentioned in Rolt (1985). Some minor canal building continued until 1905 (Bougley, 1998). Today British Waterways operates about 3540 km of canals.

The railway era started in earnest in the north of England. This is where George Stevenson masterminded the construction of the Stockton and Darlington Railway between 1822 and 1825, and the Liverpool and Manchester Railway between 1826 and 1830 (Rolt, 1988). Railway building peaked during the middle decades of the 19th century. The construction of the Settle – Carlisle Railway between 1869 and 1870 was the last major railway enterprise to be undertaken by navvies and horses (Flinders, 1981 and Colman, 1968). An example of a drystone retaining wall constructed on this line is illustrated in Figures 1.2a and 1.2b. One further main line, the Great Central remained to be built in the 1890s, but here extensive use was made of mechanical excavators. In all, nearly 33 000 route kilometres has been constructed. Network Rail is responsible for some 16 000 route kilometres of that system, which are still operational.

It emerges that most of the drystone retaining walls on the canals and railways are at least 170 years old and 130 years old respectively. Some drystone retaining walls were probably constructed on highways in the opening decade of the 20th century, but it is fairly clear that only a handful of such structures have been constructed on the transport infrastructure in the UK since 1920. It would also be reasonable to conclude that some 90 per cent of the drystone retaining walls and their modifications on the UK transport infrastructure are located on the highway network.

2 Management

This chapter describes the general strategic management of assets as an introduction to the broad processes involved. The particular requirements of drystone retaining walls at a more tactical implementation level are given in the following chapters based on this strategic approach.

2.1 The need for asset management

Like any other structure a drystone retaining wall will have a finite life before significant renewal or replacement works are required (Figures 2.1 and 2.2). This lifespan can be extended by systematic, continued repair and maintenance. Unplanned and reactive activities particularly when the structure has been allowed to deteriorate into a state of gross disrepair or even impending collapse are usually expensive and disruptive to the normal operation of the transport facility. As with other assets on the transport infrastructure the high direct and indirect cost of unplanned repairs often justifies a proactive, rather than a reactive approach to the management of the stock of retaining walls. Processes that affect a retaining wall can in some instances be quite sudden, in other cases more gradual, but both require timely intervention to ensure the safety of the structure is maintained. For example:

- increased loading above the retaining wall especially in areas of development
- excavations below and above the retaining wall leading either to undermining of the wall or providing access for water ingress
- the natural processes of weathering and decay resulting in deterioration of wall materials, typically causing loss of strength, which may result in a reduction in stability
- the growth of vegetation causing disruption to stonework.

Maintenance and repair programmes should deal with the root causes and not just the effects of deterioration.

Figure 2.1 ***Greenhill Lane, Micklethwaite, near Keighley, West Yorkshire (courtesy City of Bradford Metropolitan District Council)***

Figure 2.2 ***Greenhill Lane, Micklethwaite, near Keighley, West Yorkshire (courtesy City of Bradford Metropolitan District Council)***

An understanding of asset condition and performance is achieved through continued inspection, assessment and repair or improvement, leading to greater awareness of stability or improvement in asset quality (Figure 2.3). An integral part of this process is the management of asset data and the provision of information links between inspections and planning.

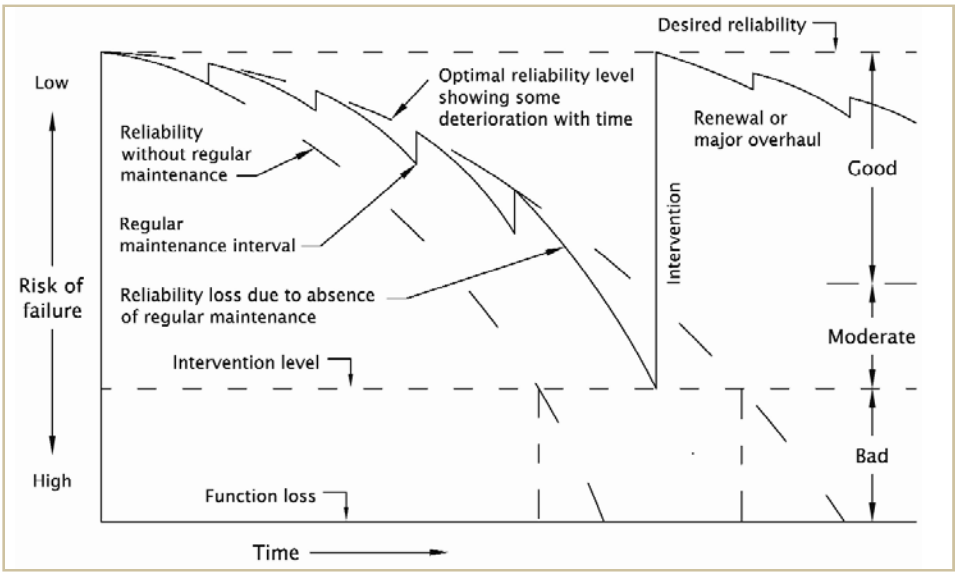


Figure 2.3 ***Relationship of serviceable life, performance and maintenance interventions (after Patterson and Perry, 1998) (courtesy Highways Agency, Mott MacDonald)***

The stock of drystone retaining walls is a huge capital asset and should be protected. The benefits of developing effective ways of dealing with the special requirements for its preservation are likely to be considerable and cost-effective.

2.2 Special requirements

When compared to other elements of the transport infrastructure, there are several features and characteristics of drystone retaining walls that require special consideration in their management:

- they are a traditional form of construction and have particular maintenance and repair needs that differ from those of modern structures
- they are often individual even unique in their character, behaviour and maintenance needs
- by their very nature these walls are flexible. Movement and bulging may not be an indication of an unstable condition. Unstable bulging may be difficult to determine
- typically information is lacking of their dimensions, construction, backfill etc
- drystone retaining walls were constructed on boundaries or have been built by adjacent landowners. In some cases drystone walls maintained by infrastructure owners are located on private property beyond the infrastructure boundary. Ownership, of the wall should it need maintenance to ensure integrity, can be complicated. The *Management of highway structures. A code of practice* (DfT, 2005) provides guidance on this issue, especially in Appendix C
- inspection is generally limited to the facing, and it is difficult to get reliable information about what lies behind this
- the effectiveness of repairs and alterations and their likely influence on the long-term performance and maintenance of the structure are not well understood.

2.3 Managing drystone wall maintenance

The maintenance of a retaining wall can be defined as all the operations necessary to preserve the existing asset and maintain it in a serviceable condition until the end of its life. These include:

- condition appraisal (inspections, testing and monitoring, structural assessments)
- routine maintenance (minor works to maintain efficient functioning and preserve condition)
- essential maintenance (structural repairs and rehabilitation)
- emergency actions (eg in response to unforeseen incidents or accidental damage).

It is necessary for asset managers to develop effective and efficient management strategies that ensure the retaining wall's fitness for purpose and remove the need for emergency action, ensuring safety in operation at an adequate level of service. These strategies must also align with the long-term objectives of the infrastructure owner and meet statutory and regulatory requirements. This is achieved by a system of maintenance planning and management for assets, implemented through a formalised system of procedures. These allow the asset manager to identify the maintenance needs of the asset stock as a whole, and of individual structures, and to develop and justify suitable maintenance plans to address these both system-wide and at the level of individual walls. This information is included in the asset management plan, which documents management objectives for the assets and sets out a clear strategy for achieving them.

2.3.1 Appraisal of current condition, performance and serviceability

To ascertain maintenance requirements it is necessary to gather, periodically update and evaluate information relating to performance and condition of a retaining wall by a process of condition appraisal (see Figure 2.4). Using this information, current performance and condition is assessed against serviceability criteria that are assigned by the asset owner. These criteria will include standards for safety as well as structural and operational performance and will vary according to the infrastructure type and owner policies and objectives. The results of the appraisal are used to assess the overall condition and identify any changes or trends, to plan routine maintenance to preserve wall condition, to introduce mitigation measures, and to trigger reactive repairs to correct unacceptable performance where a wall is not considered serviceable.

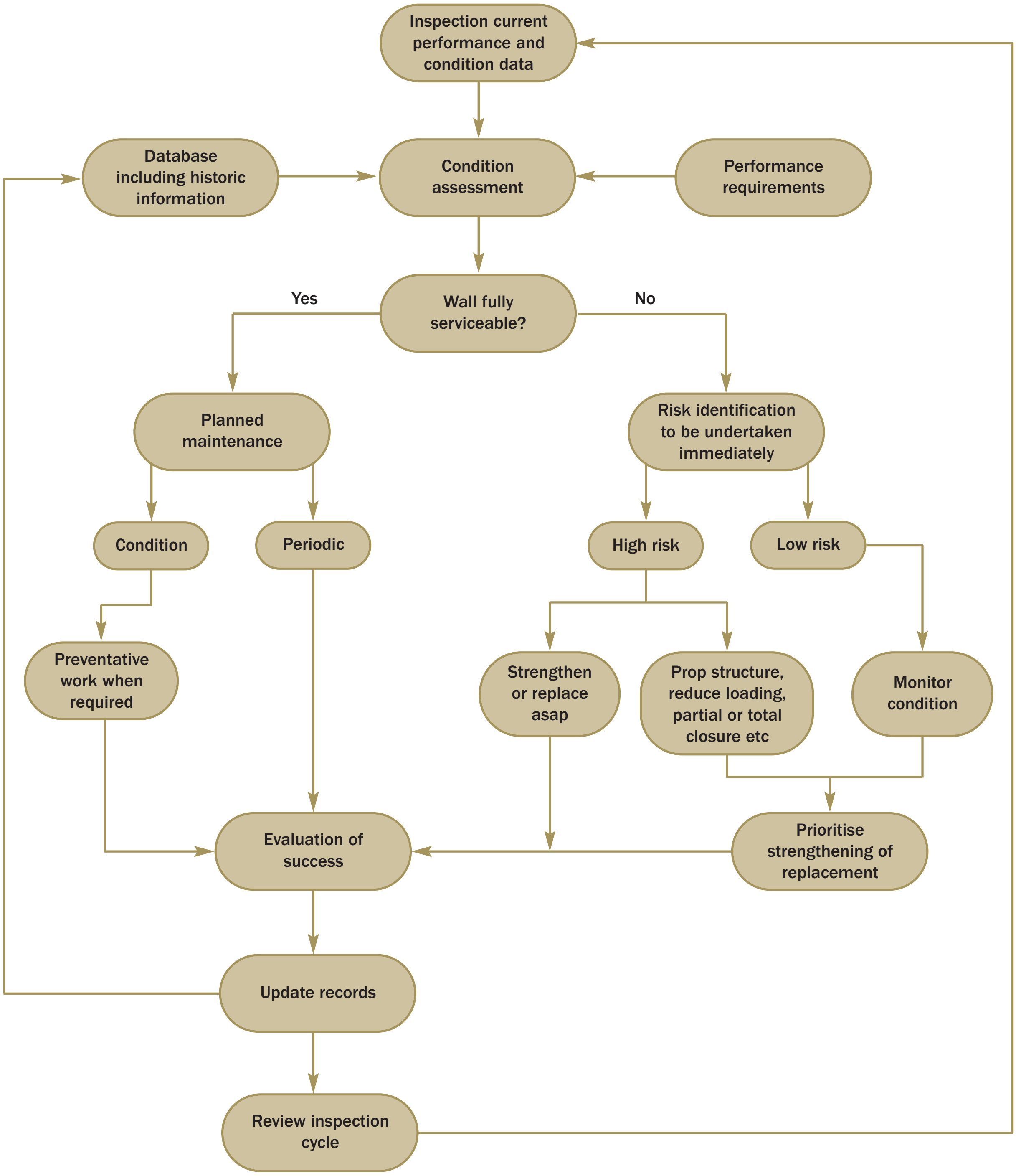


Figure 2.4 ***Maintenance interventions in response to the results of condition appraisal***

This information forms the basis for assessing the retaining wall's maintenance requirements and determining appropriate management actions, for example:

- adequacy of the existing routine maintenance regime and the possible consequences of the lack of such a regime or of it proving inadequate
- extra routine maintenance requirements
- changes in interval between inspections of retaining walls
- requirements for extra inspections and their objectives
- need for structural assessment
- essential maintenance requirements
- requirements for safety measures (restrictions on usage, introduction of traffic lights, regular inspection and monitoring).

The interval between inspections is related to the perceived degree of risk and the possible consequences. In addition to routine/planned inspections, certain observations and incidents may lead to special investigation of a retaining wall's condition and performance being required. This might involve a decrease in the interval between visual inspections, and carrying out specific investigations involving a variety of testing and monitoring techniques to assess the structural condition of the wall, the nature and cause of any defects, their extent and their potential rate of deterioration. This information is then used to compare performance with the requirements of safety and serviceability, determine the optimal management strategy and assess the need for maintenance and remedial works.

Where intervention is required, this involves implementing:

- routine maintenance works (periodic, often cyclic, maintenance tasks to repair minor defects and slow future deterioration)
- essential works (repair and rehabilitation).

2.3.2 Maintenance strategies

The maintenance strategy of serviceable retaining walls can be planned (proactive) or reactive or even a combination of the two: with the latter approach preferably being used on less important routes, where risks are low and disruption caused will be restricted. Both depend on knowledge of current condition, typically obtained by periodic inspection, and an assessment of performance against requirements.

Planned maintenance

Planned maintenance (see Figure 2.4) can be subdivided into two types:

1. **Periodic maintenance** is carried out regularly at predetermined intervals of time (eg quarterly, annually and biennially). It is suitable where maintenance requirements are relatively regular and foreseeable, or where condition-based maintenance is not possible. The maintenance period is important because if it is set too short it can result in unnecessary work and wasted resources. If it is set too long then serviceability, and sometimes safety, may fall below acceptable standards. Once sufficient experience and information has been gained, maintenance periods may be optimised. This is the most common form of maintenance of civil engineering structures and allows easy planning but may be less efficient than condition-based maintenance.

2 **Condition-based maintenance** aims to provide maintenance when needed so that intervention is always at the appropriate time and resources are not wasted. It is potentially the most suitable method for maintaining retaining wall structures. However, it requires a good knowledge of the current condition, the consequence of loss of performance and an adequate understanding of performance and deterioration so as to be able to define suitable, measurable triggers for activating maintenance interventions. Condition checking is typically carried out by regular inspections to identify visible evidence of loss of performance at an early stage, allowing problems to be dealt with before they start to affect safety and serviceability. The principal limitation of this approach is that it depends upon identifying and responding appropriately to detectable criteria. This works better for more obvious defects such as deformation, cracking, spalling and bulging, which are all clearly visible but less well for those that do not show visible symptoms such as stone deterioration behind the face and the onset of impeded drainage.

As condition appraisal continues, covering cycles of planned maintenance, unserviceable walls will become apparent as the asset ages or as part of removing a backlog. A risk-based approach is then accepted to ensure safety and value for money.

Reactive maintenance

Reactive maintenance consists of carrying out corrective remedial works without condition appraisal, often in combination with interim mitigation measures, once loss of performance has occurred and when there is little assessment of prevention (a separate response to Figure 2.4). It is not an economical or sustainable policy for long-term stewardship of major assets. It has many potential drawbacks compared to planned maintenance:

- there is a greater risk to operational efficiency and safety
- it is not possible to budget or plan for maintenance
- maintenance is likely to be more disruptive and costly
- it can allow deterioration to spread more widely. The asset condition worsens and maintenance demand is increased in the long-term.

Interim mitigation measures are of two types:

- those that reduce the loads applied to the structure
- those that improve the strength of the structure.

The former restrict traffic loading and can lead to partial or complete closure of the structure. The latter includes the use of suitable propping such as concrete blocks, gabions or sandbags to improve the strength of the structure.

Although planned maintenance can reduce the need for reactive maintenance, it is unlikely that in the case of drystone retaining walls it can be cut altogether.

Dealing with episodes of reactive maintenance is usually expensive and disruptive to the users of the adjacent transport structure. The best results are obtained when maintenance work is properly planned and prioritised in advance. This approach provides a greater margin of safety against failure and should minimise the need to resort to emergency or unforeseen action to prevent collapse or otherwise cope with unsafe conditions.

2.3.3 Maintenance planning and prioritisation

Resources for maintenance can be limited, so to ensure high-level performance requirements are met, infrastructure owners and operators need to identify the areas of their network routes and the structural assets that are most critical, to ensure safe and efficient operation. Top-level prioritisation is often considered on a route-by-route basis, the most critical routes being given a high priority for management attention. Within a route, individual elements of the infrastructure should be assessed to assist with prioritisation of maintenance needs. Criteria for prioritisation will normally include:

- level of risk
- retaining wall condition
- consequences of substandard performance and failure
- importance of route
- minimisation of maintenance costs
- environmental considerations
- budgetary constraints.

A risk-based approach can be used to identify and rank the more critical structures and to achieve optimum use of resources.

The frequency and scope of maintenance intervention will depend on the desired level of performance of the structure. In service, deterioration results in a gradual loss of performance over time. This translates into an increasing loss of reliability and risk of failure until the full service life is reached and major rehabilitation or renewal is required. Maintenance interventions are carried out to meet or to prolong the service life and keep performance and reliability at acceptable levels.

The optimal maintenance strategy will be one that provides the desired level of performance over the longest period in the most economical way. This will vary according to the policy of the infrastructure owner, the drystone retaining wall type and the specific characteristics of the actual drystone retaining wall.

There is good justification for expenditure on a programme of regular planned maintenance to keep the structure at a safe margin above the intervention level and defer the requirement for more major rehabilitation works.

2.4 Safety and environmental management

Guidance on legislation is given in CIRIA C592 (Perry *et al*, 2003) and C656 (McKibbins *et al*, 2006). All the operations carried out to preserve the stock of drystone retaining walls and their modifications must be undertaken in accordance with current statutory and owner requirements.

2.4.1 Health and safety management

Carrying out maintenance, repair, refurbishment and reconstruction works on the transport infrastructure create hazards that can put the workforce and the general public at risk. Also property and the environment can be endangered and there are the usual problems associated with the use of plant and equipment. All the potential risks associated with any work must be identified in advance and carefully managed so far as is reasonably practicable to reduce them to an acceptable level and to comply with statutory requirements and current CDM regulations. Industry guidance and standards are available to assist in complying with these requirements (Health and Safety Executive, 2007). Note that such publications will not reflect changes made to legislation and industry practice since their publication or most recent revision.

The question of ownership of the retaining wall can be a problem, but the consequences of failure can be critical. For example, a highway authority has a duty to provide safe passage to the travelling public, but another body may own an adjacent unsafe retaining wall supporting the road or land above it. The party or parties responsible for the wall in terms of safety and monetary control need to be identified.

2.4.2 Heritage conservation

The authorities listed below have a general duty to preserve and rebuild the nation's built heritage.

English Heritage

Historic Scotland

Northern Ireland Environment Agency

CADW (The Historic Environment Service of the Welsh Assembly government).

Work on retaining walls that have historic value and those within areas of outstanding natural beauty (AONB) and similar will often have special requirements applied to them. This will require consultation and co-operation with the organisations listed above. Drystone retaining walls will be afforded protection under a variety of designations of the land on which they are sited, for instance as a Conservation Area, Site of Special Scientific Interest (SSSI), Special Area for Conservation (SAC) or National Parks.

2.4.3 Environmental and wildlife conservation

There are various categories of environmental and conservation designations (both statutory and non-statutory) from an international, national, regional or local level that can be applied to sites, which can affect areas surrounding, adjacent to or within drystone retaining walls. The statutory designations afford varying levels of protection and carry with them restrictions on the types of activities that can take place, which are likely to have a significant influence on any works undertaken. These stipulate the steps that must be taken from the very outset, to notify the relevant authorities and to obtain permission to undertake any work on retaining walls. Such restrictions may have significant effect on the type and method of working and on the programming and cost of the works. For example:

- under the Wildlife and Countryside Act 1981, operations on SSSI must be agreed with the appropriate Statutory Nature Conservation Organisation (SNCO), and species listed as protected must not be deliberately killed or injured or disturbed or have their habitat damaged. Special considerations must be given to any work on such sites to minimise disruption to habitats and employ environmentally friendly methods of working
- under the Habitat Regulations 1994 and (NI) 1995, SNCOs can permanently stop operations that they consider may damage SAC or Special Protection Area (SPA) designated sites.

Newton *et al* (2005) provide comprehensive guidance on working with wildlife on site.

Environmental aspects to be considered in management and maintenance of retaining walls include:

Authorities have also to consider the influence of environmental factors on the timing of any works and of any cost escalation.

- air pollution
- noise pollution
- water pollution
- soil and waste
- discharge of water from the retaining wall drainage system
- visual effects
- land-use
- flora and fauna, particularly rare and endangered species
- consumption of limited resources (materials, energy).

In extreme cases the works may need to be classified as emergency works to ensure safety. The environmental effects may need to be considered and managed so that people are not in danger of being injured or killed.

Efforts are being made to develop methodologies for assessing and comparing the real environmental effects of alternative infrastructure management policies. A good example of such an approach is given in Steele (2004) where a life cycle analysis (LCA) approach has been applied to the management of brick arch bridges.

2.5 Drystone retaining wall information requirements

Comprehensive knowledge of an asset is fundamental to its effective management. Asset owners should make efforts to collect and collate all existing information on their assets, and to store this information safely in a form in which it can be accessed by those who might need it – including asset managers, engineers, consultants, maintenance staff and repair contractors. An inventory should be established and managed as an essential element of the management process.

A structures management system (SMS) comprises a framework that allows efficient organisation of maintenance, including activities such as information management, condition appraisal and maintenance and repair planning, and which can be used to inform, guide and support management decisions. A SMS would include all structures and also significant drystone retaining walls would be included. In it information on individual structures would be stored so that engineering and economic assessments can be undertaken. When effectively implemented, it can be a powerful tool for owners, providing assistance with implementing organisational policy, adhering to statutory requirements, making, recording and justifying management decisions, determining the best use of limited resources, and formulating and presenting business cases for obtaining funding. The various types of data collected are collated in a database, where they are stored in a useable and easily accessible format. This data forms the heart of the management system, and can be manipulated and interrogated to provide specific information required for the analysis of individual retaining walls or for all or part of the total stock of retaining walls.

Major asset owners are likely to have their own customised asset management systems to suit their particular needs. Also, several proprietary software-based systems are available, but off-the-shelf solutions may not be the most suitable unless they can adapt to specific needs. Careful consideration is needed before making such a significant and possibly long-term commitment.

Note that even the most sophisticated management systems rely on the quality and reliability of the data input. Inadequate or inaccurate data can lead to poor management decisions, whereas good quality data allows more effective and efficient management of the wall stock. So the calibre and experience of the staff using these systems is important.

It is essential that a unique number or code identifies all assets and sub-assets, ideally with number or code plates attached directly to the asset for ease of identification on site. The unique identifier of walls usually includes their location and aspect. This identifier then relates to records in the SMS. In many types of infrastructure systems for longitudinal measurement (along railway lines, pipelines, canals, major roads etc) are already in place and can be used for this purpose. However, it is also necessary to accurately record the location of features along the retaining wall.

2.6 Whole-life asset costs

In new construction, whole-life costing (WLC) provides a rational basis for decision-making, allowing comparison of a variety of alternative construction schemes and aiding the selection of one that is most economical or appropriate to the current or expected financial position. For new structures a suitable design life may be specified that will allow replacement/refurbishment in a planned manner and provide a basis for making decisions on the optimum timing and extent of maintenance works. Similar principles can be applied to the maintenance of existing structures to assist with comparison of alternative maintenance and repair strategies. However it is more difficult to set up a reliable model, particularly where structures are expected to have a long life, and the associated uncertainty of expenditure spent over the structures life time. Also there is a need to consider the specific infrastructure requirements, which will tend to dominate the maintenance costs. For example, if rail possessions or traffic management are required, the cost of these should be added in the consideration of the relative merits/costs of maintenance/repair methods.

Despite these challenges, whole-life costing represents a rational approach to evaluating alternative maintenance and repair strategies and can provide a useful framework for considering these complex issues so long as its limitations are recognised. Note that in any cost/benefit or similar analysis the cost of the existing retaining wall is zero but its value is replacement cost less the discounted expenditure for any maintenance and repairs.

Further information on asset management can be found in CIRIA C592 (Perry *et al*, 2003) and C656 (McKibbins *et al*, 2006).