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Geotechnical considerations and techniques for widening highway earthworks

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Foreword

Most of the work on which this report is based was carried out by Arup (Alan Phear - lead author, Savina Carluccio, Samantha Godden and Jane Collins), Mouchel (David Morrow) and the Transport Research Laboratory (Derek Carder) for the Safety Standards and Research division of Highways England.

Figures included in Appendix A were provided by Gifford. Tables 6.1a to d have been developed with original input provided by Birse Civils Ltd.

We would like to thank all team members at Arup, Mouchel and Highways England for assistance with the final edits and publishing of the document.

Contents

1 INTRODUCTION

1.1 This report discusses the geotechnical aspects of widening highway earthworks, both in terms of continuous lane widening and alternatives such as Smart Motorways – All Lane Running (SM-ALR), previously known as Managed Motorways or Active Traffic Management, which incorporate short widened sections.

1.2 Highways England will need to provide increased capacity through provision of additional lanes or ALR to the most heavily congested routes in order to deliver its strategic objectives (Highways England Delivery Plan 2015-2020). Many of these roads are in urban areas or adjacent to development, where public enquiries would be needed to acquire any additional land. To avoid delaying the programme, new traffic lanes and other infrastructure will instead need to be provided within the existing highway boundary.

1.3 Where the existing carriageway is on embankment or in cutting, the earthworks platform must be extended to create additional space. This report describes a number of ways to achieve this, including steepening the side slopes of embankments or cuttings, using strengthened earthworks techniques and different types of retaining structures.

1.4 For any particular scheme only some of the widening methods described may be appropriate. However, a wide a range of solutions should be reviewed to make sure that the most appropriate technical and economic solution is adopted for each particular case. Existing and proposed landscaping and land access will also need to be considered in this review.

1.5 Other important aspects that will influence the choice of widening solutions are constructability, whole life cycle cost including maintenance regimes and interaction with other assets, particularly drainage.

1.6 This report is a collection of good practice and it is meant to help with the selection of options for widening schemes. However, alternative solutions and innovative thinking are encouraged.

2 SCOPE

2.1 This report is issued to provide guidance on good practice to engineers responsible for the design of geotechnical and associated aspects of widening highway earthworks, particularly motorway widening schemes. It describes some of the factors which may influence slope stability and gives information on some available methods. **It should be noted that this report is not a design guide. Other Departmental Standards and Advice Notes are referenced in this document and should be used where appropriate.**

2.2 The sections of this report address subjects as listed below:

- Section 3 General considerations
- Section 4 Drainage
- Section 5 Ground investigations for widening earthworks
- Section 6 Widening methods
- Section 7 Specific considerations for Smart Motorways
- Section 8 Construction and maintenance aspects
- Section 9 Acknowledgements
- Section 10 References

2.3 This document directs the reader to relevant references for further reading. It should be noted that references to standards in the text have not included dates, hence reference to the current version of a standard should be made independently of this document.

3 GENERAL CONSIDERATIONS

3.1 As for all highway improvement schemes involving geotechnical activities, scheme designers should follow the requirements of standard HD 22 'Managing geotechnical risk'. HD 22 sets out procedures to ensure that geotechnical risks are identified, reported and managed over the lifetime of the scheme, via a sequence of certified reports as listed below. A Geotechnical Risk Register is compiled to document this process, and is updated, as necessary, throughout the project lifecycle from concept to handover.

a. Statement of Intent (SOI): sets out overall geotechnical strategy

b. Preliminary Sources Study Report (PSSR): documents all existing information

c. Ground Investigation Report (GIR): interpretation of any ground investigations

d. Geotechnical Design Report (GDR): documents design basis and decisions

e. Geotechnical Feedback Report (GFR): records the construction process and as-built information

3.2 Highways England maintains a digital archive of most of the existing ground data and reports related to the original construction and subsequent upgrades of the motorway and trunk road networks in England. It contains geo-referenced information for the highway network such as geotechnical reports, geological mapping, borehole records, and geotechnical feedback reports. Information on natural and man-made hazards, the condition of the earthworks, events and records of inspections and maintenance works is also part of the asset knowledge base contained in the digital archive. This is a primary information source for preparing the PSSR.

3.3 A physical assessment of the condition of the existing earthworks (walkover survey) should be undertaken to assess the general condition of the slope, slope drainage, vegetation, signs of distress etc., as reliance on existing records alone may be inadequate. On schemes where access for ground investigation may be difficult or delayed, site walkovers are important in understanding the existing conditions, constraints and hazards at an early stage. The stability of both existing and widened earthworks should be assessed. The scope of any additional ground investigation should then be defined in Annex A of the PSSR: This will need to be tailored to the methods likely to be used for widening, see Section 5 for more details.

3.4 Good fence-to-fence topographical survey information is essential to understand the existing earthworks profile and establish where widening is needed and to ascertain the potential height of retaining structures. This should be acquired early in the scheme design process and include appropriate aerial LiDAR surveys which may be combined with foot-based (traditional) surveys and vehicle-borne LiDAR. The surveys may need to be programmed to take advantage of low leaf cover in the winter months and specified to ensure the actual ground profile is detected.

3.5 Figure 3.1 presents an example decision tree for initial selection of earthworks widening solutions. The hierarchy of solutions progresses from minimum cost and low impact on programme to high cost and major impact on programme. Further examples of detailed design decision trees for cuttings and embankments on the M1 Widening Junctions 25 to 28 scheme are presented in Appendix A. They are a useful example of how, in the real world, project-specific requirements and constraints have a substantial influence on the selection of the preferred widening solution.

The following sections describe some of the common issues that are likely to be encountered in a widening scheme for different situations. Diagrams summarising some of the constraints for cuttings and embankments are also presented in Figure 3.2.

3.6 Note on the use of earth retaining and reinforced soil structures

Earth retaining walls and reinforced/strengthened soil/fill structure with hard facings where the design retained height is greater than 1.5m (1.0m in Northern Ireland) require BD 2 technical approval along with HD 22 certification. This also applies to reinforced/strengthened soil/fill which is an integral part of another highway structure.

Existing earthworks wide enough

3.7 Even where the existing earthworks are wide enough to accommodate the additional pavement required, the following points will still need to be considered:

a. Moving the edge of the carriageway closer to the toe of a rock cutting may increase the risk of rock slope instability affecting the highway operations. In this situation, the following techniques may be used:

   i. the provision of a combined debris catcher unit and surface water channel at the toe of cutting slopes (Milnes et al, 1989)

   ii. the provision of a large edge beam or verge wall at the back of the hard shoulder below cutting slopes (Stapleton and Whitfield, 1990)

b. If the existing earthwork (e.g., embankment) contains defects or at-risk features, the imposition of additional traffic loads on the crest of the slope may exacerbate stability issues or increase the risk of failures. In such cases it may be necessary to carry out remedial works prior to or concurrent with widening works. Possible techniques include the following:

   i. replacement of local failed material or soft spots with granular materials or lime stabilised material

   ii. use of soil nailing (see Section 6.5), geotextile or geogrids reinforced soil repair techniques (Johnson (1985) and Murray et al (1982)

   iii. use of deep counterfort drains or geotextile reinforced granular buttresses (Johnson (1985), Milnes et al (1989) and Greenwood et al (1985)), or the use of slope drains (Section 6.3)

iv. in situ mass improvement e.g., lime, chemical or electro kinetic stabilisation

c. Particular attention to the problems in (b) will be required when the hard shoulder is to be used as a running lane during construction work, and/or in the permanent condition as part of a smart motorway with a dynamic hard shoulder (see Section 7).

Existing earthworks not wide enough

3.8 Where the existing earthworks are not sufficiently wide to accommodate the additional lanes required, the following points will need to be considered:

a. If the condition of the earthwork gives rise to concern for stability, the problem will only be exacerbated by adding material at the top of an embankment or removing material from the toe of a cutting. Repair or strengthening of the existing embankment or cutting should be incorporated into the widening process.

b. Potential problems identified in the original site investigation such as faults, deep seated slips, natural or man-made cavities, filled ground, subsidence etc. may need to be addressed in the design of any extended earthworks.

c. The presence of organic layers, soft ground or other difficult ground conditions in the foundation of the existing embankment or in the base of the existing cutting will need assessment. Any special engineering measures taken in the original design to overcome these problems need to be incorporated in the widening process. These might include soil improvement or reinforcement, additional drainage to improve consolidation and stability, or other methods of reducing settlement and increasing stability.

d. The alignment geometry needs careful review as minor changes during the design process can change the preferred widening technique.

e Potential ground contamination associated with some old embankment and false cuttings, (e.g. colliery spoils) and likely associated environmental liabilities and disposal costs. Appropriate designs that minimise excavation of such materials or encourage use to suitable in situ improvement, use of products, e.g. glass fibre–reinforced polymer (GFRP) nails to resist aggressive ground can mitigate this impact.

Widening of existing embankments

3.9 In this situation, consideration should be given to the following aspects (see Figure 3.2 (a)):

a. The need to bench in the new works to the existing embankment in such a manner that the contact between them does not generate a plane of weakness.

b. The effects of construction and compaction of new works on the stability of or risk of causing extra settlement to the existing embankment.

c. Differential settlements and associated shear stresses may occur as the new works consolidate at a higher rate than any residual consolidation in the original embankment. The effects of differential settlement will also need to be carefully considered in the design of the transition between the existing and the new pavement and on the existing services.

d. Earthworks incorporating some types of reinforcement and soil nailing may undergo significant lateral expansion during and immediately after construction. This should be allowed for before constructing the pavement and drainage system.

3. A stability assessment needs to be included as part of the design process.

Widening of existing cuttings

3.10 In this situation, the following considerations should be made (See Figure 3.2 (b)):

a. The influence of rock discontinuities and their properties on the stability of steepened rock slopes, depending on the relative discontinuity orientations with respect to the cutting face. Further information is contained in Wyllie (2004) and Simons et al (2001).

b. The potential need to meet current requirements for sight lines when widening older motorways and trunk roads, as discussed in Standard TD 9.

c. Old earthworks may have undergone excessive deformation and if so, may have reached their residual strength.

d. A stability assessment needs to be included as part of the design process.

At-grade widening

3.11 For at-grade widening the following aspects should be considered:

a. The possible need for additional land take where widening is required, as the highway boundary is often close to the back of the verge where the road is at grade.

b. Transition details both longitudinally (e.g. the cut /fill transition between a cutting and an embankment) and transversely (i.e. between existing pavement and new pavement).

c. Differential movements if there is variable vegetation density adjacent to the existing carriageway.

e. Requirement for drainage crossfalls to be maintained for the widened section.

3.12 For all situations, the following constructability aspects are relevant:

a. The potential effects of construction on existing assets within and/or adjacent to the earthwork and on other adjacent features such as canals, railways. rivers etc.

b. The relative volumes of cut and fill likely to be generated by the widening methods adopted, although this may be difficult to balance in on-line widening schemes and may require costly double handling of material.

c. The cost of traffic management during road widening will usually be substantial and will be a major factor in the choice of method and programme.

d. Where geotextiles or related products, or soil nails are used to strengthen the earthwork, care should be taken to ensure that they are not damaged by the subsequent installation of safety fence posts, sign and lighting columns, cables and trenches, or by subsequent planting or maintenance work. The potential conflict between edge of pavement drains, which extend below the underside of capping, and the upper layers of reinforcement or nails will also need to be considered.

e. The need to achieve adequate foundation support for verge-mounted Road Restraint Systems defined in Standard TD 19 to ensure their fitness for purpose.

f. Existing drainage at the toe of embankments and the toe and crest of cuttings, see also Section 4.

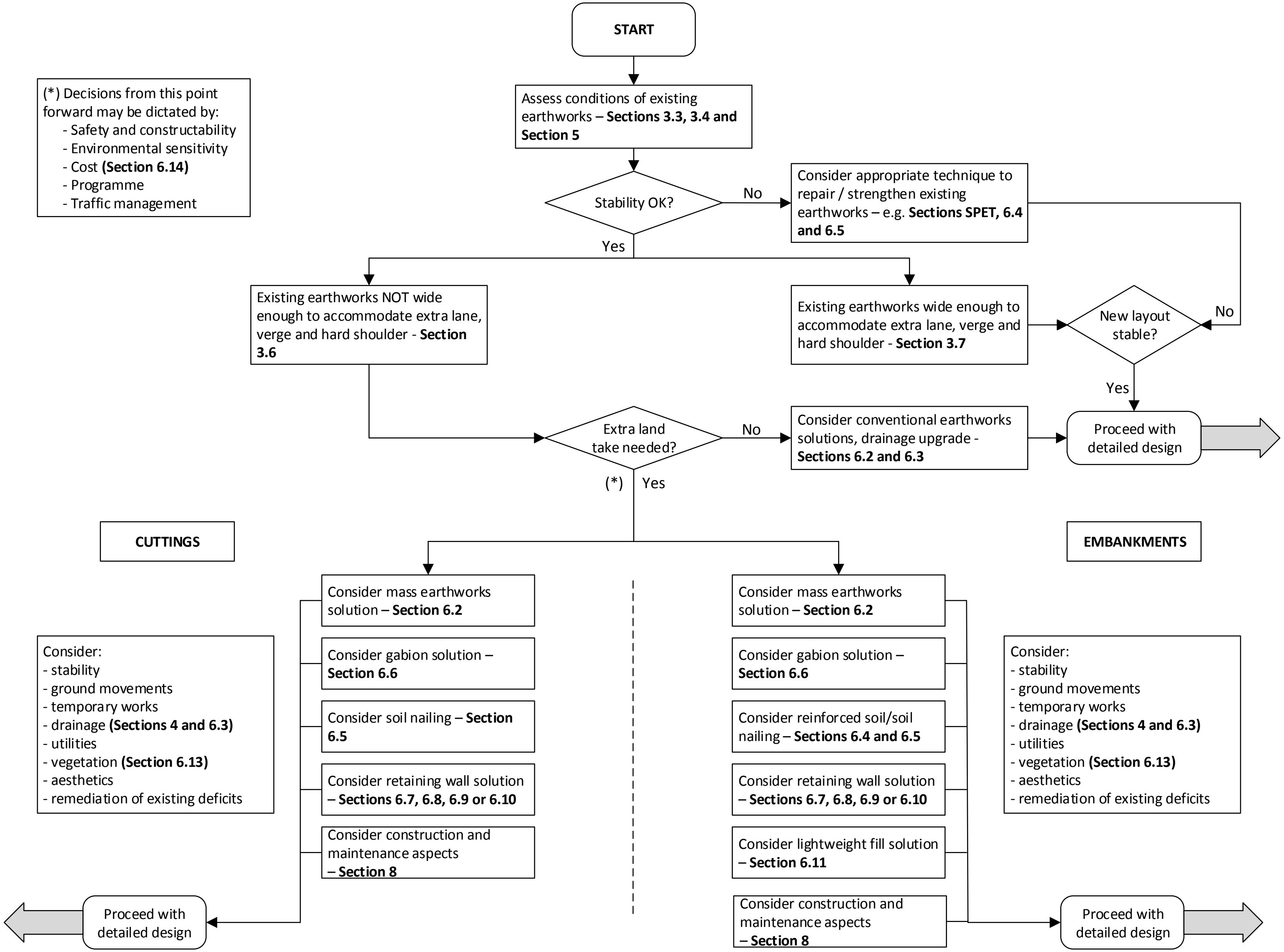
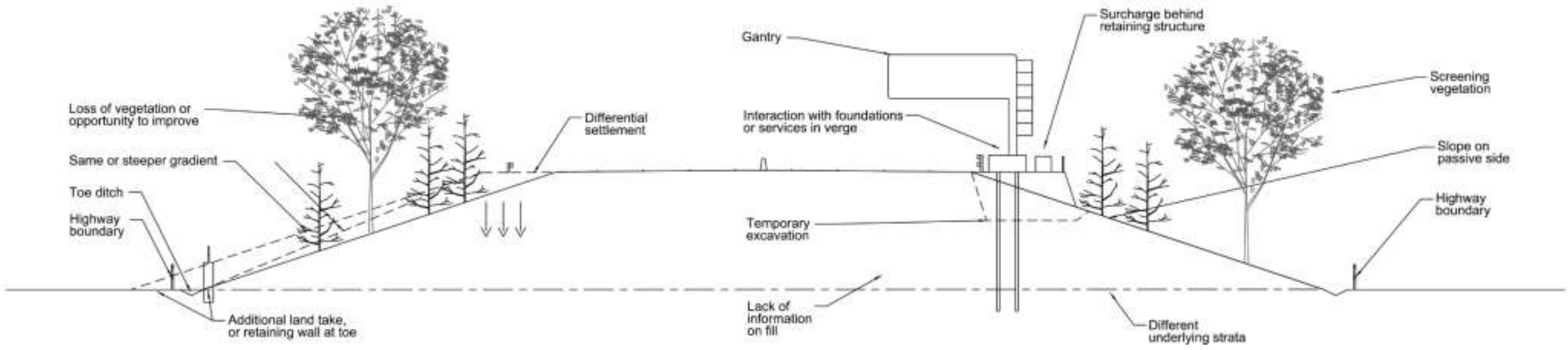
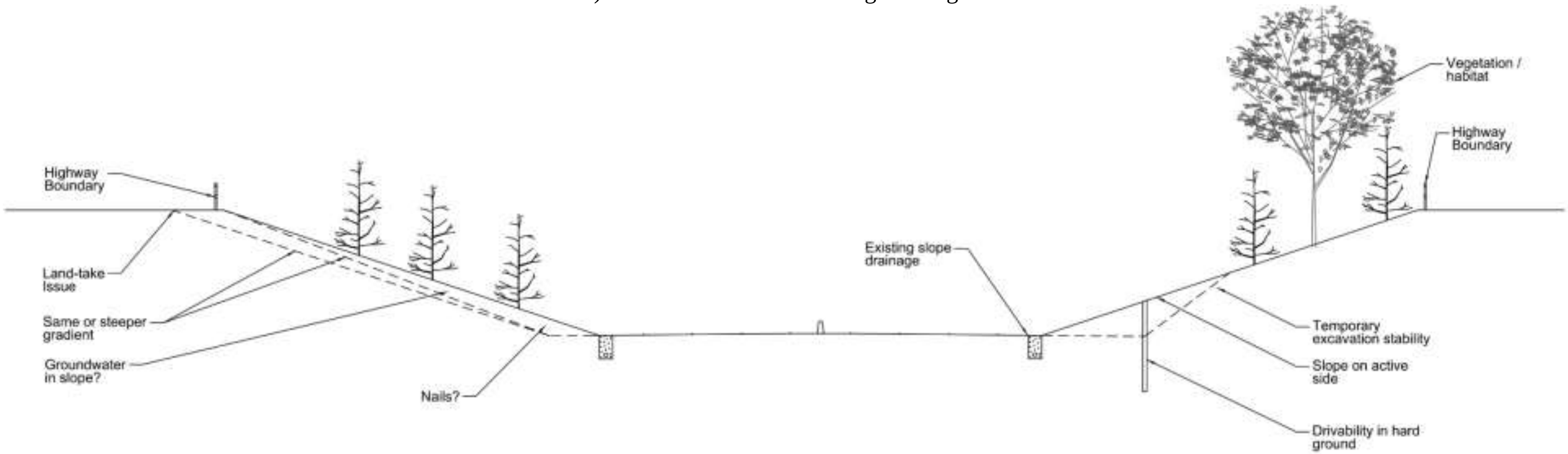


Figure 3.1 – Schematic decision tree for embankments and cuttings



a) Considerations on widening existing embankments



b) Considerations on widening existing cuttings

Figure 3.2 - Diagrams of conventional earthworks solution

4 DRAINAGE

4.1 Earthworks widening must take account of any existing slope drainage, crest or toe ditches as well as interfacing with the main carriageway drainage located in the verge. It may be possible in some circumstances to incorporate the existing drainage of the sub-base and existing drains at the toe of the embankment, or at the top of cuttings, into the new design.

4.2 In many cases, the existing drainage will need to be replaced, for example at the edge of the pavement, where combined filter and surface water drains are no longer the preferred solution. Renewed drainage may need to be sized to take account of potential climate change, which may lead to larger pipes and chambers than the existing network. Advice on edge of pavement details is given in Advice Note HA 39 and standard details are shown in the Highway Construction Details.

4.3 Where the edge of pavement drain is to be replaced, it is important to ensure that the existing drain does not act as a permeable reservoir for water to enter the sub-base, subgrade or ground outside the carriageway which may be de-stabilised by water (e.g. a slope). This can be achieved by either removing the original drain completely or introducing positive drainage from the bottom of the original drain to the new drainage system. Where the pavement is widened, the capping and sub-base construction of the extended pavement should not impede the drainage of the existing sub-base and/or capping and vice versa.

4.4 Drainage must be maintained at all times and the possible consequences of prolonged heavy rainfall or rapid thaw during reconstruction must be allowed for. The specification for sub-base and capping materials will also need to take account of this requirement.

4.5 Temporary drainage measures may therefore be required during the works as well as temporary connections to ensure that the adjacent permanent drainage continues to function.

4.6 Metallic elements such as reinforcements or nails are particularly susceptible to chloride attack. Therefore, surface run-off water and groundwater contaminated by de-icing salts must not be allowed to percolate into areas where these are used. Alternatively, products that resist chloride attack may be specified. For further information on this and other durability issues refer to HA Standard BD 12.

4.7 Drainage works are one of several elements that need to be co-ordinated in the restricted verge space. A multidisciplinary design approach should be followed to avoid clashes and make best use of the space available. During construction, temporary over-excavation for installing drainage may cut into the proposed final profile of a soil nailed slope, which would then need to be backfilled. The order of site operations must be managed to avoid this kind of interface. (See also Section 6.5 and Section 8).

5 GROUND INVESTIGATION FOR WIDENING OF HIGHWAY EARTHWORKS

5.1 As discussed in Section 3.1, geotechnical risks should be managed in line with the principles set out in the Standard HD 22 and in accordance with the Eurocodes (BS EN 1997-1 and 1997-2). However, the particular circumstances of widening existing roads must be taken into account in this process.

5.2 A key factor for highway widening schemes is that most ground investigations (GIs) and other surveys will be carried out on the verge of the existing road, where the widening works will be. These investigations will normally be carried out under temporary traffic management (TTM), with associated safety risks from the live traffic. The logistics of accessing these locations may limit the scope of the investigations. A balance needs to be found between acquiring information to de-risk and inform the design, and minimising exposure of the workforce to a high risk environment.

5.3 HD 22 sets out the process by which the management of geotechnical risk is undertaken and documented through the project life cycle. Determining the requirements for additional ground investigation is part of this process. For highway widening schemes, it is likely that there is existing ground investigation data and this should be collected and reviewed as part of the PSSR. The requirement for additional ground investigation should be considered carefully, including type, location and timing, as part of the management of geotechnical risk. Access restrictions are likely to be significant and there are significant safety concerns if working adjacent to a live highway.

5.4 In developing a ground investigation strategy, it may be necessary to restrict GI in the design phase to areas of high geotechnical risk or cost uncertainty only. Areas where investigation is required to assess low risks or for confirmatory information may be better delayed until the early phases of construction when lane closures may be available and access to the site generally is provided as part of the construction works. This will also ensure that the GI addresses the final scheme requirements avoiding abortive (and costly/risky GI) for options that are not taken forward.

5.5 As well as the geotechnical works, the GI strategy should address the logistical and access issues. Dependent on the form of contract adopted, these may be the responsibility of the contractor, the Maintenance Service Provider or Overseeing Organisation, but it is important that the interfaces are well managed. Some common relevant issues are:

a. Works to be programmed, in liaison with the Maintenance Service Provider, to minimise interference with highway operations or planned maintenance and allow time for road space booking.

b. Safe access and working area at all exploratory hole positions, which may involve lifting operations, construction of scaffolding platforms, boarding to soft ground, fencing, night working, safety barrier removal and reinstatement. Working space for each location will need to safely accommodate transport vehicles, welfare, drilling accessories and materials as well as the actual rig or excavator.

c. Traffic management should be planned across the scheme, and will involve multiple establishments to cover all the exploratory hole locations.

d. Access to or across third party land for the investigation, including matters of reinstatement; and for later access to gas/groundwater monitoring instrumentation.

5.6 Early site reconnaissance visits should be made to confirm there is safe and feasible access to each proposed location. This may involve TTM or liaison with local landowners.

5.7 At 1V:3H or steeper, earthworks slopes are often too steep for plant to access without special measures. Exploratory holes may need to be placed at the top and/or bottom of a slope, to investigate both the proposed retaining structure location and the material above or below it. Solutions used on previous projects include:

a. Embankments: exploratory hole positions may be accessed by constructing a scaffold staging to support the rig just behind the safety barrier, with the rig lifted across in an overnight lane closure. Alternatively, special tracked rigs capable of climbing up and working on sloping ground may be used to gain access from the base of the embankment. These rigs need to be safely anchored with winch ropes.

b. Cuttings: with landowner agreement an exploratory hole position may be positioned at the crest of the cutting, just inside the boundary fence but accessed from neighbouring land. Alternatively, slope climbing rigs described above may be employed with appropriate traffic management.

5.8 Many highway earthworks slopes have become significant seasonal wildlife habitats over the years. When planning ground investigations, the Maintenance Service Provider’s Environmental Manager/Co-ordinator should be consulted to ensure that the ecology is considered.

5.9 Ground investigations should include installation of groundwater monitoring standpipes and piezometers, which may include gas/groundwater sampling. Good practice is to monitor installations at monthly intervals for a minimum of twelve months, if the programme permits, to observe any seasonal variations. Instrumentation should be clearly marked and positioned in the safest possible place for future access, ideally where it will not be destroyed by the proposed works. Data loggers are increasingly used to manually or remotely acquire monitoring data. They are economic, reliable and easy to use and they minimise the need for on-road access.

5.10 Production of the factual and interpretative geotechnical reports should be carried out in accordance with the MCDHW, DMRB, British Standards and requirements of HD 22. The geotechnical risks and design objectives should be consistently carried through investigation, laboratory testing, interpretation and reporting, particularly where the form of contract involves a change of design organisation.

5.11 If not already established during the PSSR stage, a digital record should be set up to compile and collate the results from the different stages of the historical and project specific ground investigations, to build up the most complete picture possible of the ground conditions in a way that can be easily handled and communicated. A digital version of the data from the ground investigation should be saved in Highways England's digital archive for future reference, as well as copies of the PSSR, GIR, GDR, and GFR.

Table 5.1. An example of ground investigation scope

Design Element/Risk	Information Required	Typical Investigation Method
Widening of cuttings or embankments	For slope stability analysis and design of retention scheme: Drained/undrained shear strength Groundwater profile Soil profile of full slope height Embankments: properties of fill Cuttings: properties of material for re-use in earthworks	Cuttings: Boreholes from the top of the cutting (adjacent to boundary fence) to extend the full depth of the cutting. Boreholes on the line of the proposed widening solution in the lower part of the cutting. Embankments: Boreholes from the top of the embankment (adjacent to carriageway) to extend the full thickness of fill and the same depth into the underlying natural ground. Probing of soft ground, if any, at toe of embankment. Groundwater monitoring. Depending on geology, combinations of cable percussion and rotary drilling may be needed. Good quality sampling and laboratory testing to obtain shear strength parameters.
Structures (Bridges, Retaining structures, gantries)	Foundation and retaining wall design: Existing structure condition and foundation Soil profile Strength and stiffness parameters Chemical properties for buried concrete/steel	Boreholes, trial pits and inspection pits to investigate existing foundations and allow design and assessment of shallow foundations or piles. Investigations of the structural elements (e.g. concrete coring) may be part of a separate contract but are sometimes combined with ground investigation.
Pavement/ Earthworks design	Formation strength and stiffness Suitability of materials for re-use (likely to be limited)	CBR testing Plate bearing tests (dynamic or static) Earthworks materials testing Trial pits Road cores
Potentially contaminated land	Risk to humans of contact with contaminants effect on construction materials, i.e., degradation/deterioration/loss of strength	Suitable geo-environmental trial pits and boreholes to install gas/contamination monitoring equipment, based on results of PSSR.
Particular site-specific geotechnical risks (examples)	Known slope instability Historical Mining Subsidence Variable or problematic ground	Targeted investigation may use methods mentioned above as well as, where appropriate: Probing and cone penetration testing Geophysical methods Movement instrumentation and monitoring

6 WIDENING METHODS

6.1 Introduction and design considerations

6.1.1 This section describes commonly used earthworks widening and retaining solutions, as well as a selection of new and innovative techniques which may be applied in future on highway schemes. These techniques are applicable both to conventional highway widening/improvement and to Smart Motorway schemes.

6.1.2 The number of different widening solutions should be kept to a minimum within any one contract, for efficient construction. Generally, options that are safe and simple to construct and durable to maintain will be most economical in whole-life cost terms.

6.1.3 Selecting the most appropriate earthworks widening solutions requires a holistic, multi-disciplinary design approach. Inter-disciplinary interfaces may include drainage, lighting, communications, utilities, structures, environmental barriers and landscaping, and should be proactively managed as the design develops. As well as design aspects, the design team should consider:

- initial and whole-life cost, including temporary works
- impact on construction programme and traffic management requirements
- function and performance
- buildability including working space, construction sequence and plant access
- safety in construction and operation
- adjacent utilities and structures
- environmental impact in terms of noise and vibration, as well as vegetation screen retention
- ease of inspection and maintenance, durability
- visual impact / aesthetics

Tables 6.1a to 6.1d below compare these factors for widening of cuttings and embankments and for vegetated (sloping) faces and hard faces, respectively. They were developed from experience on two symmetrical motorway widening schemes and a Managed Motorway scheme. Whilst specific to the conditions of those schemes, they are also generally applicable to highway earthworks widening.

Sections 6.2 to 6.12 on different widening solutions should be read with reference to these tables.

Table 6.1a Comparison of widening options with sloping or vegetated faces for cuttings

Solution	**Comments**							
	Cost	**Programme**	**Traffic Management requirements**	**Buildability**	**Safety**	**Environmental**	**Maintenance**	**Appearance**
Regrade to same slope as existing	Low	quick	Access and egress for muckaway lorries	Simple – no temporary works	Low risk	Large area of temporary disturbance	Reduces width of access near boundary fence	As existing
Regrade to steeper slope than existing	Low	quick	Access and egress for muckaway lorries	It requires stability checks. Simple – no temporary works	Note (1)	Large area of temporary disturbance	Steeper slope	As existing
Regrade to part steeper and part existing	Low	quick	Access and egress for muckaway lorries	Simple – no temporary works	Note (1)	Large area of temporary disturbance	Steeper slope	As existing
Cut to 45 degrees and soil nail – flexible facing with buried nail heads	Low	Can increase number of rigs to speed up process	Nail length needs to be considered so as not to project into traffic lane	Simple – tried & tested. Temporary slope is controlled. Need to check nail length is within land take	Note (2)	Minimises area of temporary disturbance	Nil	Good – can accept green face treatment
Reinforced soil to 45 degrees with topsoil integrated into face	System is cost effective but temporary works cost can be high	Needs reasonable continuous length to be cost effective	Access and egress for muckaway lorries	Simple – but requires temporary works for slope during installation	Note (2)	Temporary works creates larger area of temporary disturbance – may not be able to re-plant trees locally in reinforcement	Nil	Good – can accept green face treatment

Notes (1) Safe operation –may need safety barrier above steep slope (dependent on risk assessment)

(2) Safe operation – needs safety barrier above steep slope. May need safety fence at toe of steep slope too.

Table 6.1b Comparison of widening options with vertical or hard faces for cuttings (1 of 2)

Solution	Comments							
	Cost	**Programme**	**Traffic Management requirements**	**Buildability**	**Safety**	**Environmental**	**Maintenance**	**Appearance**
Sheet piling – plain or faced	Medium	quick	Piling rig and piling frame to be considered	Good	Note (1)	Minimal disturbance except noise during installation	Low	Subjective - could be considered as “ugly” if not faced
Bored piles or H-section piles (king piles) with concrete infill panels – faced	Medium for basic installation – but facing cost can be very high	quick	Piling rig and piling frame to be considered	Good	Note (1)	Large area of temporary disturbance	Low	Needs facing
Soil nails with hard facing	Higher than with green facing	Facing prolongs duration locally – but not affect overall programme	Nail length needs to be considered so as not to project into traffic lane	Simple – tried & tested. Temporary slope is controlled. Need to check nail length is within land take	Note (1)	Minimises area of temporary disturbance	Low	Acceptable
Reinforced soil wall with concrete panels to face	Medium for basic installation – but temporary works cost can be very high	Needs reasonable continuous length to be cost effective	Access and egress for muckaway lorries and craneage for placing facing units	Good	Note (1)	Minimises area of temporary disturbance. Medium sized area of temporal disturbance depending on construction sequence.	Low	Acceptable
Gabions (with rock infill)	Low for basic installation – but temporary works cost can be very high	Reasonable	Only for delivery of materials	Simple	Note (1)	Preferable to use local stone as gabion infill	Low	Subjective – can blend into the landscape if appropriately designed

Note (1) Safe operation – needs safety barrier above vertical or steep face. May also need safety fence at toe of vertical or steep face.

Table 6.1b Comparison of widening options with vertical or hard faces for cuttings (2 of 2)

Solution	**Comments**							
	Cost	**Programme**	**Traffic Management requirements**	**Buildability**	**Safety**	**Environmental**	**Maintenance**	**Appearance**
Masonry blockwork wall	Low	Slow	Low	Only practical for low heights	Note (1)	Little temporary disturbance if low height	Low	Good
Reinforced masonry wall	Low	Slow	Low	Only practical for low and medium heights	Note (1)	Little temporary disturbance if low height	Low	Good
Mass concrete wall – cast in situ	Low	quick	Low	Simple – but temporary works needs consideration	Note (1)	Acceptable	Low	Subjective – better if faced. Graffiti may be a problem
Mass concrete wall – large precast blocks	Low	Quick	Access and egress for delivery and craneage for placing units	Simple – but temporary works needs consideration	Note (1)	Acceptable	Low	Subjective – better if faced. Graffiti may be a problem
In situ reinforced concrete wall	High	Slow	Low	Traditional – but many trades involved	Note (1)	Acceptable	Low	Acceptable. Graffiti may be a problem
Precast reinforced concrete wall	High	Slow	Access and egress for delivery and craneage for placing units	Simple – but temporary works needs consideration	Note (1)	Acceptable	Low	Acceptable. Graffiti may be a problem

Note (1) Safe operation – needs safety barrier above vertical or steep face. May also need safety fence at toe of vertical or steep face.

Table 6.1c Comparison of widening options with sloping or vegetated faces for embankments

Solution	**Comments**							
	Cost	**Programme**	**Traffic Management requirements**	**Buildability**	**Safety**	**Environmental**	**Maintenance**	**Appearance**
Overfill to same slope as existing – bench into existing	Low	quick	Access and egress for muckshifting lorries	Simple – no temporary works	Low risk	Large area of temporary disturbance	Reduces width of access near boundary fence	As existing
Overfill to steeper slope than existing – bench into existing	Low	quick	Access and egress for muckshifting lorries	Simple – no temporary works	May need safety fence above steep slope (dependent on risk assessment)	Large area of temporary disturbance	Steeper slope	As existing
Overfill part of slope to steeper than existing – bench into existing	Low	quick	Access and egress for muckshifting lorries	Simple – no temporary works	May need safety fence above steep slope (dependent on risk assessment)	Large area of temporary disturbance	Steeper slope	As existing
Reinforced soil slope at top of embankment with green face	Low	quick	Low requirement	Good	May need safety fence above steep slope (dependent on risk assessment)	Large area of temporary disturbance	Low	Acceptable
Hybrid fill and soil nails	Low	quick	Nailing rigs / muck shift	Good	May need safety fence	Minimal	Medium	Acceptable

Table 6.1d Comparison of widening options with vertical or hard faces for embankments (1 of 2)

Solution	**Comments**							
	Cost	**Programme**	**Traffic Management requirements**	**Buildability**	**Safety**	**Environmental**	**Maintenance**	**Appearance**
Sheet piling – plain or faced	Medium	quick	Piling rig and piling frame to be considered	Good	Safe operation – needs safety barrier above vertical face	Minimal disturbance except noise during installation	Low	Subjective - could be considered as “ugly” if not faced
Bored piles or H-section piles (king piles) with concrete infill panels – faced	Medium for basic installation – but facing cost can be very high	quick	Piling rig and piling frame to be considered	Good	Safe operation – needs safety barrier above vertical face	Large area of temporary disturbance	Low	Needs facing
Soil nails with hard facing	NOT considered to be a practical solution for embankment widening							
Reinforced soil wall with concrete panels to face	Medium for basic installation – but cost of temporary works (supporting excavation against road and services, etc.) can be very high. Requires continuous length to be cost effective	quick	Access and egress for muckaway lorries and craneage for placing facing units	Good	Safe operation – needs safety barrier above vertical or steep face	Minimises area of temporary disturbance. May require overdig for width of grids.	Low	Acceptable
Gabions (with rock infill)	Low for basic installation – but temporary works cost can be very high	Medium (although can be slow for long lengths)	Only for delivery of materials	Simple	Needs safety barrier above vertical or steep face. Risks associated with: manual handling; long duration on the network.	Preferable to use local stone as gabion infill,	Low	Subjective – can blend into the landscape if sympathetically designed

Table 6.1d Comparison of widening options with vertical or hard faces for embankments (2 of 2)

Solution	**Comments**							
	Cost	**Programme**	**Traffic Management requirements**	**Buildability**	**Safety**	**Environmental**	**Maintenance**	**Appearance**
Masonry blockwork wall	Low	Slow	Low	Only practical for low heights	Safe operation – needs safety barrier above vertical face	Little temporary disturbance if low height	Low	Good
Reinforced masonry wall	Low	Slow	Low	Only practical for low and medium heights	Safe operation – needs safety barrier above vertical face	Little temporary disturbance if low height	Low	Good
Mass concrete wall – cast in situ	Low	quick	Low	Simple – but temporary works needs consideration	Safe operation – needs safety barrier above vertical face	Acceptable	Low	Subjective – better if faced. Graffiti may be a problem
Mass concrete wall – large precast blocks	Low	Quick	Access and egress for delivery and craneage for placing units	Simple – but temporary works needs consideration	Safe operation – needs safety barrier above vertical face	Acceptable	Low	Subjective – better if faced. Graffiti may be a problem
In situ reinforced concrete wall	High	Slow	Low	Traditional – but many trades involved	Safe operation – needs safety barrier above vertical face	Acceptable	Low	Acceptable. Graffiti may be a problem
Precast reinforced concrete wall	High	Slow	Access and egress for delivery and craneage for placing units	Simple – but temporary works needs consideration	Safe operation – needs safety barrier above vertical face	Acceptable	Low	Acceptable. Graffiti may be a problem

6.2 Earthworks (regrading) solutions

Regrading earthworks with existing materials at same or steeper slope:

6.2.1 The simplest solution to earthwork widening, space permitting, is to follow the original slope angle and material type and regrade the slope by cutting or filling within the existing highway boundary, see Section 3 Figure 3.2. New fill should be benched into the existing slope, removing potential planes of weakness by excavating back into sound material. It may also be possible to justify regrading at a slightly steeper slope, subject to design checks.

Regrading the entire slope will involve removal of vegetation, so may not be suitable where the vegetation needs to be retained as a habitat or for visual screening, particularly where there is a long slope.

If the existing earthwork contains any observed or developing defects such as signs of instability, weathering or softening, this may be repaired or strengthened locally as part of the scheme and designed accordingly.

Widening embankments with granular materials or stabilised cohesive materials

6.2.2 The top of embankments may be widened by inserting a wedge or shoulder of high strength granular materials or chemically stabilised cohesive materials, e.g. lime stabilisation, possibly using a steeper slope angle. This solution can be used provided that the existing slope below has sufficient stability to accommodate the additional weight.

The design of any granular wedge must prevent percolated water collecting at the bottom if it which could soften underlying clay materials. The fill is typically specified under the Specification for Highways Works (SHW) Table 6/1 Class 1.

Chemically stabilised materials must be demonstrated to be likely to retain sufficient strength in the long-term. Further information is given in Rogers and Bruce (1990), which deals with the strength of lime stabilised clays, and Advice Note 74.

6.2.3 It is often a requirement to re-establish or retain vegetation and topsoil after undertaking regarding works. See Section 6.13 for further details.

6.3 Slope drainage to permit steepening

6.3.1 Slope drainage is used in highway earthworks to reduce pore pressures and thereby improve stability, commonly in new and existing cutting slopes. However, drainage is generally used concurrently with other techniques to improve slope stability. Slope drainage systems ideally need a design life comparable to the 60 year design life of a highway slope, and should take account of climate change design criteria. Drainage systems should be designed to accommodate maintenance. On existing slopes, drainage systems over 10 years old may need renewal to maintain long term sustainability.

6.3.2 When considering slope drainage, ground investigation is required to help identify the failure mechanisms and confirm that the stability will be adequately improved by drainage. For reasonably isotropic soils in terms of permeability, design charts of the type given in Hutchinson (1977) may be used, otherwise the drainage should be sized based on analysis.

Slope drainage techniques

6.3.3 Available techniques of slope drainage include:

a. slope drains, counterfort drains (see Figure 6.2) and rock ribs

b. filter and fin drains

c. vegetated slopes

d. open ditch and surface water channels

e. vertical and horizontal bored drains

Further information on the techniques, references and design methods and documented case/field studies are included in the report entitled ‘Drainage of earthworks slopes’ prepared for the HA by Halcrow/TRL (2008).

6.3.4 With all forms of sub-surface drainage, the granular or geotextile filter must be correctly designed for the soil in contact with it. Vertical deep drains are used to improve short or long term stability of cutting slopes against deep-seated failure whereas shallow, closely spaced drains help reduce the incidence of shallow, planar slips. Bored horizontal drains may be used in large cuttings with well-defined seepage zones, however their subsequent maintenance requires consideration.

6.3.5 In principle, slope drainage is also applicable for embankments. However, there is a risk that this will allow water to percolate into drier materials at depth within the embankment. Compacted clay fills are not fissured like natural clays and tend to be less permeable, and slow to reach equilibrium with the installed drainage.

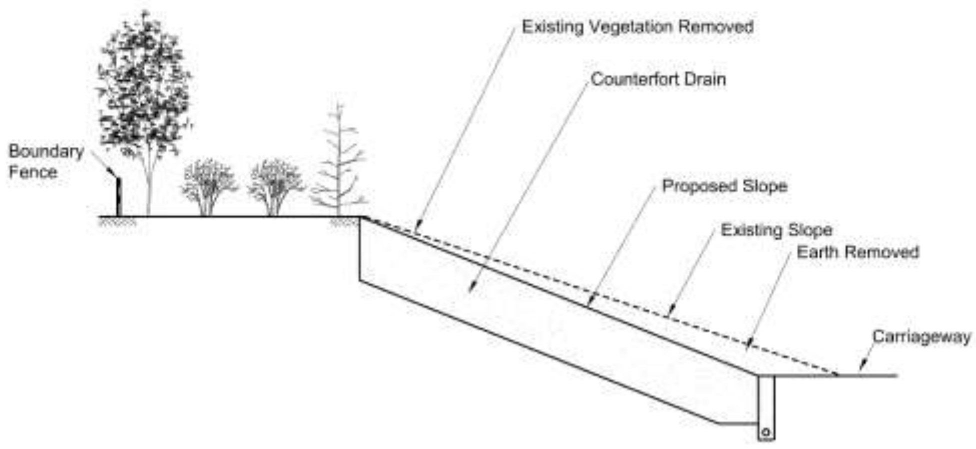


Figure 6.2 Widening of a cutting at a steeper slope angle than existing using counterfort drains (diagrammatic only)

6.4 Reinforced soil

6.4.1 Reinforced soil provides a cost effective method for constructing earthworks, steep slopes, and vertical walls, with or without a facing. Horizontal layers of reinforcing elements are placed between layers of compacted fill material, thereby increasing the shear strength of the soil mass. A typical reinforced soil slope is shown in Figure 6.3, indicating the action of the reinforcement. The main components of the system are:

a. Reinforcing elements - geosynthetic reinforcement is most commonly used for all applications; however metallic strips are also used in the construction of reinforced soil retaining walls.

b. Fill material - fill material must be frictional or cohesive frictional, and may be selected from a range of soil types.

c. Facings - facings may be employed, but are normally only used for near vertical slopes and walls. Segmented facing panels are predominantly used.

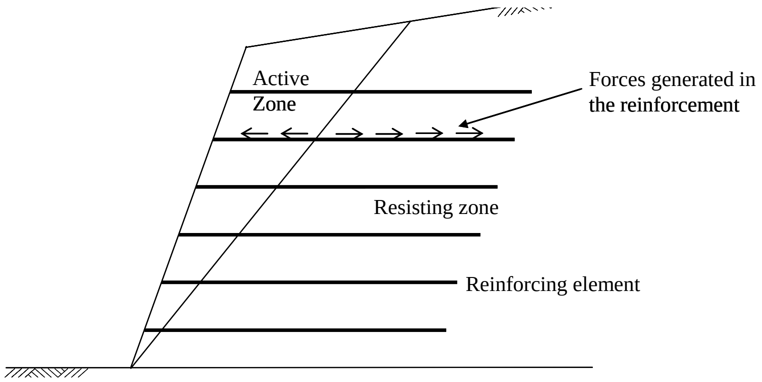


Figure 6.3 Section through reinforced soil slope

Sources of information

6.4.2 Important sources of information on reinforced soil include:

- BS 8006-1, Code of practice for strengthened/reinforced soils and other fills
- BS EN 14475, Execution of special geotechnical works – Reinforced fill
- Advice Note HA 68, Design methods for the reinforcement of highway slopes by reinforced soil and soil nailing techniques
- PD 6694-1, Recommendations for the design of structures subject to traffic loading to BS EN 1997-1
- ISO/TR 20432, Guidelines for the determination of the long-term strength of geosynthetics for soil reinforcement
- Information covering all aspects of reinforced soil and its applications is provided in Jones (1996). The use of geosynthetic reinforcements is considered in detail by Jewell (1996).

Applications for highway earthworks widening

6.4.3 Where space is available, reinforced soil techniques are applicable to widening an embankment supporting a motorway. The technique is not usually applicable to widening within a cutting, as a large temporary excavation would be needed.

a. Highway network slopes have commonly been strengthened and steepened using this technique. Reinforced soil is also often used for reinstating a failed slope. The slope face is usually vegetated to resist the erosion of the fill material and to improve the aesthetic appearance.

b. Vertical slopes or walls can also be constructed, and are commonly used in highway improvement schemes. It can be difficult to retain topsoil and establish vegetation on a vertical face, so proprietary modular facing units are normally employed. Walls with retained heights greater than 3m can provide substantial savings over traditional constructions such as gravity or spread based walls. Reinforced soil walls can accommodate differential ground movements greater than 1:100 without exhibiting or suffering distress, e.g. a differential settlement of 1:95 has been recorded on an in-service reinforced soil bridge abutment in Wales (Brady et al, 1995).

Anchored earth

6.4.4 Anchored earth is a method for constructing vertical or near vertical retaining walls, similar to reinforced soil, but that makes use of more clayey fill materials. For anchored earth the resistance is developed by passive soil pressures within the fill material at the bearing surface of the anchor. Applications are the same as for reinforced soil walls, but the technique is less widely used. Details of an anchored earth retaining wall in Scotland (A75), were reported by Brady et al (1994). It may be suitable for larger widened sections where there is space to install the anchors.

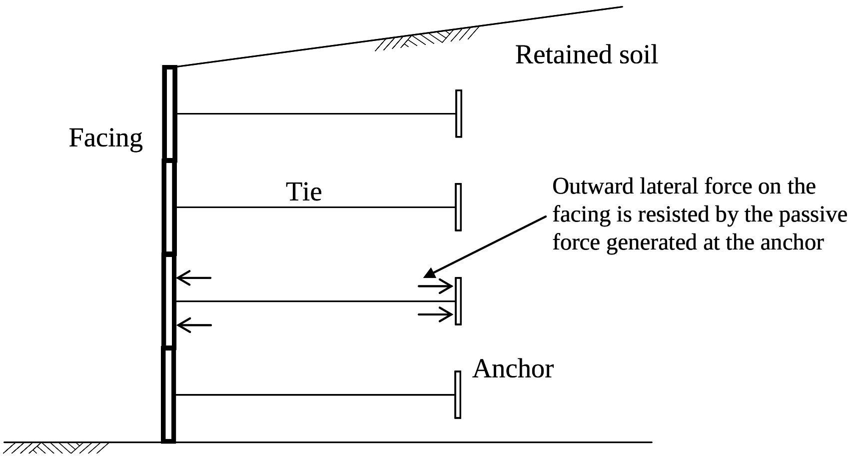


Figure 6.4 A section through an anchored earth wall (diagrammatic only)

Design considerations

6.4.5 Reinforced soil slopes and walls may be classified as "structures" in Standard BD 2 on the basis of retained height, slope angle or type of facing. They should be designed in accordance with BS 8006-1 (implemented by PD 6694-1) and with BS EN 1997. PD 6694-1 also includes the design of anchored earth structures. Reinforced soil slopes and walls not covered by Standard BD 2 are classified as 'strengthened earthworks' as per Standard HD 22 and should be designed as such.

The design approach requires verification of various ULS using limit equilibrium calculations with a postulated failure mechanism to balance forces and moments and or various SLS using numerical analysis or simplified closed form solutions to estimate forces and displacements as necessary. Other serviceability considerations like facing appearance and cracking should be considered. Careful consideration is required particularly regarding the facing and reinforcement connections, part of the internal design checks which tend to govern the design in most cases.

Construction issues, durability and creep

6.4.6 Information on construction issues is given in BS EN 14475. The durability of the reinforcing elements is an important factor for the longevity of the slope or structure. Metallic reinforcements will corrode in-service. Severe pitting corrosion can occur in chemically aggressive fill materials, e.g. Blight and Dane (1989) and Winter et al (2002).

6.4.7 Geosynthetic reinforcements tend to undergo creep deformation for given sustained service loads which may adversely impact structure safety and performance. An overview of the mechanisms that affect the long term performance of geosynthetics is presented by Watts (2003), and the derivation of creep data by Watts et al (1998). A guide to the durability of geosynthetics is provided in ISO/TR 20432.

6.5 Soil nailing

6.5.1 Soil nailing is used to stabilise soil slopes and faces in situ. Reinforcing elements or soil nails are inserted into the ground after the slope is excavated. It is effective to prevent failure of cutting slopes or permit them to be steepened, or to improve the stability of existing embankment slopes. A schematic representation of a cutting widened by soil nailing is shown in Figure 6.5.

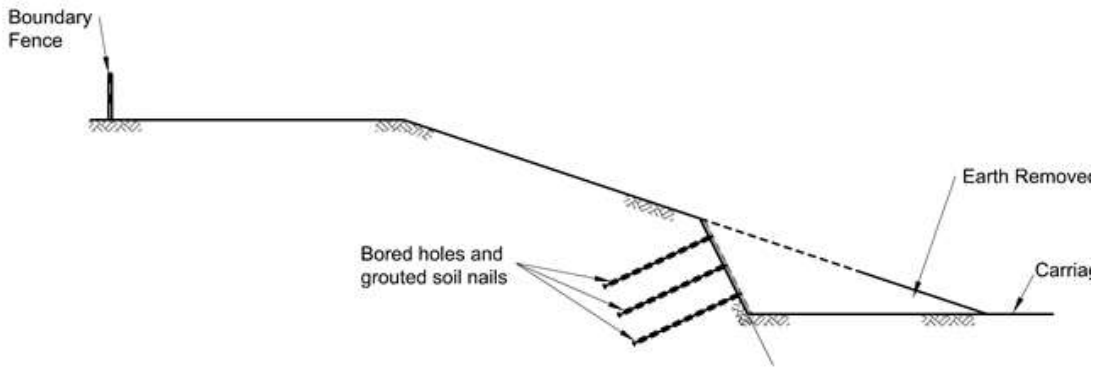


Figure 6.5 Widening of a cutting using a steepened toe stabilised with soil nailing and a facing (diagrammatic only)

Sources of information

6.5.2 CIRIA Report C637 (Phear et al. 2005), Soil nailing – best practice guidance, gives further guidance on the matters presented in the following sections. Other important sources of information on soil nailing include:

- Advice Note HA 68, Design methods for the reinforcement of highway slopes by reinforced soil and soil nailing techniques
- BS 8006-2, Code of practice for strengthened/reinforced soils, Part 2: Soil nail design
- Pr EN 14490, Execution of special geotechnical works – Soil nailing
- United States Federal Highways Administration, Manual for design and construction monitoring of soil nail walls, 1998
- Clouterre, Soil Nailing Recommendations, French National Research Project Clouterre (1991)

Applications for highway earthworks widening

6.5.3 a. Stabilising new cuttings - where ground is excavated at an angle steeper than that at which it can stand safely then soil nails may be used to improve the stability. Normally the cut slope is excavated ‘top down’ in benches from which the soil nails and facing are installed, until the full slope has been stabilised. The nails become loaded as excavation induced movements occur, and greater loads are generated in the nails and facing as the slope angle increases.

b. Existing cutting stabilisation - soil nailing can be used as a preventative measure to enhance the local or overall stability of an existing slope, hence reducing the risk of a first time failure before it occurs. After installation of the nails, checks may need to be undertaken to demonstrate the improvement in stability. In this case the nails do not take up load unless further movement occurs.

c. Embankment stabilisation - soil nailing is commonly used for infrastructure embankment stabilisation. CIRIA Report C592 (Perry et al. 2003b) covers issues pertaining to the use of soil nailing for embankments. Where widening is installed at the crest of a marginally stable embankment, soil nailing of the lower slope can increase the overall stability.

Design considerations for soil nails

6.5.4 In a similar way to reinforced soil (see Section 6.4), soil nailing is a passive system that requires soil strain for the friction forces to be mobilised and for the nails to take up load. If predicted movements are unacceptable (for example where supporting a carriageway), a stiffer solution may be more appropriate.

6.5.5 As soil nailing is a mass reinforcement technique, a minimum of two rows of nails are needed even for low-height slopes. For most slopes there should be at least three or four rows. Soil nails are installed in staggered rows and inclined 5° to 20° below the horizontal. Horizontal and vertical spacing is typically in the range of 1.0 to 2.0m.,

6.5.6 For existing highway cutting slopes the design may need to take account of existing vegetation and wildlife and often soft or flexible facing systems may be preferred, in association with landscaping.

6.5.7 The method of nail installation chosen will have a direct impact on the pull-out resistance that can be used in the design. Test nails should be specified to be representative of the production nails.

6.5.8 Appropriate drainage should be installed to manage and control water flows and suitable whole-life monitoring and maintenance will need to be carried out.

Soil nail materials, systems and durability

6.5.9 a. Drilled-then-grouted soil-nailing systems use an inclined drilling rig to open-bore a hole to the design depth. The reinforcing tendon, with centralisers to ensure the required cover, is installed and the grout placed using a tremie pipe to the base of the hole. A cased drilling system can also be used.

b. Self-drilled soil nail systems use the reinforcing tendon as the drill rod fitted with a sacrificial drill bit. Hollow bar reinforcement is used to inject the flushing medium (typically grout) at the drill bit location. As the diameter of the hole is generally smaller than with open-bore techniques, hand-held tools can be used for short soil nails. This is an advantage where access is difficult. There is a danger that the relative flexibility of the reinforcing tendon / drill string can result in misalignment of the soil nail in variable ground conditions. Extra clearance to services or underground structures should be provided and centralisers should be used along the nail.

6.5.10 Soil nail tendons are typically steel bars or tubes of 20 to 50mm diameter but may also be made of glass fibre–reinforced polymer (GFRP). Self-drilled GFRP nails are less suitable in hard ground as they are prone to shattering and/or torsional damage, particularly with longer nails. The drilled holes are typically of 80-120mm diameter. Following grouting, the nail is then connected by a threaded arrangement to a bearing plate at the surface. The steel components may have corrosion protection measures such as galvanising or impermeable PVC or HDPE ducting, depending on the required durability. The nail detailing should also ensure continuity of the corrosion protection system over its entire length and into any facing system or head plates/bearing pads.

6.5.11 Depending on ground conditions, the designer may need to specify limits on the maximum depth, length and slope of benches that can be excavated. Pr EN 14490 gives guidance on this. Any bulk excavation needs to be controlled so that the stability of the overall slope is maintained, and face trimming is not left uneven which can adversely affect the facing.

Facings

6.5.12 Selecting and detailing appropriate facings for soil-nailed slopes and walls is fundamental to the performance of the soil-nailed slope or wall. Facing selection needs to consider site constraints, environment and aesthetic requirements.

The role of the facing is to confine and stabilise the near surface soil between the nail heads, avoiding progressive shallow failure. The three commonly used facing types are soft facings, flexible structural facings and hard structural facings, as summarised below:

a. Soft facings - these retain the vegetation layer / topsoil and prevent surface erosion on relatively shallow slope faces, but they depend on the establishment of vegetation for long term performance. They commonly comprise geogrids or other erosion control geotextiles. The selection and maintenance of suitable vegetation is covered in Coppin and Richards (1990) and CIRIA Report C637 (Phear et al. 2005).

b. Flexible structural facings - these provide long-term stability of the face of the soil-nailed slope by transfer of the soil load from the soil nails to the nail heads (see Figure 6.5). Coated metallic meshes or proprietary heavy rock meshes are commonly used. Sometimes the mesh incorporates a geotextile to support vegetation growth, which is sustainable up to about 50-60° to the horizontal with suitable aftercare. Design methods for these facings are given in CIRIA Report C637 (Phear et al. 2005), but these methods have been developed further since the publication of that report.

c. Hard structural facings - these are often used where steep, or vertical, soil-nails slopes or walls are required, because of the face loadings to be resisted and to limit deformation. These generally comprise sprayed concrete reinforced with steel mesh. Design methods for hard structural facings are given in Clouterre (1991), FHWA (1998) and CIRIA Report C637 (Phear et al. 2005).

6.6 Gabions

6.6.1 Gabions are wire mesh boxes containing coarse stone fill, which are installed side by side and laced together to form a simple gravity structure. Gabions are flexible, and can accommodate larger total and differential settlements than other wall types. The stone fill is usually very permeable and will allow retained fill to drain freely.

Sources of information

6.6.2 Sources of information on gabions and gabion walls include:

- CIRIA Report C516, Modular gravity retaining walls
- Specification for Highway Works (SHW) Clause 626
- BS EN 1997 – Eurocode 7, Geotechnical Design
- Advice Note HA 85, Road Improvement within limited land take, DMRB Vol 10, Section 2.

Applications for highway earthworks widening

6.6.3 Gabion walls are frequently used for retaining structures to support the widening of both highway embankments and cuttings, see Figure 6.6.

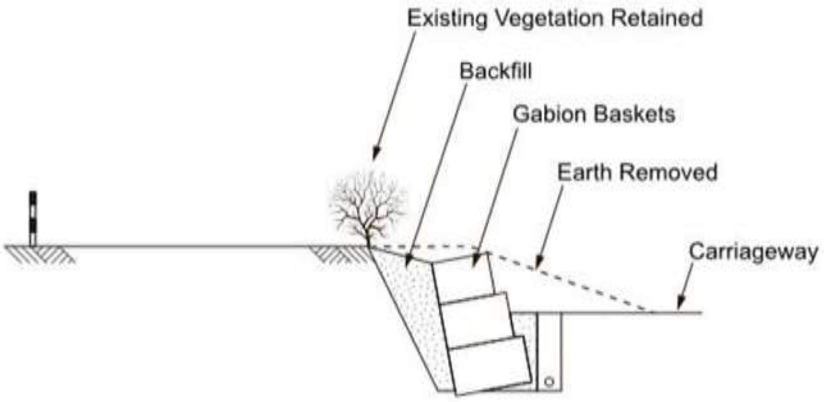


Figure 6.6 Widening of a cutting using a low height gabion wall (diagrammatic only)

Design considerations

6.6.4 Gabions are typically formed using woven steel wire mesh or welded steel wire mesh, either with a galvanised coating or a PVC (or other polymer) coating for additional durability. Clause 626 of the SHW addresses the requirements for the gabion mesh materials. A design life of at least 60 years is expected.

6.6.5 Gabion stone may be natural gravel, quarry stone or crushed concrete meeting the strength, durability and grading criteria of Class 6G selected granular material in SHW Table 6/1. These requirements ensure that the gabion structure remains robust and is not subject to internal settlement due to degradation of the stone over the design life of the structure. Increasingly, particularly in lowland Britain where quarry stone is at a premium, recycled gabion stone is being considered.

6.6.6 Gabion retaining walls are designed as a gravity mass retaining wall structure. Details of the design methodology are given in BS EN 1997. Other design guidance is given in CIRIA Report C516.

6.6.7 Gabion walls can be built with either the front face or rear face stepped. It is desirable to incline the wall at least 6 – 8 degrees from the vertical towards the retained fill. They are constructed typically in 1.0 or 0.5 m high courses.

6.6.8 For gabions supporting a carriageway or gabions placed to retain cuttings, the requirement for safety barriers will need to be assessed using TD 19 and the Road Restraint Risk Assessment Process.

6.6.9 Gabions can look attractive in rural locations or where they can fit in with a rocky landscape and vegetation. The appearance of the front face of the gabions can be controlled by hand placing selected stone fill to suit the surroundings. The quality of finish required should be specified in Appendix 6/10 of the Specification. Advice Note HA 85 gives guidance on the environmental and aesthetic aspects of road widening, including gabion walls.

6.6.10 A safety fence could be added at the top of a gabion wall to prevent falls. A socket for the fence posts should be provided along the wall.

Construction of gabion walls

6.6.11 Gabion retaining walls can be constructed cost effectively; however the process can be slow, particularly if hand packing to present a good visual appearance is required. Health and Safety risks relate to slow construction resulting in increased exposure to risks from the live motorway and to manual handling of stone. Use of pre-packed baskets should be considered to reduce such risk.

6.7 Low height modular walls

6.7.1 Modular wall construction encompasses a wide range of different techniques and materials, all using prefabricated elements. Most of the wall types addressed in this section are only suitable for limited heights, typically less than 3m retained height.

Sources of information

6.7.2 Sources of information on low height modular walls include:

- HA Standard BD 30, Backfilled retaining walls and bridge abutments

- CIRIA Report C516 (Chapman et al., 2000), Modular gravity retaining walls

Applications for highway earthworks widening

6.7.3 Low height modular walls are frequently used for retaining structures to support the widening of both highway embankments and cuttings.

6.7.4 There are two broad groups of modular retaining walls:

i. Gravity retaining walls constructed with a large number of small elements, e.g. masonry block walls, crib walls and dry-stack masonry walls. These types may be suitable where site constraints render other wall types impractical; they also have a high tolerance to differential movement. Many proprietary systems exist.

ii. Cantilever walls constructed with full height pre-cast units, typically manufactured in ‘L’ or ‘inverted T’ shaped reinforced concrete sections. These walls require a good foundation and do not readily tolerate differential movements. They may be better suited to highway widening situations where long lengths of wall of constant height are required.

Some of the forms of construction are illustrated in Figure 6.7. A summary of construction, appearance and durability aspects of the most common different types of modular walls is presented in Table 6.2 of CIRIA Report C516 (Chapman et al. 2000).

Design considerations for modular walls

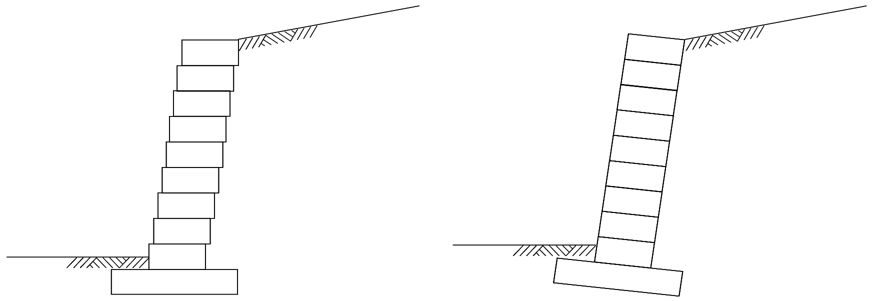
6.7.5 Designs should be in accordance with either the requirements of BS EN 1997 or BS 8002, together with HA Standard BD 30. Comprehensive guidance on the design and suitability of different modular wall types is provided in CIRIA Report C516 (Chapman et al. 2000), including the selection of material properties and loading conditions. Advice for regular inspections and maintenance is also provided.

6.7.6 Modular blocks are manufactured with a wide variety of differently textured and coloured facings from which selection can be made to suit the local surroundings. Alternatively, lightweight facing units may be attached to the wall face. Blocks with a voided face or irregular texture may assist with the attenuation of traffic noise.

Construction

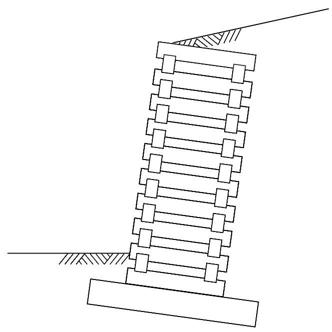
6.7.7 Modular walling systems use straightforward construction techniques that are applicable to most widening schemes. They are typically founded on a mass concrete strip footing that supports the starter course of blocks. As additional courses are added to a wall during construction, the retained fill material should be placed in layers, but not exceeding the height of the wall.

6.7.8 Good workmanship is essential to achieve a high standard of finish and sound construction without misalignment or accumulated errors in successive courses. In all cases the use of specialist labour is advised.

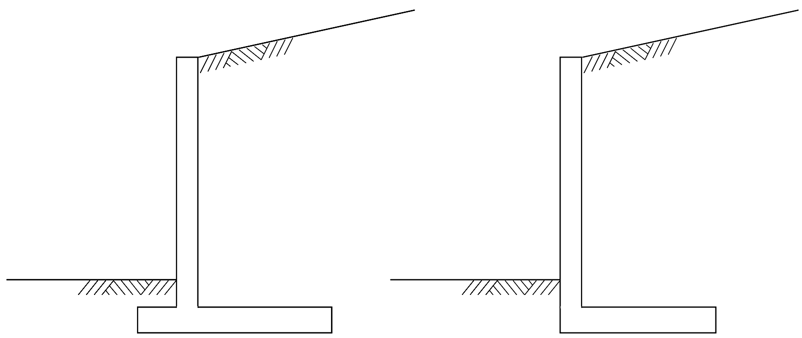


(a) Drystack wall with stepped face

(b) Sloping drystack wall with a flat face



(c) Single cell crib wall



(d) Reinforced concrete stem walls (cantilever wall), “T” shape and “L” shape

Figure 6.7 Examples of some different types of low height modular walls

Durability

6.7.9 Modular wall systems manufactured from reinforced concrete in accordance with the relevant standards are inherently durable, although the action of de-icing salt may need to be considered in exposed locations. The durability of other materials, e.g. some wooden elements used for crib walling, may need to be confirmed during the design. Recycled plastic crib wall systems are also available on the market.

6.8 Bored pile walls

6.8.1 Bored pile retaining walls generally comprise a row of closely spaced piles or micropiles. As well as a widening solution, they provide enhanced stability against deeper-seated failure mechanisms (CIRIA Report C592, Perry et al, (2003)). Piles may either form the retaining wall themselves or may support a low height cantilever wall.

Sources of information

6.8.2 These sources give comprehensive information on this widely used civil engineering technique, and accordingly this section on bored pile walls is relatively short.

- BS EN 1997 – Eurocode 7, Geotechnical Design
- BS EN 1992-2 – Eurocode 2, Design of concrete structures
- CIRIA Report C580 (Gaba et al. 2003), Embedded retaining walls – guidance for embedded design
- Specification for Highway Works Series 1600 (and Notes for Guidance for same)
- BS EN 1536, Execution of special geotechnical work – bored piles

Applications for highway earthworks widening

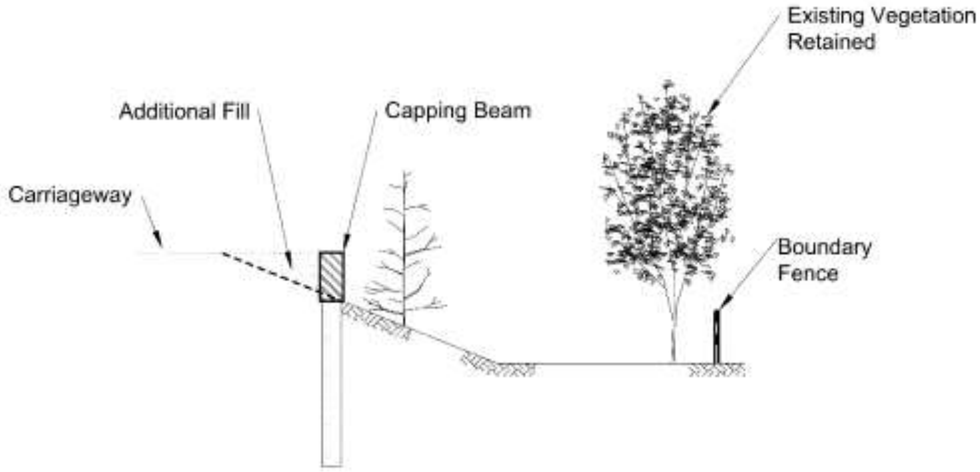
6.8.3 Bored pile walls may be used for retaining structures to support the widening of both highway embankments and cuttings. Examples of widening solutions using bored pile walls are shown in Figure 6.8. Micropiles (bored piles of less than 300mm diameter and drilled grouted piles) can be installed with lightweight drilling rigs of less than 10T in weight, and may be an effective solution for smaller walls.

6.8.4 Bored pile walls are effective in constrained locations where bulk excavation is not possible, and where there is a need to control ground movement or limit vibrations. However they require significant specialist plant, temporary works, working space and time to install. For this reason, bored piles are rarely the most cost-effective solution for low and medium-height walls (less than about 3m), but may be a good solution in over-consolidated clay soils and weak rocks where there is a substantial retained height.

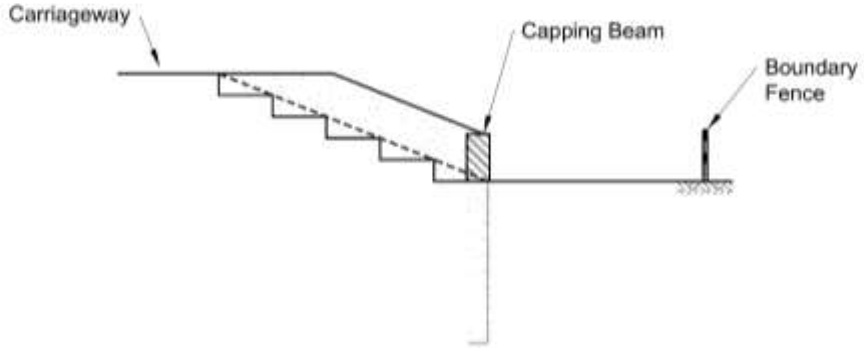
Design of bored pile walls

6.8.5 The design of embedded pile walls is discussed in CIRIA Report C580 (Gaba et al. 2003) and BS EN 1997 and many other published documents. For highway widening schemes, the size of plant to be used may constrain the choice of pile size.

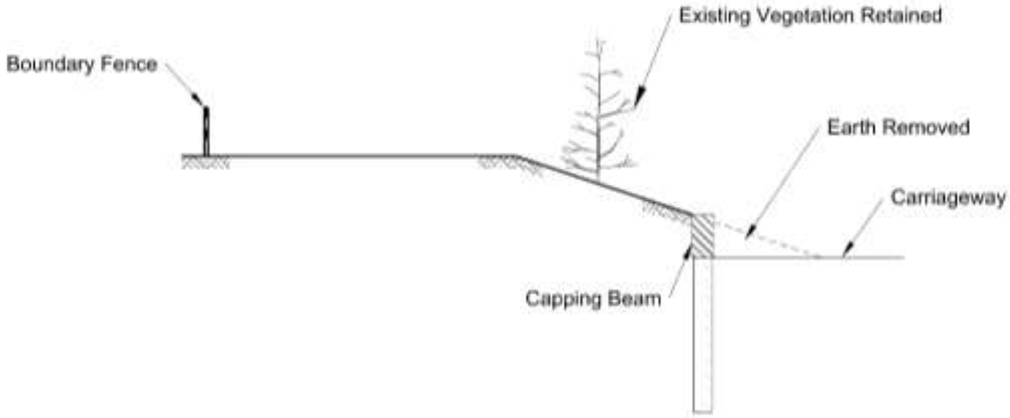
6.8.6 Bored pile walls generally need a secondary facing to look attractive. Advice Note HA85 gives guidance on the environmental and aesthetic aspects of road widening, including bored pile walls.



a) Widening of an embankment using a bored pile wall near the crest (diagrammatic only)



b) Widening of an embankment using a bored pile wall at the toe (diagrammatic only)



c) Widening of a cutting using a bored pile wall near the toe (diagrammatic only)

Fig. 6.8 Examples of widening using bored piles.

Construction of bored piles and bored pile walls

6.8.7 The construction of bored piles is covered in detail in BS EN 1536 and CIRIA Report C580 (Gaba et al. 2003). A concise summary is given in CIRIA Report C592. The method of pile boring will be dependent on ground conditions. Continuous flight auger (CFA) rigs are commonly used for installing bored piles as this avoids the need to use temporary casing to support the borehole. Open bored methods should not require support fluid.

6.8.8 For pile installation, a service crane will usually be needed for the piling rig, as well as space for lay down areas, spoil management, concrete deliveries and muckaway lorries. On a typical highway widening scheme, bored piling operations may require more than one lane to be closed to give enough working space as well as maintaining an access route. Contraflows may be needed to carry out bored piling in day-time, or the operations may be confined to night shifts.

6.8.9 A piling platform and access ramp may need to be built so the piling rig can be positioned on the line of the proposed wall, which may be some distance up or down slope. This can be compacted fill or involve partial excavation of the slope. The type of piling rig will affect the access arrangements and this should be considered in design.

6.9 Steel sheet pile walls

6.9.1 Steel sheet pile walls are constructed by driving, vibrating or hydraulically pushing steel profiles into the ground to form an embedded retaining wall.

Sources of information

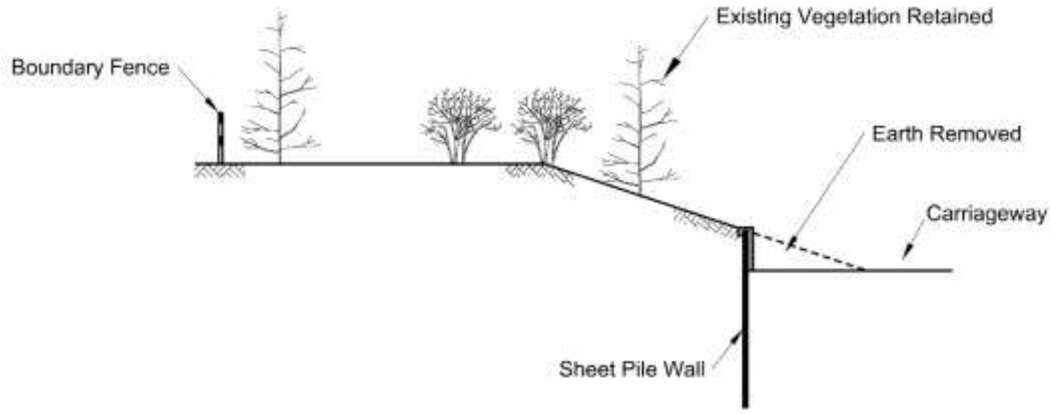
6.9.2 The main sources of information on steel sheet piling include:

- BD 42, Embedded retaining walls and bridge abutments
- The Piling Handbook (ArcelorMittal, 2008)
- BS EN 1997, Eurocode 7 – Geotechnical Design.
- CIRIA Report C580 (Gaba et al. 2003), Embedded retaining walls – guidance for embedded design
- SHW Series 1600 (and Notes for Guidance for same)
- BS EN 12063, Execution of special geotechnical work – sheet pile walls.
- BS EN 1993-5, Eurocode 3, Design of steel structures

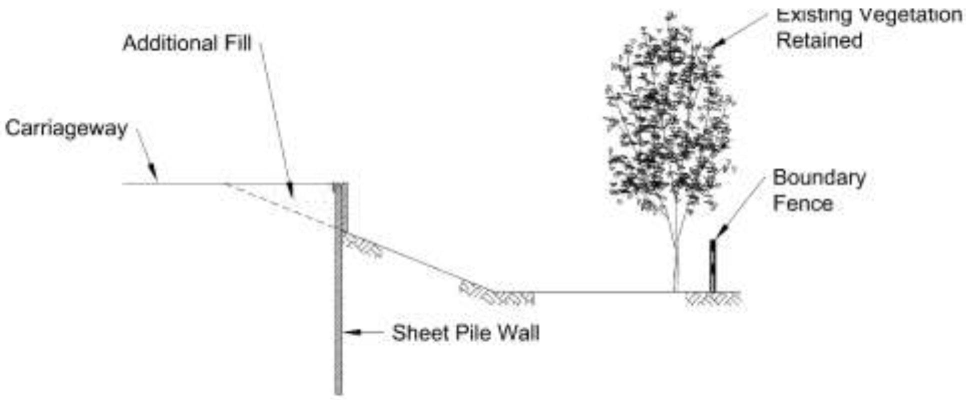
These sources give comprehensive information on this widely used civil engineering technique, and accordingly this section is limited to commentary on their application in highway earthworks widening.

Applications for highway earthworks widening

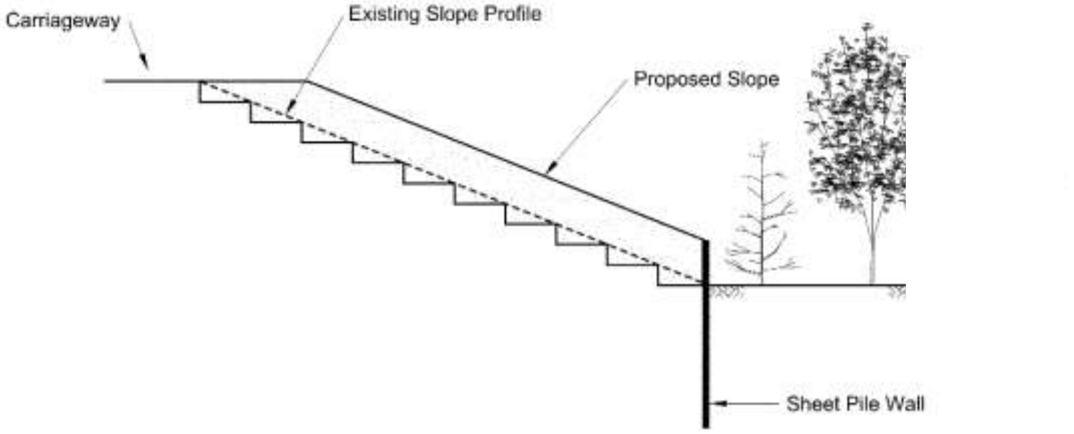
6.9.3 Steel sheet pile walls are extensively used in highway schemes to widen and/or stabilise embankments or cuttings (see Figure 6.9). They can also be used to resist deep or shallow failure mechanisms or as erosion protection at the toe of an embankment. Cantilever (unpropped) steel sheet pile walls are mainly used for low to moderate retained heights (up to about 3m). For greater retained heights, sheet pile walls are usually tied back using one or more rows of pre-stressed anchors so as to control the lateral deflections and bending moments. Cantilevered steel sheet pile walls may permit large movements in weak soils.



a) Widening of a cutting using a steel sheet pile wall near the toe (diagrammatic only)



b) Widening of an embankment using a steel sheet pile wall near the crest (diagrammatic only)



c) Widening of an embankment using a steel sheet pile wall at the toe (diagrammatic only)

Fig. 6.9 Examples of sheet pile walls used for highway earthworks widening

6.9.4 Steel sheet piles are a proven economical solution, quick to install, generating no arisings and require minimal temporary works depending on the scale of operation. They can be used in both granular and cohesive soils, but pre-boring may be required in stiff or dense soils and weak rocks. However, it should be noted that pre-boring may cause additional deflections on the pile after installation due to the weakened surrounding material. Steel sheet pile walls are a hard faced solution which may not be suitable in areas of sensitive visual impact or in rural areas.

Design and construction

6.9.5 Details of steel sheet pile sizes, their properties and installation guidance are given in the Piling Handbook (ArcelorMittal, 2008). Normal embedded retaining wall design procedures are generally applicable to the design of sheet pile walls. Reference should therefore be made to Standard BD 42, BS EN 1997-1, CIRIA Report C580 (Gaba et al. 2003) and there are many other published documents dealing with this subject.

6.9.6 Series 1600 of the Specification for Highway Works and BS EN 12063 address the construction aspects of sheet pile walls. A driving trial is recommended when ground conditions are particularly complex or if vibratory or hydraulic installation is proposed. Appropriate drainage through the piles should be provided to maintain any groundwater flow and to prevent the build-up of groundwater against the pile.

6.9.7 Design is to be undertaken with constructability in mind and consideration should be given to aspects such as noise, ground movements due to installation and driveability. Refer to ArcelorMittal Piling Handbook for further advice on driveability.

Durability and corrosion protection

6.9.8 Steel sheet piles usually have a protective coating, painted sealed clutches, and/or an additional sacrificial thickness of steel to allow for the potential corrosion during the life of the wall. The rate of corrosion will depend upon the aggressiveness of the ground, and, for the exposed faces, on the aggressivity of the atmosphere. This will be site-specific, so appropriate specialist advice should be obtained. Some guidance is provided in BS EN 1993-5. Guidance on measures to increase the effective life of steel piles are given in the Piling Handbook (ArcelorMittal, 2008).

6.10 Plastic sheet piles

Applications for highway earthworks widening

6.10.1 Plastic sheet piling may provide a cost effective and environmentally friendly alternative solution to other techniques such as low height modular walls (see Section 6.7) for small scale widening with low retained heights (up to about 1.5m) and no need for temporary works. Successive rows of plastic sheet piling may be a way of resisting shallow failures on earthworks slopes. Few monitored trials of plastic sheet piling in highway works are reported, although their use in waterway and flood control walls is better documented.

Design considerations

6.10.2 The same standards and design guides listed in Section 6.9.2 apply to the design of plastic sheet pile walls. Where testing of the plastics material is appropriate the relevant British and/or European Standards are listed by Carder et al (2002).

6.10.3 Plastic sheet piling has many apparent advantages which include ease of handling and transportation of the lightweight piles, good corrosion resistance, and the opportunity to use recycled materials in manufacture. In some instances, use of a system not requiring heavy construction plant and its associated access may assist in minimising traffic management measures.

6.10.4 There are perceived structural concerns about driveability of plastic sheet piling compared with traditional steel sheet piling, but techniques have been developed to ensure driveability in many soil types and plastic sheet pile driving specialists should be consulted at an early contractual stage. A driving trial will probably be needed in difficult ground. The piles can also be installed in a narrow trench and backfilled with mass concrete.

6.10.5 The limitations of plastic sheet piles are:

a. Plastic sheet piles have a lower bending moment resistance than steel products of similar cross-section. The section modulus is normally advised by manufacturers. Carder et al (2002) review products available at that time, although the ranges are much improved since then.

b. When used as cantilever walls, plastic sheet piles are typically only structurally viable for retained heights of up to about 1.5m.

c. Plastics generally respond to short term loads in a reasonably elastic manner. However, under sustained lateral loading, creep deformation may occur. Carder et al (2002) simulated the sustained lateral loading of low height piled walls in the laboratory and measured the creep deformation. The manufacturer should be consulted on the allowable load and bending moment for their product.

d. Accelerated weathering tests were carried out on recycled uPVC sheet piles by Carder et al (2002). After an equivalent 40 years of weathering, the tensile strength, elongation at yield and flexural properties of the pile material were virtually unaffected. Impact tests after an equivalent weathering of 25 years showed no deterioration, after 40 years “exposed face up” samples although still quite tough, were brittle showing a large reduction in both energy and displacement to failure. Information on the weathering of other plastics materials is reported by Brady et al (1994a).

6.11 Lightweight fill

6.11.1 Highway earthworks widening sometimes requires construction of widened embankments on poor foundations or weak compressible ground. In such cases, lightweight fills may be incorporated into the embankment to reduce vertical stress on the foundation. This can minimise consolidation of the underlying soils and potential differential settlement of the widened embankment (see Figure 6.10).

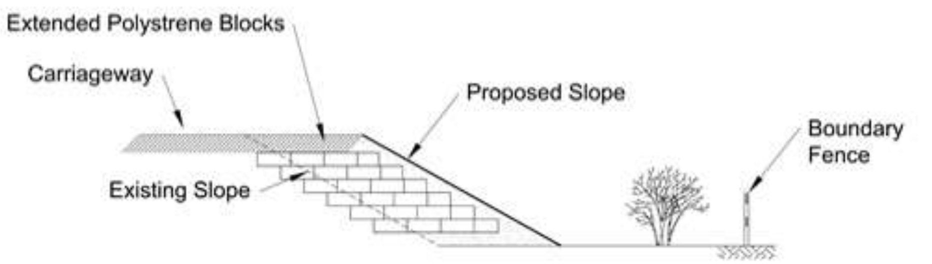


Figure 6.10 Widening of an embankment widening using expanded polystyrene lightweight fill (diagrammatic only)

6.11.2 The principal materials that are currently widely used as lightweight fill are (in order of increasing bulk density):

a. polystyrene

b. expanded clay

c. pulverised fuel ash (pfa)

Tyre bales can also be used as lightweight fill and have a density of about 550 kg/m^3, see Section 6.12. Other lightweight fills include innovative materials or hollow pre-formed structural elements. Information on these should be sought from their suppliers.

Application for highway earthworks widening

6.11.3 Designs for any earthworks widening operations should consider the compatibility of the new and old constructions with particular regard to post construction movements. Environmental aspects should also be considered. The environmental impact in the long term of the fill material or any leachate should be assessed. In extreme cases the fill material may need to be contained within an impermeable membrane.

Polystyrene fill

6.11.4 Polystyrene is an ultra-lightweight fill material that substantially reduces vertical stress under an embankment. It has a bulk density of up to approximately 100 kg/m^3. It is bulky to transport but easy to handle. Care must be taken to avoid contact with degrading agents or solvents such as petroleum products, and in situ protection will be required on schemes adjacent to or beneath the highway.

6.11.5 Sources of information: Sources of information on polystyrene lightweight fill include:

- TRL Contractor Report CR356 (Sanders and Seedhouse, 1994), The use of polystyrene for embankment construction

- BS EN 14933, Thermal insulation and lightweight fill products for civil engineering applications, factory made products of expanded polystyrene (EP), Specification
- TRL CR 341, N J O' Riordan and J W Seaman, 1994

Design and construction of polystyrene fill

6.11.6 Design and construction guidelines on the use of polystyrene for embankment construction are provided in TRL CR356. Further information on design and construction with the UK is provided by Sanders (1996).

6.11.7 McElhinney and Sanders (1992) document the first use of polystyrene for the construction of a highway embankment in the UK on the A47 Great Yarmouth Western Bypass, opened in 1986. The alignment passed over soft organic deposits on the approach to a bridge over a railway line. Extruded polystyrene was used in preference to the cheaper expanded polystyrene because the latter has substantially higher water absorption and no long term creep data were available at that time. The long term performance of the embankment is reported by Williams and Snowdon (1990). Most polystyrene lightweight fill applications since have used expanded polystyrene fill.

Expanded Clay

6.11.8 Expanded clay or expanded shale lightweight fill comprises ceramic granules of predominantly gravel-size, which are manufactured by heating and firing natural clay or shale at high temperatures. It typically has a compacted bulk density of 700 to 900 kg/m^3 (Holm and Valsangkar, 1993), although some imported sources can provide a compacted bulk density of about 300kg/m^3. Expanded clay lightweight fill has been used on several HE and other trunk road schemes in the UK.

Design and construction of expanded clay fill

6.11.9 The expanded clay granules are frost-resistant and chemically inert. The lightweight fill is free-draining and has good resistance to water retention.

6.11.10 When used as backfill to retaining walls, expanded clay or other free-draining lightweight fill reduces the horizontal earth pressures acting on the back of the wall considerably in comparison with conventional selected granular fill (e.g. Class 6N or 6P) and this can result in economies in the wall construction.

6.11.11 Expanded clay fill is installed by the same plant as is used for placing conventional fill. Compaction is typically achieved by tracking the lightweight fill with several passes of a medium-sized tracked excavator or bulldozer. A layer of conventional fill needs to be placed on the embankment side slopes over the expanded clay fill to confine it, and this outer layer of conventional fill needs to be raised concurrently as the level of the lightweight fill core is raised. Once confined beneath a layer of geotextile and a layer of conventional granular fill or sub-base, the expanded clay fill usually provides a competent foundation for the road pavement.

Pulverised Fuel Ash

6.11.12 Pulverised fuel ash (pfa) has a slightly lower compacted bulk density than naturally occurring fill materials, typically in the range between about 1500 and 1800 kg/m^3 (Sear, 2001). However, Advice Note HA 44 recommends an upper bulk density of 1650 kg/m^3 for pfa to be used as lightweight fill. Pfa is classified in Table 6/1 of the SHW (MCHW 1) as Classes 2E (general fill) and 7B (fill to structures and reinforced soil); also Classes 7G and 9C (cement stabilised capping).

Sources of information

6.11.13 Sources of information on pfa include:

- Sear (2001), The properties and use of coal fly ash
- Advice Note HA 44, Earthworks – Design and preparation of contract documents
- United Kingdom Quality Ash Association (various dates), data sheets and best practice guides
- TRL Report 519 (Winter and Clarke, 2001), Specification for pulverised fuel ash for use as a general fill

Design and construction of pfa earthworks

6.11.14 Sources of pfa include conditioned pfa (obtained directly from power station dust collection systems), lagoon pfa, and stockpiled pfa (often available at or close to its optimum moisture content). Pfa properties of density and moisture content can vary between or within sources. This variability affects the ability to compact pfa, which is of critical importance when the material is placed on poor ground, adjacent to a structure or placed upon existing fill material.

6.11.15 Clauses 5.58 to 5.66 of Advice Note HA 44 provide information on the usage and typical properties of pfa. Winter and Clarke (2001 and 2002) give further guidance on the use of pfa for earthworks.

6.11.16 Pfa is very susceptible to erosion and freshly prepared surfaces should be covered with natural over fill materials as soon as possible. As for all earthworks, water control and provision of adequate drainage are important for stability.

6.11.17 Specific health and safety issues should be considered when using pfa. Environmental issues and the appropriate COSHH regulations are described in UKQAA (various dates).

6.11.18 Pfa has been successfully applied as fill material on many civil engineering schemes as general fill for the construction of embankments and as selected structural fill. Case histories include a reinforced soil bridge abutment in Stirling which used pfa fill (Snowdon et al, 1988); and a full-scale trial of a reinforced soil retaining wall at Dewsbury (Jones et al, 1990). The trial examined and confirmed the suitability of reinforced soil structures built on soft ground using pfa fill.

6.12 Tyre bales

6.12.1 "Tyre bales" is an informal name for URRO (Used Rubber Recycling Operations) blocks specifically designed for use in engineering works. The use of tyre bales in construction schemes within the United Kingdom has increased in recent years, partly from a desire to use economic innovative systems and partly because of the increasing number of waste tyres available.

Sources of information

6.12.2 Sources of information on tyre bales include:

- TRL PPR 45 (Winter et al, 2005), Tyre bales in construction: Case studies
- TRL PPR 80 (Winter et al, 2006), Tyre bales in construction
- PAS 108 Specification for the production of tyre bales for use in construction

6.11.3 Applications for highway earthworks widening: It is likely that tyre bales will typically be used in conjunction with one or more of the techniques described in Sections 6.2 to 6.12 inclusive. Figure 6.11 shows an example of the use of this technique for widening an embankment.

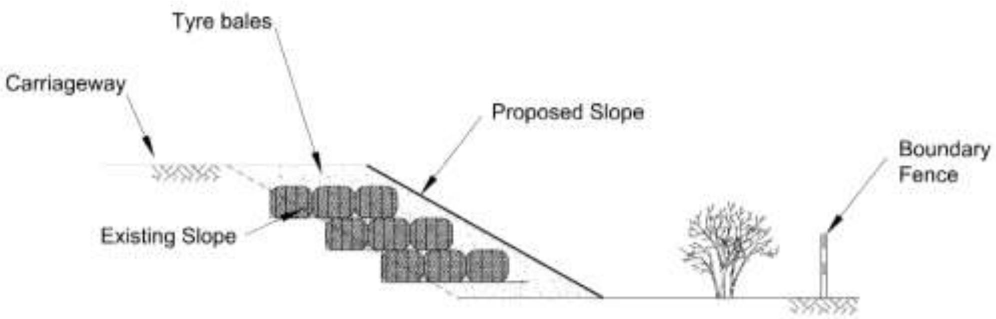


Figure 6.11 Widening of an embankment using tyre bales (diagrammatic only)

Design and construction of tyre bale solutions

6.12.4 Tyre baling involves the use of a specialist machine to produce a highly compressed, lightweight block containing between 110 and 120 tyres, for use in construction (Winter et al, 2006); The bales are approximately 1.3m x 1.5m x 0.82m, with a mass of around 890 kg and a density of approximately 0.55 Mg/m^3. Individual blocks are usually tied by galvanised steel wires (but mesh and polymeric materials can also be used) and when completed are sufficiently regular that they may be stacked. The baling machines are trailer mounted and may be transported to locations where there are large volumes of tyres. The energy required to recover used tyres as tyre bales is much less than that required to conduct other recovery processes – typically about 2 to 6%.

6.12.5 Since late-2005 both UK-mainland Regulators (ie Environment Agency and Scottish Environment Protection Agency) view tyre baling and the subsequent use of such materials in construction as a low risk activity, negating the need for Waste Management Licences.

6.11.6 Tyre bales are lightweight and even when internal voids and spaces are infilled with sand to improve stiffness and stability they are still considerably lighter than conventional embankment fill. They are cheaper than other special lightweight materials used in embankments (e.g. expanded polystyrene blocks and expanded clay fill).

6.11.7 PAS 108 (2007) has been developed to provide potential users with assurance that bales of consistent and verifiable quality are procured. It also provides some guidance in formulating preliminary design and construction proposals.

6.11.8 Tyre bales are regular in size and fairly regular in shape – but the faces are slightly convex and irregular compared with a well-filled gabion. The tyre bales are likely to need to be top soiled or possibly fronted with an improved face to improve the visual impact.

6.13 Methods of improving slope stability

6.13.1 In the case that existing slopes within highway widening schemes are defective or only marginally stable, the following techniques may be used to improve the stability of existing slopes, normally in conjunction with one or more of the widening methods described in Sections 6.2 to 6.12:

a. spaced bored piles

b. lime piles

c. vegetation

d. live willow poles

Improving the stability of existing and/or widened slopes as part of the widening scheme should be considered in relation to benefits and economies of scale, traffic management and site possession and, in general, as a proactive asset management good practice.

More details on each technique and sources of information are included in the following sub-sections.

Spaced bored piles

6.13.2 Spaced bored piles can improve the stability of a clay slope that has been steepened or widened at the crest or toe, leading to a reduction in the overall factor of safety against deep-seated failure. In the case of existing failures, the failure surface must be identified from ground investigation and this will dictate the penetration and location of the piles. This is a near permanent solution to resist potential deep-seated slope instability (see Figure 6.12) and it is generally used to repair large scale existing failure. The provision of walings between piles at the ground surface may also assist in preventing shallow failures.

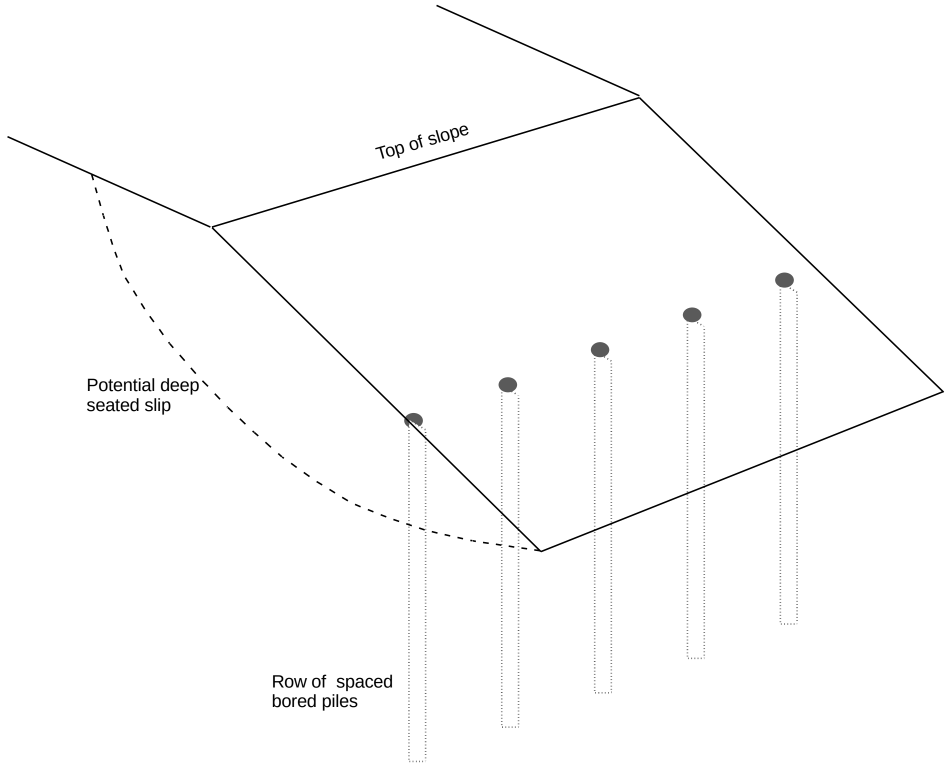


Figure 6.12 Slope stabilisation using a row of spaced bored piles

6.13.3 The spacing and diameter should maximise the arching of the soil between the piles and minimise the flow of soil between them. The typical spacing is in the range of 3 to 5 pile diameters, with 3 diameters indicated to be an optimum. Pile diameters are typically between 600mm -1200mm, depending on the rig that can be mobilised (Hayward et al (2000), Carder (2005), Durrani and Reddish, (2008)).

6.13.4 The design procedure for designing the piling system to either stabilise or steepen a slope involves evaluating the restoring shear needed to achieve the required factor of safety for overall stability of the slope and design the most appropriate pile layout to provide the required resistance.

6.13.5 Design methods which may assist in determining the pressures acting on the upper part of the pile within the potential zone of yielding are reviewed by Carder and Temporal (2000).

6.13.8 Instrumented case history studies using a single row of spaced bored piles to stabilise slopes on the HA network, are reported by Carder and Barker (2005a; 2005b).

Lime piles

6.13.9 Shallow failure of ageing clay slopes of highway embankments and cuttings can be prevented by the installation of grids of small diameter lime piles. This technique is more generally used for repair and larger scale works e.g. to stabilise potential shallow slope failures or as an alternative to using cement or lime stabilisation. As this solution has only been used occasionally for widening schemes on Highways England's network, detailed consideration would be needed to assess their suitability for a particular location.

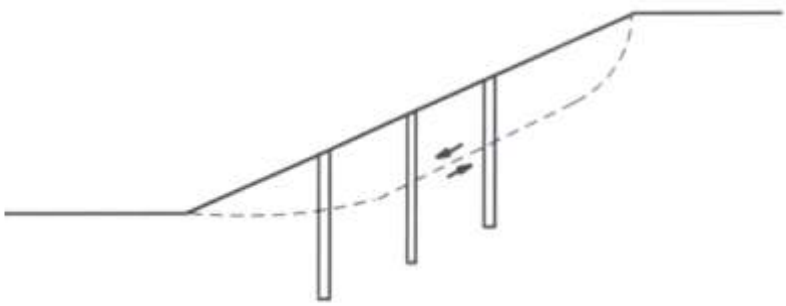
6.13.10 The piles can be formed from either pure quicklime or lime-stabilised soil. The short-term benefit in stability is gained from a reduction in pore water pressure and dehydration of the clay surrounding the pile as water is absorbed from the slope to hydrate the lime. Over longer terms the original ground water levels are likely to be re-established, however by this time various chemical and pozzolanic reactions will have occurred resulting in sufficient strength increase for the piles to improve stability by dowelling action.

6.13.11 Lime piles are typically about 200mm diameter and spaced at 2m centres. The piles should be deep enough to intercept the potential slip surface and penetrate beyond it into stable ground. Simple methods for deciding on the spacing and depth of the piles were reviewed by West and Carder (1997). The long term undrained shear strength of pure quicklime piles has been reported as 400kPa by Rogers and Glendinning (1997) and as a higher value of 700kPa by Brookes et al (1997). These strengths were largely based on testing of piles installed in London Clay; laboratory strength testing should be carried out prior to installing lime piles in other clays.

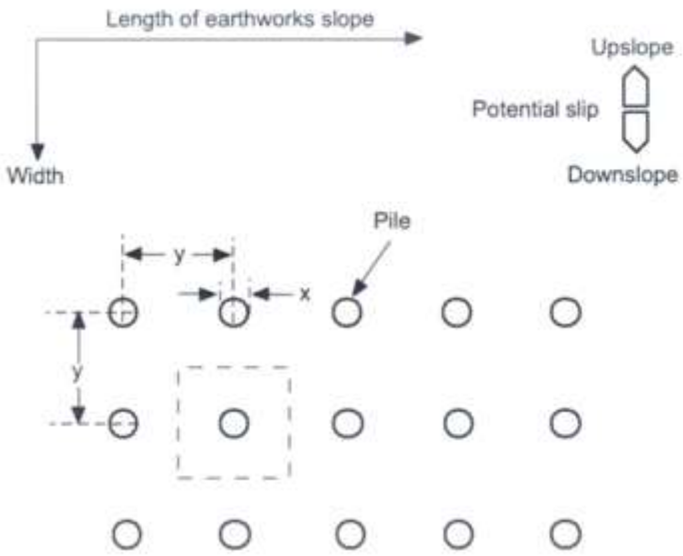
6.13.12 Lime piles can be installed using slope climbing drilling rigs, long reach equipment or rigs working from scaffolding platforms without disturbing the existing slope. Granulated quicklime is generally used to construct lime piles and should comply with BS EN 459-1 and reactivity tested in accordance with BS 6463.

6.13.13 Exhumation of lime piles after hydration has shown that, although rigid, they are also very brittle. This gives rise to concerns about their resistance to lateral movement of the clay slope. One solution is to install a plastic water well screen as a close fitting liner to the borehole prior to placing and compacting the quicklime within it (Brookes et al, 1997).

6.13.14 An instrumented full-scale trial of lime piling on a Gault Clay embankment slope is reported by Carder et al (2001).



(a) Protection against shallow failures (diagrammatic only)



(b) Pile installation (diagrammatic only)

Figure 6.13 Installation of a grid of small diameter lime piles to improve the stability of a slope

Vegetation

6.13.15 Vegetation can improve the stability of slopes primarily through soil moisture depletion, root reinforcement, buttressing and arching, and surface cover shading of the soil. However, the stability of the new slope should not be relying purely on the presence of vegetation as this could die off or be removed, or be impacted by climate changes. Established vegetation will cover the soil surface and root growth can penetrate to a depth of up to about 500mm (although 80% of the root is in the top 50mm) for grasses and up to 5m for trees.

In highway widening the careful selection of appropriate vegetation can be a cost effective option in the following situations:

a. Where an improvement in the stability of clay slopes against shallow-seated failures is required.

b. Where construction of a steeper, but nevertheless stable, slope is needed. As well as the benefits of enhancing landscape quality and being aesthetically pleasing, the use of vegetated steeper slopes in widening situations requires less land-take so resulting in cost savings. There may be advantages in combining a bioengineering approach with geosynthetics in steepened slope applications.

c. As an indirect method of improving slope drainage, vegetation cover prevents ingress of water into slopes encouraging surface water runoff at a controlled rate. The root growth acts to reduce pore water pressures and to bind the surface layers together minimising both erosion and the formation of shrinkage cracks.

6.13.16 Where vegetative cover has been removed as part of the widening works, there may be some merit in re-establishing vegetation at an early stage if the planting season is appropriate. This may help to prevent soil erosion and local instabilities during construction, if the slope surface is left bare for any significant length of time. Where needed, a maintenance regime for vegetation should be established to avoid causing potential stability issues.

6.13.17 The bioengineering role of vegetation in determining the moisture regime and stability of earthworks has been discussed in detail by Coppin and Richards (1990), Marsland et al (1998), Marriott et al (2001), and MacNeil et al (2001). The advice of a specialist in ground bio-engineering should be sought.

6.13.18 Quantification of the benefits to slope stability, in terms of reducing the risks of both shallow and deep-seated failures, are given by Coppin and Richards (1990) and Greenwood (2006a), who gives a framework for adapting routine investigation procedures to consider vegetation issues.

6.13.19 There are a number of reviews which cover the general growth of vegetation and the selection of appropriate plant groups, e.g. Coppin and Richards (1990), Bache and MacAskill (1984), Schiechtl and Stern (1992). Full scale trials of on-slope planting have been carried out to assess the suitability of different species, see Marriott et al (2001) and MacNeil et al (2001). A demonstration trial was also conducted by CIRIA on the M20 motorway near Maidstone (CIRIA, 1996).

Live willow poles

6.13.20 Installation of live willow poles offers an easy, relatively rapid and cost effective method of ensuring that vegetation is successfully established both at surface level and at depth within a slope. The live poles provide a form of vegetated soil nailing or dowelling which improves slope stability and can be used in the prevention and repair of shallow slips on highway slopes. Further benefit to the stability of the slope is also gained through establishment of a root system and a reduction in the soil moisture. As with other forms of vegetation, the stability of a new slope should not rely solely on live willow poles as they could die off or be removed.

In highway widening, live willow poles may be particularly effective in stabilising slopes in the following cases:

a. Where the slope shows incipient signs of shallow failures, willow poles can be installed before or after the carriageway widening works as no heavy construction plant is required.

b. Where some steepening of an otherwise stable slope has occurred, willow pole installation will act to prevent the development of shallow slips.

c. Open, unshaded slopes are more likely to benefit from willow pole installation. Where there is already significant vegetation, the improvement in stability may be marginal.

6.13.21 Identification of the potential or existing location, depth and extent of any shallow failures of the slope and any water bearing strata are of paramount importance at the ground investigation stage. The location of any on-slope drainage systems or buried utilities should also be surveyed to prevent their damage during planting.

6.13.22 The spacing between poles is critical in ensuring that arching, rather than flow, is sustained between adjacent poles (Wang and Yen, 1974). The maximum shear force that each pole can provide to sliding can be calculated as for laterally loaded piles by assuming passive pressures act in the stable soil and active pressures in the failing mass above. The methods of Broms (1964) and Poulos and Davis (1980) are typical of these approaches.

6.13.23 Detailed advice on the procurement, preparation, installation and maintenance of willow poles is given by Steele et al (2004).

6.13.24 Three full scale trials were carried out at A10 Hoddesdon, M1 Toddington and A5 Milton Keynes respectively and a proactive maintenance program at M23 Gatwick (Steele et al, 2004; Barker, 2000). These trials followed a preliminary trial at Iwade (Barker, 1997; Steele et al, 2000), a literature review carried out by Hiller and MacNeil (2001), and a draft specification produced by Barker and MacNeil (2001).

6.14 Comparative costs of alternative widening solutions

6.14.1 The cost of each widening solution per metre run of earthwork is difficult to evaluate because of the competitive commercial market and the considerable variation of costs between different parts of the country. Therefore, only comparative costs of the main alternative earthworks widening solutions have been presented.

6.14.2 The comparative costs presented in this section are for a symmetrical motorway widening scheme to achieve sufficient width for one extra lane with retained heights of about 1.1 m in medium plasticity clays. The comparative costs are given in Table 6.3a (for cuttings) and Table 6.3b (for embankments).

Basis of comparative costs

6.14.3 The base case is a mass earthworks solution. It assumes regrading a 5m high cutting at the existing angle to achieve sufficient width for one extra lane, per linear metre of verge. This is used as the base case for both embankment and cutting solutions; by comparing Tables 6.3a and 6.3b, it can be seen that widening embankments is generally more expensive than widening cuttings. Two slope heights have been considered with the aim of showing that the cost of some solutions depends on the geometry or height of the slope.

6.14.4 The comparative cost of each widening option was estimated - based on unit rates for the construction elements of each option. These were obtained from price books, industry specialists and analyses of previous widening schemes using cost data provided by Highways England.

6.14.5 The estimated costs of each option included all direct construction costs of the permanent works and any associated temporary works, such as the temporary sheet piling required for some options.

6.14.6 The estimates excluded the costs of items that are required for the widening scheme irrespective of the chosen earthworks widening option, such as traffic management, carriageway drainage or pavement construction for the new hard-shoulder.

6.14.7 The costs for the “T” or “L” shaped reinforced-concrete cantilever walls and the reinforced soil walls built at the crests and toes of embankments are significantly affected by the need or otherwise for temporary sheet piling to support the temporary excavations safely where space is restricted. The lower value in the range quoted in Table 6.3b is without temporary sheet piling (where viable) and the higher value is with temporary sheet piling.

Programme impact

6.14.8 A qualitative indication of the impact on programme (low to high) has been added to the comparative costs presented in Tables 6.3a and 6.3b. The effect on programme should always be taken into consideration in the selection of the optimal widening solution because options which are slow to construct could significantly increase the overall scheme costs including traffic management and site establishment.

Table 6.3a – Comparative costs of widening cuttings

Cutting widening solution	**Cost as multiple of the base case (5m high cutting regrade)**		**Programme impact**
	Overall slope height		
	< 3m	**5 – 10m**	
Regrade at existing angle	0.5 or more	Base case = 1	Low
Regrade at steepened angle	Up to 0.5	About same	Low
Regrade at steepened angle with counterfort drains	About same	About same	Low
Regrade at steepened angle with a rock-fill wedge at base of cut	Not applicable	Up to 2	Low
Contiguous bored piled wall at base of cut (assumes 450 mm diameter piles at 600mm centres)	5 to 6	5 to 6	High
Spaced bored soldier piles with waling at base of cut (assumes 450 mm diameter piles at 1800 mm centres)	4 to 5	4 to 5	High
Steel sheet pile wall at base of cut	2 to 3	2 to 3	Low
Plastic sheet pile wall at base of cut (1)	Up to 2	Up to 2	Low
In situ reinforced concrete L-shaped wall at base of cut	2 to 4	4 to 5	High
Precast reinforced concrete L-shaped wall at base of cut	2 to 4	2 to 5	High
Soil nails with hard facing at base of cut	Up to 3	Up to 3	Potentially High
Soil nails with flexible facing at base of cut	Up to 2	Up to 2	Potentially High
Gabion wall at base of cut	Up to 3	No data	Potentially High

Notes:

(1) The table presents comparative costs obtained in 2008.
(2) Plastic sheet piles wall may not be appropriate in some ground conditions, based on toolkit 50% cheaper than steel equivalent.

Table 6.3b – Comparative costs of widening embankments

Embankment widening solution	**Cost as multiple of the base case (5m high cutting regrade)**		**Programme impact**
	Overall slope height		
	< 3m	**5 to 10m**	
Overfill with imported selected granular fill at existing angle(1)	Up to 2	2 - 5	Low
Geogrid reinforced slope of selected granular fill at steeper angle (4)	2 - 3	3 - 4	Potentially High
Lightweight fill - expanded clay (5)	2 - 3	2 - 6	Low
Lightweight fill – expanded polystyrene (EPS) (6)	5 - 10	>10	Low
Tyre bales (7)	<1	<1	Low
Contiguous bored piled wall at crest of bank (450mm dia. piles at 600 mm centres)	5 - 6	5 - 6	High
Contiguous bored piled wall at base of bank (450mm die piles at 600 mm centres)	6 - 8	6 - 8	High
Spaced bored soldier piles with waling at crest of bank (450mm dia piles at 1800 mm centres)	5 - 6	5 - 6	High
Spaced bored soldier piles with waling at base of bank (450mm dia piles at 1800 mm centres)	No data	No data	High
Steel sheet pile wall at crest of bank	3 - 4	3 - 4	Low
Steel sheet pile wall at base of bank	3 - 4	3 - 6	Low
Plastic sheet pile wall at base of bank	Not appropriate	Not appropriate	Low
No net load increase block work wall (8)	4 - 5	4 - 5	Low
Reinforced concrete L-shaped wall at crest of bank (3)	4 - 8 (2)	12 - 16 (2)	High
Reinforced concrete L-shaped wall at base of bank (3)	4 - 6 (2)	6 - 9 (2)	High
Steep reinforced soil slope at crest of bank (3)	4 - 6	8 - 10	High
Steep reinforced soil slope at base of bank (3)	4 - 6	7 - 9	High

Notes:

(1) The table presents comparative costs obtained in 2008.
(2) It assumes no temporary works / sheet piling required.
(3) Costs assumes no parapet, open-box beam, safety fence and wooden post & rail fence along top of wall.
(4) See Paragraph 6.17.6 for assumptions about temporary sheet piling or otherwise.
(5) Geogrid approx. 30% of reinforced concrete wall (from MDC toolkit) or 110% of granular wedge (from M1C1).
(6) Expanded clay 1.1 times cost compared to conventional fill (from MDC toolkit), this value may need reducing as a steeper angle can be achieved.
(7) EPS 5 times cost of conventional fill (from MDC toolkit), this value may need reducing as steeper angles can be achieved.
(8) Tyre bales 20 to 50% cheaper than imported fill (from MDC toolkit)
(9) Based on 1.4 times spaced bored piles.

7 WIDENING SOLUTIONS FOR SMART MOTORWAYS

7.1 "Smart Motorways" is the term that Highways England uses for enabling dynamic control of traffic for congestion and incident management. It is a developing technology and current best practice guidance is contained in Interim Advice Note IAN 161. Smart Motorways include Controlled Motorways (CM), Active Traffic Management (ATM), Managed Motorway-Dynamic Hard Shoulder (MM-DHS) and All Lane Running (ALR) schemes. Some major all-purpose roads also incorporate mandatory variable speed limits and will have similar infrastructure. As the Highways England's programme of Smart Motorway schemes share many common elements, there is scope for development of standard details and products to achieve efficiencies in design and construction across the programme.

7.2 Smart Motorway schemes typically have the following components:

- Variable mandatory speed limits displayed on gantry mounted matrix signs (all)
- Controlled use of the hard shoulder as a running lane (ATM, MM-DHS and ALR)
- Emergency Refuge Areas (ERAs) which are lay-bys for emergency use
- Increased technology solutions including CCTV, matrix signs and speed monitoring

Earthworks widening for Smart Motorways

7.3 Widening solutions are typically used in two situations on Smart Motorway schemes:

a. Where the existing motorway verge is too narrow to fit new drainage, vehicle restraints, access routes or communications ducts, it may need continuous widening with a small "local toe treatment" type of retaining wall or earthworks solution. Plastic sheet piles or concrete edge beams have been used in this context, for retained heights of about 0.5m, providing the overall stability of the slope is not reduced to unacceptable levels. Ideally the verge infrastructure design should be co-ordinated to avoid the need for such treatments in most cases.

b. Limited lengths of carriageway are widened by several metres to create space for the Smart Motorway infrastructure such as ERAs, gantry bases (including space for communications cabinets and chambers), and minor structures such as CCTV and roadside matrix signs. The location of these features is fixed by operational requirements rather than ideal topography or ground conditions, and so earthworks or retaining solutions are needed to permit local widening, with retained heights of typically up to 3 metres.

7.4 The first completed Smart Motorway scheme in the UK was the M42 Active Traffic Management (ATM) pilot scheme between Junctions 3A and 7, opened in 2006. Over the 17 km length of the scheme, 39 ERAs were constructed involving 4 km of retaining walls, as well as nearly 100 gantry bases (Malan, 2006). The ability to construct the works within limited hard shoulder and lane closures was the most significant factor in the choice of earthworks widening solution.

Standardised design approach

7.5 With so many repeated features, experience shows that it is beneficial to adopt a standardised hierarchy of solutions. ERAs tend to be self-contained features, with a standard footprint. On the M42 pilot, a “menu” of widening solutions to accommodate variations in ground conditions, working space and environmental constraints was developed for cutting and embankment situations, based on the options in Tables 6.1a to 6.1d included in Section 6 of this report.

Gantries on Smart Motorway schemes:

7.6 A feature of Smart Motorway schemes is the provision of gantries at regular intervals along the motorway. These include truss gantries that span the entire motorway carrying advance direction signs or matrix variable speed indicators, and cantilever gantries supporting larger matrix signs or exit signs. Recently, to avoid foundations in the central reserve, “super cantilever” gantries have been developed with a truss boom that cantilevers from a verge foundation to span one carriageway. Gantry foundations should be co-ordinated with adjacent earthworks widening solutions, enabling access for a piling rig if needed and designing for the construction and permanent loads.

Emergency vehicle turnarounds and hard standings

7.7 IAN 68 describes the potential provision of emergency turnaround areas and hard standings for emergency vehicles adjacent to the carriageway. These are much smaller in width and length, than the ERA but the recommendations of this section will general also apply to their construction.

Need to address incipient embankment slope failures

7.8 When the hard shoulder is converted to a running lane, as in ALR schemes, the HD 41 Feature Grade of existing or incipient slope defects may be increased (refer to HD 41 Maintenance of highway geotechnical assets). The design should include assessment of the need for repair or remediation of any such defects that might have an increased risk of encroaching on the carriageway as a result of a scheme.

8 CONSTRUCTION AND MAINTENANCE

8.1 Some details of construction have been given in earlier sections of this report and further details are given in the references. The overarching principle is to minimise the exposure to risk of the construction and maintenance workforce and the travelling public, whilst working effectively within the confines of the site. The following aspects are particularly emphasised:

Important rules for working on earthworks slopes

8.2 There are three important principles for working on earthwork slopes.

a. DO NOT remove material from the toe of the slope except under controlled conditions which maintain stability.

b. DO NOT stockpile material at the top of the slope or on the slope.

c. DO NOT allow water to enter the slope and check that the existing drainage system is functioning correctly.

Working in bays or short sections

8.3 In many situations involving excavation into an existing slope, it will be necessary to work in short sections such that the material left in place on either side of the excavation provides arching support. The time for which the excavation is left unsupported must be as short as possible, especially with cohesive soils where the re-equilibration of negative pore water pressures may cause instability.

Minimising disturbance to existing slopes

8.4 Many side slopes on motorway and trunk road earthworks are already showing signs of distress, and on others a heavily vegetated and desiccated crust may be disguising softened material at a lower level. All construction techniques cause some disturbance, which will need to be kept to a minimum by using appropriate types of plant located in the appropriate place.

Existing vegetation on earthworks slopes

8.5 Where trees or shrubs exist on the embankment or cutting slope, they may be of value as a natural habitat or for visual screening of the motorway from neighbouring developments. Highways England's scheme-specific Environmental Co-ordinator should be consulted to establish if any where it is desirable to retain the vegetation, and if so what protection measures need to be adopted. Clearance of vegetation for temporary working space may need to be controlled or restricted as it could potentially lead to stability issues. This requirement may affect the choice of widening solution.

Compaction of new fill

8.6 There is some evidence to suggest that good compaction of fill materials in embankment side slopes increases the stability of the slope in the longer term. Good compaction control is therefore of primary importance: Table 6/4 of the Specification for Highway Works shows that it is possible to achieve as high a level of compaction using a larger number of passes and smaller compacted layer thicknesses with lightweight compaction plant as it is with heavy equipment. The former is to be preferred where stability is critical or space is at a premium.

Construction sequencing

8.7 The sequence of site operations, the handling of materials and the location of plant accesses are essential matters which must be catered for as part of the design. To overlook these matters may lead to instability, create dangerous hazards and increase costs, particularly on long narrow worksites.

Requirements for working near live traffic

8.8 Department for Transport requirements for working spaces and safety zones must be observed: safety zones are covered in the Traffic Signs Manual, Chapter 8.

Finishing works for earthworks slopes

8.9 When using any of the techniques described in Section 6, the finished side slopes should, wherever possible, be top-soiled, grassed and seeded in accordance with Clause 618 of the Specification for Highway Works. On steeper slopes, it may be necessary to incorporate measures to reduce the incidence of soil erosion. A programme of after-care may be needed to make sure the vegetation is securely established to be successful in the long term.

Buildability of earthworks widening solutions

8.10 Further information on buildability aspects is contained in Section 6 Tables 6.1a to 6.1d and Coppin and Richards (1990).

Differential settlements and embankment widening

8.11 Differential settlements between embankment extensions and existing embankments should be estimated as part of the design of the earthworks widening scheme and need to be confirmed to be acceptable.

Cut/fill balance

8.12 Schemes should aim to maximise re-use of materials. However, due to the small quantities involved and the constraints of programming and narrow verge working, there may be limited scope to stockpile materials on widening and Smart Motorway schemes.

Noise and vibration

8.13 Works adjacent to built-up and residential areas may be restricted by a desire to minimise noise nuisance. One common source of noise is sheet piling, and various rigs are available to reduce the noise of pile driving in favourable ground conditions. However, environmentally friendly leader rigs need a piling platform adjacent to the wall alignment.

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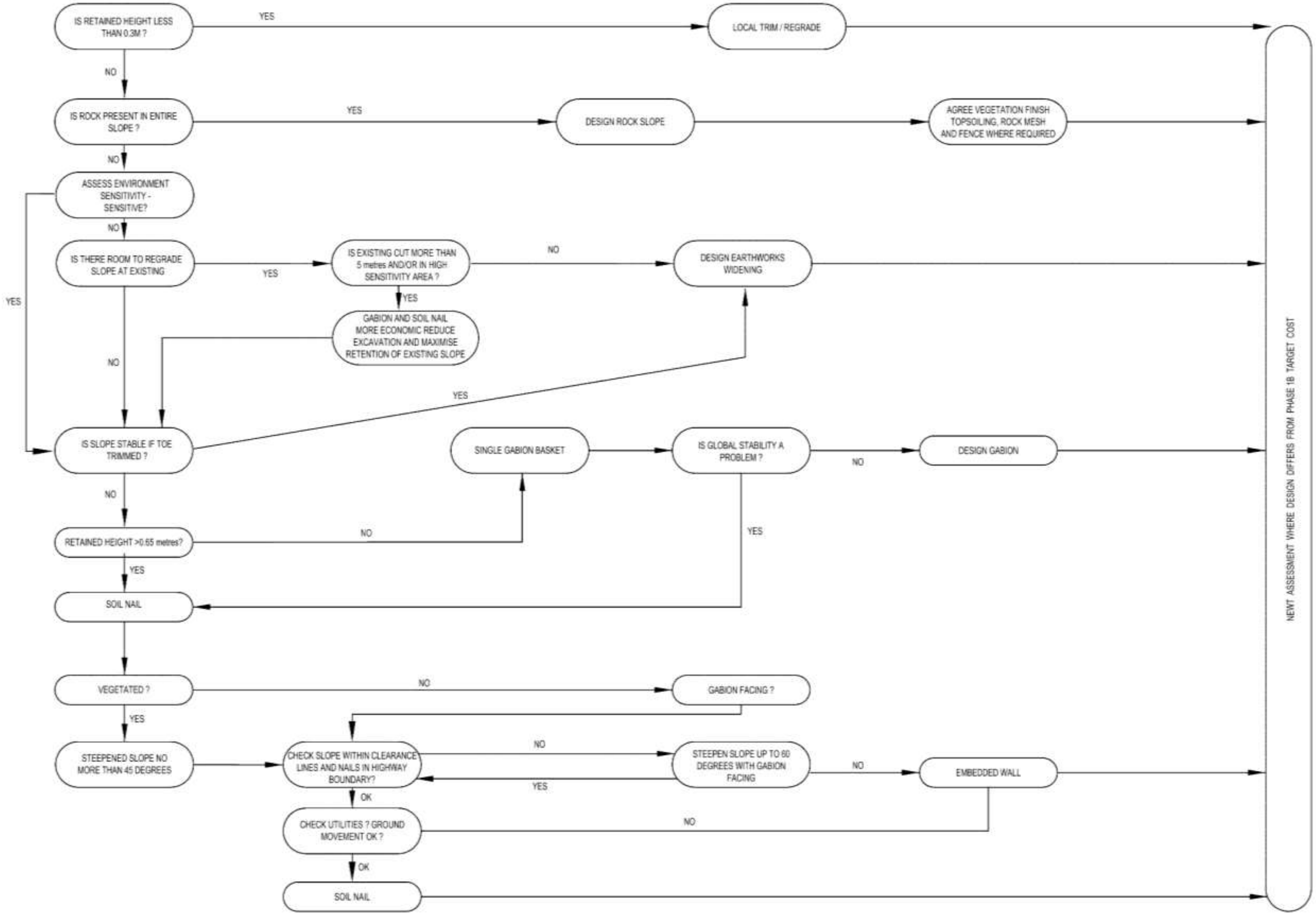
Appendix A

A1 Example of detailed design decision tree for cutting widening from M1 Widening Junctions 25 to 28



A2 Example of detailed design decision tree for embankment widening from M1 Widening Junctions 25 to 2