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Forensic Examination of Critical Special Geotechnical Measures: Counterfort Drain Information Note

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Executive Summary

The effective design, specification and construction of Special Geotechnical Measures (SGMs) is critical to the efficient operation of the National Highways Strategic Road Network (SRN). Given the required performance of the SRN in terms of resilience, reliability, redundancy and recovery it is essential that SGMs are themselves reliable in terms of performance and life; resilient to external conditions such as earthworks deterioration and extraordinary conditions (e.g. climate change). Around 100 different types of SGMs are used on the SRN and the early installations of some SGMs are approaching the end of their design life and the design, specification and application of many of these techniques is based on limited studies.

This Information Note is part of a series that reports on investigations of specific SGMs, in this case Counterfort Drains, and makes recommendations on their future use. A detailed account of issues identified on the Strategic Road Network (SRN) and other infrastructure is given drawing from relevant research and applied studies and inspection of counterfort drains in various settings.

Advice is given on the design, construction, inspection, maintenance and decommissioning of Counterfort Drains. A series of recommendations is made for Counterfort Drain SGMs with the most important being that they cannot meet the required design life for slopes of 60 years, as the filter/separator and drainage aggregate element are likely to need remediation or replacement. There is a body of evidence that suggest that this will be required at between 15 and 25 years. There is substantial evidence that in the UK, counterfort drain design, specification and construction is frequently not at a level that would promote longevity of this nature.

Overarching recommendations include increasing the early involvement of operational and maintenance geotechnical input and a move to cease the practice of contractor self-certification.

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1 Introduction

This Information Note on Counterfort Drains is part of a wider study of the performance of critical Special Geotechnical Measures (SGMs) (Duffy-Turner et al. 2022). It is one of a series that reports on investigations of specific SGMs, in this case Counterfort Drains, and makes recommendations on their future use.

Based on Atkins/Jacobs (2020), Counterfort Drains (CFDR) are defined as “*gravel-filled drains extending to full earthwork depth/height”*. They have been used since the first half of the nineteenth century (Hutchinson, 1977) to stabilise embankments and cuttings with high groundwater pressures (Macdonald et al., 2012; Bromhead, 1984; Hutchinson, 1977).

Counterforts are also commonly used in conjunction with Crest Drains, Slope Drains (Herringbone Drains) and Toe Drains to provide both surface and groundwater drainage for slopes (Burland et al., 2012). It should be noted that separate SGM types have been defined for Crest Drain (CSDR), Cut off Drain (CODR), Herringbone Drains (HBDR), Slope Drains (SLDR), Rock Ribs (RIBS) and Toe Drains (TODR) within the drainage SGM category.

Counterfort Drains are commonly used to address problems as they arise during the construction of infrastructure embankments and cuttings and as emergency remedial works on existing embankments and cuttings (reparative or remedial design).

Counterfort Drains usually run down the ‘fall line’ of slopes (i.e. the line of steepest slope) which is usually perpendicular to the crest of the slope. They are typically 0.6m to 1.2m wide trenches (Figure 1) which are normally lined and covered with a geotextile filter/separator, to prevent erosion in the slope and silting up of the drain. Older examples may have a granular filter material rather than geotextile. They are usually filled with stone or granular backfill and may have a slotted ‘collector’ pipe laid in the base.

Counterforts are typically between 2m and several metres deep and are often designed to penetrate below known slip planes to drain the failure zone (Hutchinson, 1977). Where counterforts are backfilled with rock fill, or other relatively high shear strength materials, they can be used to provide strengthening or ‘buttressing’ elements to earthworks and are also known as Rock Ribs (Hutchinson, 1977). To provide the buttressing effect the counterforts need to be installed at relatively close spacings of between 5m and 10m (Macdonald et al., 2012).

Counterfort Drains appear frequently on the Strategic Road Network (SRN) and are usually primarily intended to fulfil the drainage function with the buttressing function being subsidiary and only rarely forming the focus of design.

Figure 1: Regraded slope on the Cumbrian Coast Railway with Counterfort Drains. The upper slope above the rock fill blanket is clayey till and the area covered by the rock fill blanket is glacial sand (believed to be an esker). The counterforts also have slope (herring bone) drains to pick up localised water, they are generally concealed by the rock fill blanket. This highlights the need for detailed as built records to aid with future inspections, analysis and maintenance. Note the crest drain for the slope outfalls via a reno mattress lined channel on the right-hand side of the (image J. Murphy and Sons Ltd.)

2 Issues Identified on and off the Network

2.1 Issues Identified on the Strategic Road Network (SRN)

A series of site inspections of Counterfort Drains was conducted between October 2020 and February 2022 to establish the prevalence, nature, condition and setting of Counterfort Drains on the SRN. The details of the sites are presented in Appendix A. During these site inspections a number of issues were identified.

A common observation was that the debris left from vegetation management was deposited on the surface of drains potentially clogging the drainage media in the long term (Figure 2) as it decomposes and enters the drain structure. While it is not entirely clear whether the debris was deliberately placed in these locations it did seem more prevalent on sub-horizontal herring bone drains connected to the counterfort drains where these were present (Figure 3). It could be that the debris from vegetation maintenance was not originally deposited on the drain surfaces but transported over time under the action of water and gravity. As the deposition of such debris on slope surfaces has become common practice in recent decades this may have significant implications for drain efficacy and such practices may need to be either carefully managed or ceased on slopes with such sub-horizontal drains.

Figure 2: Vegetation debris from vegetation maintenance with the potential to block the structure of the drainage media (A14 [no SGM number, National Grid Reference NGR SP 62450 77600], October 2020)

Figure 4 illustrates the build-up of leaf matter; this appears to be entirely natural and without the implication of being the result of any maintenance activity. Over time as the leaf matter decomposes and enters the drain structure it has the potential to reduce its efficacy. In Figure 4 it is clear that the brambles that largely cover the site have not established within the drains themselves, while in Figure 5 moss with the potential to block the drain can be observed. Vegetation growth can be observed beginning to encroach into the margins of the drain surface (Figure 2 and Figure 3), potentially leading to a significant decrease in the efficiency of the drains in the long term. Figure 6 illustrates the effect of such clogging on the drainage media; this drain is likely to have been constructed in the late-1970s or early-1980s.

These issues indicate that there is a need to ensure that vegetation removal does not reduce the efficacy of counterforts, or any other form of drain, and also for periodic maintenance to rake away any leaf debris that builds up on the drain surface along with the removal of vegetation growing on and into the drain structure.

Figure 3: Vegetation debris from vegetation maintenance with the potential to block the structure of the drainage media (A14 [no SGM number, National Grid Reference NGR SP 62450 77600], October 2020)

Figure 4: Vegetation debris with the potential to block the structure of the drainage media. The width of the drain is approximately 1.2m (A30, SGM 2053, January 2021)

Figure 5: Vegetation debris and moss growing on the surface of a Counterfort Drain with the potential to clog the structure of the drainage media. (A30, SGM 1924, January 2021)

Figure 6: The effects rotted vegetation and soil migration into the drainage media can be seen by the degree of clogging in the centre of this approximately 1m wide Counterfort Drain; the aggregate sizes generally range from around 20mm to 90mm (A30, SGM 2065, January 2021)

Post-construction settlement of drains often occurs at either the head of the drain or at the junction with feeder drains, such as herringbone drains, creating a preferential path for erosion and deposition of material within the drains causing later clogging. An example of such settlement is illustrated in Figure 7 at the junction with a herringbone drain on a cutting slope. This has created a preferential water path and associated erosion and downslope washout of the drainage media. Such settlement can also be observed in Figure 8 which is an image of a recently installed drain – here the large (over) sized fill has either been incompletely filled during construction or settled significantly after construction.

The scale of the issue at this site can be gauged from Figure 9, a counterfort drain that extends to the top of the cutting slope, where the cavity extends the full width of the drain and vertically by around 0.5m. The potential for future erosion of material that could be transported to the carriageway below is clear. Indeed, this may explain the oversized fill at the surface potentially having been placed as a means of preventing the erosion of standard drainage (typically Type A or Type B) media which can be more readily mobilised and transported.

Figure 7: Settlement of drainage media at the junction with a feeder drain, in this case a herringbone drain. A 13cm scale can be seen towards the top-centre of the image within the red circle (A30, SGM 2065, January 2021)

Figure 8: Settlement of large-sized drainage media at the head of a herringbone drain, that links to a counterfort drain (M6 J34 northbound on-slip, no SGM number, NGR SD 49665 65240, March 2021)

Figure 9: Settlement of large-sized drainage media at the head of a counterfort drain (M6 J34 northbound on-slip, no SGM number, NGR SD 49665 65240, March 2021)

The primary function of a counterfort drain is to intercept the water from within the earthworks slope. There is, however, often a desire to additionally intercept surface and near-surface water from the earthworks slope and any slope above as well, including from existing drainage. The counterforts at the M6 Junction 34 site are understood to have been installed in response to washouts experienced and wet areas observed on the cutting slope during and after Storms Eva, Frank and Desmond. The need for adequate drainage of the cutting slope was very clear from observations made by the authors from the M6 during this time period. It is also clear that the field above (Figure 10) has a role to play in ensuring an effective drainage solution. The field is characterised by a bowl-shaped catchment and exhibits linear patterns that appear to correspond to land drains; water from the crest drain does not, therefore, reach the headwall and enter the counterfort drain system. Indeed, it appears that the overflow from the sidewall of the crest drain to the north of the headwall pictured in Figure 11 may be responsible, at least in part, for the erosion illustrated in Figure 9.

One of the land drains referred to above can be seen in Figure 12 where it reaches the slope surface approximately 2m to 3m from the nearest counterfort drain; a steady flow of water was observed, demonstrating that the drain was active following heavy rain the preceding day. Neither the crest drain at this site, nor the counterfort drains, intercept the existing field drains in an effective manner (this is one of several such instances that were observed at the M6 site).

Figure 10: The field above the slope referred to in Figures 8 and 9, and Figures 11 to 12. While not particularly evident from the photograph the field forms a large bowl-shaped catchment, is observably boggy and wet, and the line of existing near-surface land drains are also evident in places (M6 J34 northbound on-slip, no SGM number, NGR SD 49665 65240, March 2021)

The consequence of water overflowing the crest drain was observed in contemporaneous (20202) Google Street ViewTM imagery which illustrated significant erosion of the slope and the drainage media amongst other things. (unfortunately, this imagery is no longer available on Street View) It seems clear that there are several needs at this site, as follows:

- The drawdown of water from within the slope.
- The collection and management of surface water from the slope above.
- The collection and management of water from existing land drains where they reach the surface of the cutting slope.

Figure 11: Slope crest drain and headwall intended to channel water into the counterfort drain below. Note the invert of the pipe is at a slightly higher elevation than the sidewall of the crest drain. As a result, water overtops the crest drain prior to entering the pipe and flows onto the slope and the Counterfort Drain below, see Figures 8 and 9 (M6 J34 northbound on-slip, no SGM number, NGR SD 49665 65240, March 2021)

Figure 12: A land drain daylighting on the slope surface approximately 2m to 3m from the nearest counterfort drain (M6 J34 northbound on-slip, no SGM number, NGR SD 49665 65240, March 2021)

The constructed system of counterfort drains, herringbone drains and a crest drain appear to be intended to address the first two of these but not the third. The intention seems to be to collect the groundwater and surface water from the cutting slope and also the surface water from the slope above into the counterfort system; no attempt appears to have been made to collect water from the shallow land drains in the slope above and that extend into the cutting slope.

Notwithstanding the success, or otherwise, of the particular scheme, this does raise questions about whether surface and groundwater should be dealt with separately or in combination. Clearly, dealing with both in a single system introduces additional complexities including the need for counterfort drains to be open at the surface in order to collect surface water, creating vulnerabilities to infiltration of fines, clogging and erosion, and for additional connections to take surface water from, for example, a crest drain. Dealing with groundwater and surface water separately will increase costs as essentially two systems are required.

The foregoing has focussed purely on counterfort drains. However, one site was encountered at which the counterforts were apparently designed without a drainage function (Figure 13) smaller sized aggregate was used, and the available design details allude to this approach. Clearly, this is a valid approach, but its benefits seem somewhat obscure especially as additional drainage was not introduced during the remedial works to install the counterforts and the counterforts appear to have been completely enclosed. The use of a suitable drainage media and a simple tie-in to the existing embankment toe drain would have been relatively straightforward and potentially added value to the project.

Figure 13: Counterfort constructed with the intention that it only act as a counterfort, that is without having a drainage function (A303, SGM 3329, January 2021)

During the course of this project the authors inspected nine counterfort drain sites. While many of the constructions are quite old others were more recent with the M6 Junction 34 counterfort drains understood to have been constructed around 2014/15. No evidence of a geosynthetic wrap to separate the drainage media from the surrounding soil and to provide a filtration function was found at any of the sites. Such geosynthetics are typically located at depths of around 300mm although some evidence of their presence nearer to the surface is often visible at shallower depths. The potential for excavation to uncover such filters was limited, however all reasonable efforts were made to do so and in some cases, such as parts of the M6 site, it was possible to inspect to such depths. The use of geosynthetics in this manner helps to prevent the infiltration of both soil and decayed vegetation from entering and clogging the drain system. This absence can be partly explained by the age of some of the drains, which might well pre-date or be contemporaneous with the introduction of geosynthetics to widespread use within the construction industry. This factor does not, however, explain the apparent absence of geosynthetics in more recently constructed drains. This absence of geosynthetics is not unique to the SRN and is mirrored in the authors' experience on other transport infrastructure networks, albeit perhaps not to the same extent.

Issues surrounding clogging of counterfort drains (and filter drains in general) were also highlighted (Figure 14). Surface clogging due to a build-up of leaf litter and humous and washing in of fines (fouling) were all observed. This clogging was worsened where trees were found to be growing on top of the drain and also where roots had actively followed and invaded the course of drains (Figure 15).

Figure 14: A counterfort drain that has become clogged over time with leaf litter, humous, fines and invasive roots (M42, SGM 9685, February 2022)

While there is little known about these drains, including their date of construction, it is clear that they have been in place for several decades. No geosynthetic or other form of filter was encountered and illustrates the potential for such drains to lose their effectiveness; indeed, Figure 14 clearly shows that the permeability of the residual drain is unlikely to be much higher than the surrounding soil. Slope parallel drains were also encountered at this site and although in a similar condition the upper part of the slope generally appeared well-drained.

In contrast, the lower part of the slope was considerably wetter, and spring-like features were observed at locations consistent with a geological boundary (Figure 16). The flow of water from one of these features had caused soil to clog the surface of the drain (Figure 17) and water, soil and debris to reach the hard shoulder. It is understood that water and debris have in the past reached lane one.

Figure 15: A counterfort drain with a series of tree roots following the drain (M42, SGM 9685, February 2022)

The edge of carriageway filter drain at the toe of the slope had been inundated with soil and vegetative debris, seemingly over a long period, and its current efficacy is not known. However, inspection of a grated catch pit (Figure 18) demonstrated that water was running freely in the pipe within this drain. No positive connection to the vertical slope filter drain could be observed within the catch pit. It is likely that the vertical slope drain simply buts up to the edge of carriageway filter drain.

The remedial design solution at the site includes two counterfort drains connected to low angle herringbone drains. These will be difficult to construct, much more so than either a vertical or horizontal drain due to the angle of excavation and excavator relative to the slope. An alternative approach to dewatering the wet areas at the site would be to excavate a wider area to say 1m depth, place a geosynthetic filter/separator and fill the void with rockfill, to form a rockfill drainage blanket. This approach would provide a greater cross-sectional area for resilient drainage and might reduce the risk associated with creating inclined herringbone style drains. It would also design out construction risks as required by the Construction (Design & Management) Regulations 2015.

Figure 16: A spring like feature at the head of a counterfort drain (M42, SGM 9685, February 2022)

Figure 17: A spring-like feature at the head of a counterfort drain (M42, SGM 9685, February 2022)

Figure 18: A vertical slope drain is located where the person is standing and the edge of carriageway filter drain runs along the verge with a grated catchpit visible in the foreground (M42, SGM 9685, February 2022)

2.2 Issues Identified on other infrastructure networks

In addition to the site inspections undertaken specifically for this project, the authors have drawn on their experiences of working on slope drainage for various asset owners, thus providing a significant breadth and depth of knowledge on the use of Counterfort Drains and of drainage more generally. Much of this experience backs up the findings from the National Highways questionnaire survey of issues on the SRN (Duffy-Turner et al., 2022).

The main issues encountered on other, including non-road/highway, assets included:

1. *Records*: The lack of records, or poor-quality records/recordkeeping, of the location, purpose and design of slope drains including Counterfort drains. Often there is significant vegetation cover on many slopes which may prevent the drains being recorded during routine asset inspections.
2. *Drain Type*: Confusion over the types and purposes of slope drains (e.g. Crest Drain, Counterfort Drain, Slope Drain), their respective functions and therefore their specific design, construction and maintenance requirements. This is particularly important where the Counterfort Drains have also been designed to act as Rock Ribs, or buttresses (Hutchinson, 1977). To act as these reinforcing Rock Ribs, the Counterfort Drains must extend/penetrate the slip surface for a sufficient distance to enable their shear resistance to be mobilised.
3. *Use as Carrier*: If Counterfort Drains and their constituent collector pipes are used, without modification, as a carrier to convey water from Crest and Interceptor Drains down slope (Figure 19) it is possible that the collector pipe, and thus the drain, will act as an infiltration feature, releasing collected water into the slope. Given the inherent difficulties in intercepting and collecting water, once it has been collected it should not enter any system where it can escape and potentially create an opportunity for infiltration into the

slope. It should be transported in a carrier pipe and not in a collector pipe. In addition, introducing such large quantities of water, as in a carrier pipe, means that other design considerations including high flow rates and other associated issues come to the fore.

4. *Lack of Understanding*: The lack of understanding of the, often conflicting, requirements when Counterfort Drains are required to cope with both surface water flow and also groundwater flow. Surface water flows may:
    a. Carry significant quantities of debris such as litter and leaf litter which can clog the surface of drainage aggregates and associated pipe networks (Figure 19).
    b. Have sufficient energy to mobilise and transport soils and drainage aggregate leading to potential erosion, instability and internal erosion of both the slope and the drain. Figure 20 shows an unmodified counterfort drain, without a filter, which was used to convey water from a crest drain down the slope to a toe drain. Internal erosion led to collapse of the counterfort drain and the adjacent slope. The erosion of the drainage aggregate and the surrounding slope at a Counterfort Drain due to surface water flow onto the drain on the SRN has been observed at the M6 Junction 34 site.
    c. Transport significant quantities of sediment which can reduce the permeability of filters and geotextile filters/separators (Figure 21), and the permeability and shear strength of aggregates.
5. *Filtration*: The lack of provision of a filter or geotextile filter/separator. In Counterfort Drains where incompatible materials are juxtaposed may lead to internal erosion (Figure 20) or fouling of the aggregate.
6. *Inlet and Outlet*: The lack of positive and robust inlet/outlet connections. These enable the location, inspection and required maintenance of the Counterfort Drains. Their omission can lead to the drain outlet becoming buried and blocked, compromising its function. This can also lead to the drain becoming a means for water infiltration, increasing slope water, and reducing slope stability. The outlet should have a positive outfall at the discharge point to avoid infiltration and saturation of the slope, particularly near the toe (Figure 22).
7. *Collector Pipe*: Counterforts should have a 'collector' pipe. These allow the collection of water and ensure it is conveyed out of the slope as readily as possible to prevent the possibility of increased pore pressures (Macdonald et al., 2012).
8. *Poor Construction*: Poor construction of drainage assets, including *inter alia* 'smearing' of geotextile filters and 'contamination' of drainage aggregates and Rock Fill with fine grained material during installation, which is not addressed by the Contractor Self Certification process or during the handover to Asset Delivery (Figure 23) shows a 'new' upper UPVC carrier pipe installed above a historic clay pipe to increase the capacity. No orifice to bring the pipe into the catchpit has been created, thus significantly throttling the pipe capacity.
9. *Standard Spacings (typically 5 to 10m):* The use of standard spacings rather than targeting Counterfort Drains, and associated Slope Drains, to intercept discrete issues (e.g. springs,

land drains, natural soil pipes, water bearing lenses, etc.). At some sites the drains have been constructed after the topsoil placement making it difficult to identify problem areas.

Figure 19: Direct connection of a Crest Drain into an un-modified Counterfort Drain. The rock fill (modified Class 6B) of the counterfort drain is exposed in the base of the Crest Drain. The rockfill has become clogged by leaf litter and soil carried by the surface water flow (image the authors: courtesy of Network Rail)

Figure 20: Collapse of a Counterfort Drain and surrounding slope due to internal erosion. The modified class 6B rockfill is in direct contact with the soils. Water could be heard flowing in the Counterfort Drain. The toe of the drain is shown in Figure 19 (image the authors: courtesy of Network Rail)

Figure 21: Geotextile filter separator on the upstream edge of a filter drain which had become fouled with fines during construction. The filter drain contains Type B drainage aggregate which is also fouled by fines (image the authors)

Figure 22: Toe of the Counterfort Drain in Figure 20 showing water issuing from the drain into the cess and carrying significant fines. The toe of the counterfort and the connection with the cess drain has become clogged by fines. Note that this is following removal of a previous build-up of deposited silt and sand (image the authors: courtesy of Network Rail)

Figure 23: New upper level UPVC pipe (blue) installed above a historic clay pipe drainage system to increase the capacity of the drainage network. The upper pipe (blue) discharges against the sides of the catch pit rings as no opening has been formed (image the authors)

2.3 Review of Literature on the Performance of Counterfort Drains

Given the lack of sites where exhumation of Counterfort Drains was taking place and forensic investigations could be undertaken, a review of the literature on the performance of Counterfort Drains was undertaken to supplement the site observations (Section 2.1).

The literature indicates that for the assessment of likely groundwater reduction, the assumptions and lack of representative parameters indicates little justification for precise mathematical modelling (Price & Fitch, 2017). Evaluations using the empirical approaches described by Hutchinson (1977), Bromhead (1984) and Stanic (1984) can be used, but Macdonald et al. (2012) recommend adopting a peak water level 1.5m above the theoretical water level curve from Hutchinson (1977) and a high groundwater level from the ground model and not an average. Seepage analysis can be readily undertaken using up to date, commonly available and easy to use groundwater modelling software packages which allow steady state and transient groundwater scenarios to be modelled. However, given the generally poor performance observed for Counterfort Drains, the more conservative empirical approaches described above provide a useful check of the outputs from such models.

Stanic (1984) recommended that the ratio between spacing and depth of the drain below the original ground water level should not be more than 4:1.

Many authors advocate that the top of Counterfort Drains should be sealed with a geotextile filter/separator and then a clay seal typically 300mm thick (Price & Fitch, 2017; MacDonald et al., 2012; Farrar & Brady, 2000; Farrar, 1994). However, this makes them more difficult to locate, especially where construction records are poor. More pertinently, there are cases where some interception of surface water may be desired and in such cases a geotextile wrap around the drainage aggregate in the Counterfort Drain is used with typically the top 300mm of the drainage aggregate being outside the geotextile filter/separator (see Section 3.4).

Stylianides et al. (2015a) suggested that clogging of the drainage aggregate, from either the surface or from the bottom up, is a major factor in the deterioration of filter drain performance. Given the commonality of filter drains with Counterfort Drains this factor may be equally used in considering the deterioration of Counterfort Drain performance.

Case histories (Stylianides et al., 2015a) indicate that clogging of the top of drains can occur in five to seven years. Hence, where clogging of the top of the drain is a possibility and the drain is required to take surface water flows, the maintenance schedule should consider scarification and cleaning of the aggregate forming the top of drains at a frequency of five-years. This recommendation also fits in with Price & Fitchs' (2017) recommendation to flush Counterfort Drains at five-year intervals to ensure continued performance. They recommend this is done via the upstream end access points and at the outlet.

The filter drain aggregate used in counterfort drains applications are in accordance with MCHW 1, Clause 505 (accessed March 2022), as discussed by Farrar & Brady (2000):

- Type A: 0mm to 20mm aggregate – well graded general purpose filter material suitable for dealing with road detritus and some but not all soils.
- Type B: 20mm to 40mm aggregate – uniformly graded for use as a free draining backfill where there could be high flows, but a filter is considered essential as the grading is generally too open to retain soil.
- Type C: when the soils to be drained require a particular grading of filter aggregate.

BS EN 13242 (BSI, 2015) defines the material constituents and BS EN 13285 (BSI, 2018) defines the gradings for Types A and C, respectively while BS EN 13242 defines the geometrical requirements for Type B. In general, wide gradings are allowed to maximise the potential use of local sources.

For Counterfort Drains the Network Rail (2016) Standard Detail SD 327 shows Modified Class 6B Selected coarse granular material (125mm to 225mm) (MCHW 1) aggregate with a geotextile filter/separator.

Price & Fitch (2017), Macdonald et al. (2012) and Stylianides et al. (2015b) found that in filter drains Type A material is more prone to clogging than coarser Type B material. Coarser material such as modified Class 6B, or similar, with a suitable filter or geotextile filter/separator is likely to provide higher flow capacity and will provide a greater shear strength.

Price & Fitch (2017) used a selected aggregate with a fines content to act as a suitable filter/drainage aggregate. This was used in conjunction with a perforated collector pipe with a geotextile filter sock in order to promote the formation of an effective permanent filter cake. They reported that drains should be constructed uphill from the outfall and where this was not done there were mixed experiences. They also highlighted the importance of regular engineering inspection during excavation to verify that the encountered ground conditions are consistent with the ground model used for design

Macdonald et al. (2010, 2012) indicate the need for effective outfalls at the toe of Counterfort Drains to ensure that the water collected is removed from the slope. Often there is a change in gradient at the toe of the Counterfort Drain and this can lead to a build-up of sediment and fouling of the drain. This is a particular problem where there is no collector pipe in Counterfort Drains.

Spink et al. (2014), Ballard et al. (2015), Stylianides et al. (2015a) and Farrar (1989, 1990, 1994) all indicate that cleaning or replacement of filters, geotextiles and drainage aggregate is likely to be required at between 10 and 25 years of use. This need to unclog filter drains and/or refurbish the drainage aggregate is widely recognised. Indeed, there are industrial scale systems designed to achieve just those ends including, but not limited to, Carnell's award winning STONEmaster™ system[1].

Price & Fitch (2017) reviewed a number of projects in New Zealand, and these indicated that well designed, constructed and maintained Counterfort Drains work with no obvious deterioration in performance over a period of 15 years. This seems to indicate that a service life of around 20 years might be appropriate for well designed, constructed and maintained Counterfort Drains. After that refurbishment of the filter, geotextile and aggregates are likely to be necessary and this should be made clear in the design from the outset.

Counterfort Drains, Slope Drains and other filter type drainage are particularly prone to root ingress (Figure 15) which causes damage to the drain and can act to trap debris (Spink et al., 2014). Spink et al. (2014) and WRc (2012, 2018), in their 'Sewers for Adoption' documents, provide guidance on the proximity of different types of vegetation from drainage systems. They recommend that three metres either side of the drain are cleared of vegetation at least every seven years and provide guidance on the proximity of various types and species of vegetation. Counterfort Drains are typically spaced at between 5m and 10m and strict adherence to this guidance would render between all and approximately two-thirds of the slope free of trees and shrubs. As vegetation can assist with the management of water on slopes and the roots can have a reinforcing effect, there clearly needs to be a site-specific balancing of the advantages and disadvantages of vegetation planting. However, what is clear is that both planted and self-seeded trees and shrubs on slopes with Counterfort Drains will require active management during the service life of the drains and that this should include a commitment to ensure that debris from such activities is not deposited on top of the drains or in locations where it may migrate to the tops of the drains.

[1] https://lcrig.org.uk/news/stonemaster-wins-environmental-award

3 Design

3.1 Standards

There is little in the way of detailed design/specification advice or procedure in recently (within five to 10 years) published guidance on the design of Counterfort Drains in the usual sources such as CIRIA Guides, TRL Reports, British Standards, DMRB/MCHW or Network Rail Standards.

The guidance that is provided mainly points the designer to papers by Hutchinson (1977) and Bromhead (1984). Significantly, for Counterfort Drains there is no British Standard information and very little in the way of other standards or guidance. Price & Fitch (2017) give guidance based on the long term (15 years) assessment of Counterfort Drains.

Table 1 summarises the relevant documentation available, with an indication of the level of information provided in these documents.

Table 1: Matrix of relevant documentation available for Counterfort Drains (CFDR)

Level of information provided: Background (red) / Marginal (amber) / Comprehensive (green)		**Relevant to:**		
		Design	Specification	Construction
Publisher	**Document number and title**	**CFDR**	**CFDR**	**CFDR**
CIRIA	CIRIA (Perry et al., 2003a) C591 Infrastructure cuttings - condition appraisal and remedial treatment	Marginal	Marginal	Marginal
CIRIA	CIRIA (Perry et al., 2003b) C592 Infrastructure embankments - condition appraisal and remedial treatment	Background	Background	Background
NH	MCHW Vol 1 Series 500 Drainage / Vol 2 NG 500		Marginal	
NH	DMRB, CD 522 Drainage of runoff from natural catchments	Marginal		
NR	NR/CIV/SD/327 Standard Detail: Drainage systems - slope drainage details RD1, RD2, RD3	Background	Marginal	Marginal
NR	NR/L2/CIV/005/01 to /15 (Network Rail, 2018) Drainage systems manual	Background	Marginal	Marginal
TRL	TRL PPR341 (Carder et al., 2008) Drainage of Earthwork Slopes	Background	Background	Background

Similarly, for construction, there is little in the way of detailed advice in the recent (within 5 to 10 years) published guidance on the construction of Counterfort Drains in the aforementioned sources. There are construction detail drawings in the Network Rail

Standards (Network Rail, 2018) and there is some good guidance in Hutchinson (1977), Macdonald et al. (2012) and Price & Fitch (2017).

3.2 Definition and Purpose

Hutchinson (1977) specifically defined Counterfort Drains as: "*…drains which penetrate into solid ground beneath a slip surface, and therefore also provide some mechanical buttressing to the slope…*". Hence, it is vital that the problems with any slope where Counterfort Drains are to be considered are as fully defined as possible, just as they would be for any other planned construction works.

Issues to be considered in the design of counterfort Drains include:

1. Identification of potential surface water flows and shallow groundwater flows which may be contributing to the instability, for example:
    a. Terrain analysis to determine likely surface and shallow groundwater flow routes and areas of flow concentration so that these can be treated by other means (Crest Drains/Cut-off Drains).
    b. Identification of other sources of shallow groundwater which could be mitigated by Crest Drains/Cut-off Drains (e.g. land drains such as identified discharging onto the slope on the M6 Junction 34, see Section 2.1).
2. As a general principle, once water has been collected it should remain collected and any potential for it to re-enter the slope should be prevented.
3. Identification of surface water flows which could lead to clogging or erosion/instability of slope drainage (e.g. M6 Junction 34, see Section 2.1).
4. Given the differences in the issues and corresponding design requirements for dealing with surface and groundwater it is essential that it is recognised that where Counterfort Drains are required to cope with both, then standard Counterfort Designs are not appropriate and specific design and specification will be required to manage the specific flow rates and associated energies.
5. The type of slope failure being remediated and the depth and geometry of the failure plane/planes.
6. Groundwater levels and the likely range of their seasonal fluctuations.

3.3 Associated Drainage

3.3.1 Land Drainage

There are many types of surface land drainage such as ditches, rills and grips and these are usually readily observed by a trained eye and would normally be taken account of by surface drainage such as Crest Drains and Cut-off Drains.

Deeper subsurface drains are not so obvious, but their surface expression can often still be visible, and they can produce significant effects on the groundwater and stability of slopes.

There are three principal types of manmade sub-surface land drainage: pipe drains, mole drains and subsoiling (Droy, 2010; Robinson, 1990; AHDB, 2018).

Piped drainage is a primary system which is often used in conjunction with secondary mole drains or subsoiling at closer centres (typically a few metres). The creation of Mole drains involves drawing a 'bullet' and expander on the back of a plough through the soil to form a semi-permanent 'pipe' and to fissure the soil above. Subsoiling involves drawing tines through the soil to create fissures.

Piped drains consist of clay pipes/tiles (100mm to 150mm diameter, for example) or perforated plastic pipe (typically 60mm to 160mm diameter) which are typically laid at depths of 600mm to 1500mm and typically spaced at 5m to 15m spacings but may be up to 40m or more. The authors have experience of them being at closer spacings and at shallower depths.

Where such drains intersect with either cutting or embankment slopes then these drains should be positively intercepted and taken to a safe outfall. Crest Drains and Interceptor Drains should be used for this purpose where possible. Where this is not possible then targeted drains will be required.

In addition to manmade land drains, it is the authors' experience, in particular in glacial deposits across northern England and Scotland, that many washout (debris/earth flow) or translational failures occur in locations where natural soil pipes[2] are observed during forensic inspection of the failures (Figure 24 and Figure 25).

3.3.2 Crest Drains and Interceptor Drains

Crest and Interceptor drains can be effectively used to intercept and collect both surface water flows and land drainage (manmade or natural). However, there is the potential that these drains can enable water to infiltrate into the crest of the slope. Hence, it is vital that these drains are designed and constructed to ensure that water infiltration is minimised. These drains should be designed and constructed to ensure there is a constant and effective fall towards the outfall, with no low spots to enable ponding and infiltration. The use of impermeable membranes to prevent water infiltration on the downslope face of drains is also beneficial.

Where the outfall for these drains has to traverse or descend steep slopes then particular design and construction care is required to ensure that water does not have the opportunity to infiltrate into the slope and that high velocity/energy flows are not created without appropriate management or dissipation measures, see Figure 1; energy dissipation channels (e.g. cascades, steps, textured surfaces) can be used to reduce the velocity and therefore energy of such flows.

[2] Soil pipes are naturally formed, relatively shallow water conduits, are typically tens to hundreds of millimetres in diameter and may extend metres to tens of metres laterally. They are formed where water flow and pressures within the soil lead to erosional processes that form pipe-like cavities. As these develop their dimensions may exceed the ability of the soil to form a stable roof (crown), leading to collapse. Such collapses can lead to changes in the surface flow patterns on, and/or a build-up of pore pressures within, a hillside potentially leading to wider instability.

Figure 24: Example of a natural soil pipe, with significant water flow, encountered during the excavation of a crest drain above the location of a washout (debris flow) failure in till, west Cumbria (image the authors)

Figure 25: Example of one of a number of natural soil pipes, with significant water flow, observed in the back scar of a washout (debris flow) failure in till, west Cumbria (image the authors)

Guidance on suitable flow velocities for pipes is given in Network Rail (2018) 'NR/L2/CIV/005/09, Module 9, Drainage Design' which states maximum flow velocity for pipes shall not exceed 3.0m/s. Similar guidance for channels is provided by Hearn & Hunt (2011) who indicate flow velocities should be limited to 3.0m/s for lined channels and 1.2m/s for unlined channels, but project specific limits will depend on the material forming the channel.

Counterfort or other Slope Drains generally should not be used as carrier drains, to convey water from Crest and Interceptor Drains to the toe of a slope, as this risks infiltration of water into the slope and the potential for damage to pipes or mobilisation and transport (erosion/failure) of the drainage aggregate. If this is unavoidable then the Counterfort Drain will need to be modified for this purpose, for example by having separate carrier and collector pipe systems and detailing of the drainage network.

Care should be taken to ensure that significant overland flows or overtopping of Crest or Interceptor Drains do not create flows down the surface of Counterfort Drains and mobilise and transport (erode) the drainage aggregates (see for example M6 Junction 34 as described in Section 2.1).

3.4 Basis of Design for Counterfort Drains

The design of Counterfort Drains must clearly identify and assess the slope failure mechanism(s) and depth(s) to be treated by the drains, so that appropriate types of drain can be selected.

Given the potential for a variety of drainage systems on a slope to interact it is vital that the often-competing requirements of the various systems are clearly understood and accounted for. Where there is a need for Counterfort Drains to intercept both groundwater and surface water then they will need to be designed to cope with the often-competing requirements of such a combination. The key features of a Counterfort Drain and the ancillary drain system are shown in Figure 26.

The potential for the drain to receive and cope with significant overland flows, and in particular stream flows concentrated over a short length of drain, should be taken into consideration (inter alia by means of aggregate selection) as these flows may mobilise and transport the drainage aggregate causing a washout onto the asset below.

For the design of the Counterfort Drain the approaches proposed by Hutchinson (1977) or Bromhead (1984) can be used for the prediction of water drawdown and to determine the required spacing for dewatering. Stanic (1984) gives further guidance that the ratio between the drain spacings and the depth of the drain below the original ground water level should not be more than 4:1. Macdonald et al. (2010, 2012) recommend adopting a peak water level 1.5m above the theoretical water level curve from Hutchinson (1977) and a high groundwater level from the ground model and not an average.

The approaches described by Hutchinson (1977) and Bromhead (1984) are considered satisfactory. However, seepage analysis can be readily undertaken using up to date, commonly available and easy to use groundwater modelling software packages which allow steady state and transient groundwater scenarios to be modelled. However, given the generally poor performance observed for Counterfort Drains, the more conservative empirical approaches described above provide a useful check of the outputs from such models.

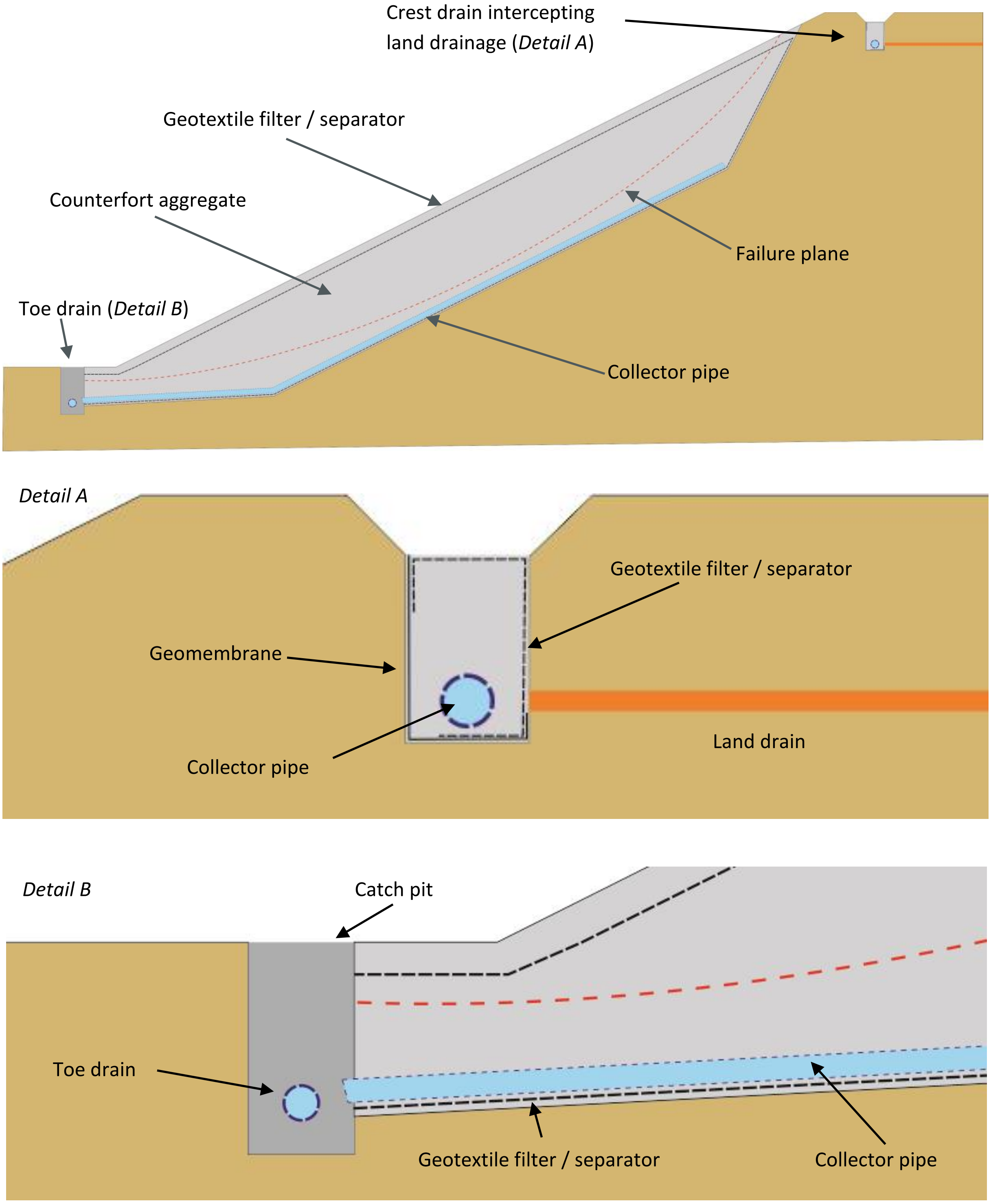

Figure 26: Schematic details of a typical Counterfort Drain

Buttressing can be an important element of Counterfort Drain design, although it was found to be accounted for in the design of only one of the nine sites examined (see Section 2.1). If part of the design, a preliminary design for the buttressing effect can be achieved by taking a pro-rata approach using the shear strength of the in-situ soil and the drainage media, although a formal three-dimensional analysis of some form should be considered for the final design.

Counterfort Drains should be designed with a suitable enclosing, usually geosynthetic, filter/separator. The filter should be selected so as to ensure that the drainage aggregate does not become fouled by fines and so that there is no internal erosion by loss of fines from the slope into the drain. The filter should be designed for the soils in which the drain is constructed. The geosynthetic will not prevent migration of the fines into the drain but will promote the formation a filter cake that builds up over time and prevents such migration. Clearly such filters will only work with unidirectional flow and a reverse flow will destroy the filter cake that has been built up. This emphasises the need for the flow to be controlled within Counterfort Drains and for the design to ensure that water does not back up in the drainage trench and promote flow outwards into the slope thus destroying both the filter cake and reducing the stability of the slope.

The drainage aggregate should be selected to provide the required drainage function and, where required, the shear strength to provide the buttressing effect. Coarser aggregates such as Type B and modified 6B are less prone to fouling and may be preferred options. Where the fines content of the aggregate is variable, or site conditions may lead to fouling of the aggregate during construction, then consideration should be given to an additional geotextile filter wrap surrounding the collector pipe.

The base of the Counterfort Drain needs to have a continuous fall to prevent ponding and potential infiltration of water into the slope. It is recommended that all counterforts that take water from other parts of the drainage system (e.g. Crest Drain, Interceptor Drain, and so on) should include a carrier pipe which outfalls to a catchpit at the toe to enable inspection and maintenance (e.g. jetting), in addition to the normal collector pipe to collect ground water and, potentially, surface water entering the drain.

For critical locations the inclusion of monitoring should be considered. Remote monitoring (Arup, 2020) such as piezometers, soil moisture probes or water level sensors, for example, could be used to detect a build-up of water in the drain. These require specific design detailing to ensure that they will be effective in the long term.

With regards to drainage installations, safe access for maintenance should be a specific design feature and clearly specified therein.

3.5 Technical Approval

The procedures, documents and certification for a slope with Counterfort Drains shall be in accordance with DMRB CD 622 'Managing Geotechnical Risk'. This is applicable for all works undertaken on the SRN, as well as third party works, that impact geotechnical assets thereon. This allows the geotechnics risks to be clearly identified through all the phases of work including options, development of design, construction and hand over to the Asset Delivery team.

In accordance with CD 622 (DMRB) a Special Geotechnical Measures Form (SGMF) can be used by agreement between the Designated Geotechnical Advisor (DGA) and the Overseeing Organisation's Geotechnical Advisor (OOGA). If a SGMF is used, then this should include its own certificate.

Effective liaison between the geotechnical and drainage teams of the Overseeing Organisation and the designer is essential to the successful design of slope drainage in general and Counterfort Drains in particular.

4 Construction

4.1 Installation

As with most drainage work the outlet should be constructed first and then the works progressed in an upstream direction, as recommended by Price & Fitch (2017). This also ensures that any overlaps of geotextiles and geomembranes will be in the correct orientation, thus reducing the requirement for person entry into any excavations to adjust the overlaps.

Excavation of trenches should be undertaken in short sections to mitigate for potential side wall collapse. In difficult ground conditions and for deeper excavations some form of trench support is likely to be required (Figure 27).

Where high surface or groundwater flows are experienced, it is likely that over pumping of water will be required (Figure 27).

For steep and or large slopes, specialist plant such as long reach excavators or slope climbing excavators (e.g. Menzi Muck or similar) are likely to be required from both an ease of access and a safety perspective (Figure 28).

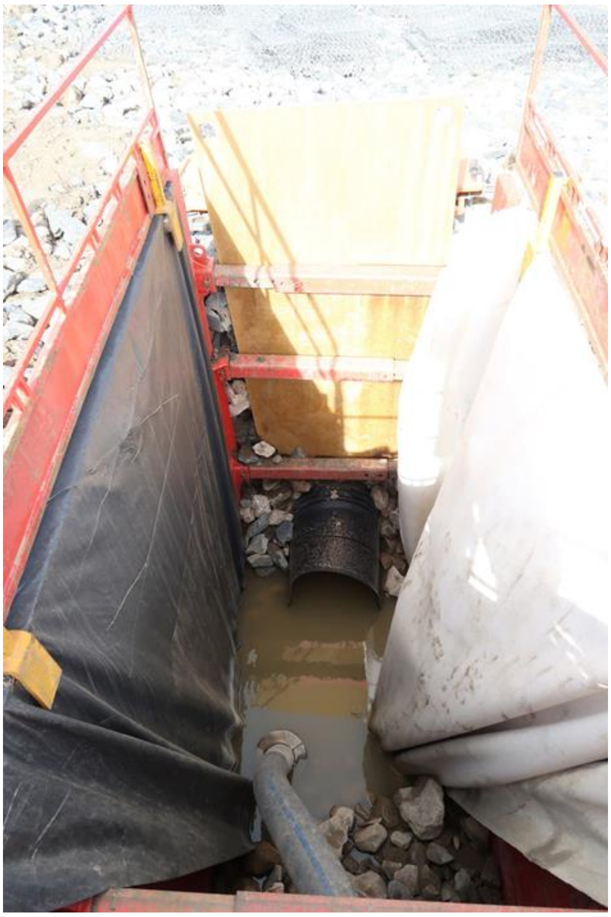

Figure 27: Filter drain excavation with trench support and over pumping of groundwater inflow on the Cumbrian Coast Railway (image the authors: courtesy of J. Murphy & Sons Ltd)

Figure 28: Tethered slope climbing excavator (Menzi Muck) installing Counterfort Drains on a large steep slope on the Cumbrian Coast Railway (image the authors: courtesy of J. Murphy & Sons Ltd)

4.2 Supervision and Construction Quality Assurance

During excavation of drains (Price & Fitch, 2017) it is essential that regular inspections of the excavations are undertaken by the designer to validate the ground model and to ensure that the drain design is appropriately modified to effectively capture any significant groundwater issues.

Adequate and competent personnel for construction and supervision should be provided to ensure that construction follows both the design and specification requirements and the requirements of the MCHW.

Construction quality assurance records should be kept and provided to the Overseeing Organisation throughout the construction process and for SGMs the records of the auditing process should be captured in the Geotechnical Feedback Report (GFR). In light of the above issues regarding quality control it is also recommended that the Overseeing Organisation should maintain an independent set of quality records for all activities.

4.3 Construction Acceptance

Observations on the SRN and of the wider UK infrastructure portfolio have found the self-certification process to be suboptimal. A move to cease Contractor self-certification and revert to a more conventional designer-led certification scheme in order to ensure quality of execution of Works is strongly advised.

It is important that snagging is undertaken (and corrective measures completed) prior to the contractor leaving the site and that the Works Examiner is similarly afforded adequate opportunity to formally accept the work. In many instances these activities will need to be planned and executed prior to removing traffic management.

Acceptance once site access is restricted (i.e. once the highway is fully operational) is frequently not an option as access without Traffic Management is at best limited and at worse unsafe. It is recommended that provision for early inspection be built into the contract along with the potential consequential non-payment of all or part of the contractor's final invoice.

Digital as built records of Counterfort Drains and their outfalls, and any other associated drainage such as Crest Drains, Herringbone Drains and Toe Drains, should be provided and the inventory incorporated into the geotechnical and drainage asset management systems.

5 Operations and Maintenance

5.1 General

Earlier and more extensive operational and maintenance geotechnical input to Major Works should be undertaken in order to ensure specification compliance, acceptability for use and handover to the operator. The effective implementation of this recommendation along with moving away from contractor self-supervision and certification increases the likelihood that Works are built correctly first time and greatly reduces the risks associated with future defects and deterioration. This becomes even more critical in the light of predicted climate change which is expected to require increased resilience in drainage systems and exacerbate geotechnical asset deterioration.

5.2 Inspection, Monitoring, Assessment and Maintenance

Geotechnical assets typically have long service lives and generally deteriorate slowly over time. However, they are susceptible to both surface and ground water drainage issues (MCHW 1, Series 500) with as many as 74% of all geotechnical failures having some drainage related problems (Lane et al., 2019).

The serviceability and stability of slopes with Counterfort Drains is highly dependent on the functioning of the drains. The inspection, including monitoring and assessment, and maintenance regime for Counterfort Drains, and the slopes whose stability and serviceability is dependent on them, should be determined by the designer and highlighted in the Geotechnical Feedback Report produced by the DGA, within six months of the end of the construction phase.

There is a number of interrelated inspection and maintenance standards that should be taken into consideration when developing the regime. GS 801 '*Asset delivery asset inspection requirements*' (DMRB) requires the following inspection and assessment regimes for piped drainage systems and geotechnical assets:

- "*Piped drainage systems and piped grips - 10 years with 10% per year.*
- "*Inspection regimes to assess and record asset condition of the geotechnical asset shall be in accordance with DMRB, with the following frequencies.*
    1) *routine inspection – frequency based on risk assessment;*
    2) *principal inspection – frequency based on risk assessment.*"

GM 701 '*Asset delivery asset maintenance requirements*' (DMRB) requires the following maintenance works for Counterfort Drains and Catch Pits:

- "*Grips and counterfort drains - Clear / re-cut grips and counterfort drains, clear weed growth and debris – every 2 years.*
- *Catch pits - Clear/empty silt and debris from catch pits – Annually.*"

Clearly vegetation and in particular shrub and tree growth (see Section 2.1), and associated root development and invasion, on or adjacent to Counterfort Drains adversely affects their performance. Hence, removal of such vegetation is a key maintenance element. The frequency of this work should be set initially in the GFR and then updated taking cognisance of the findings of Routine and Principal Inspections.

Visual inspection of the surface of Counterfort Drains will only provide limited information on their performance as:

a. The surface can become clogged by debris and yet the drains can be working beneath this.

b. The drains can become fouled by fine grained material from the base upwards (Stylianides et al. 2015a, 2015b).

Hence, it is vital that the outlets for the Counterfort Drains are regularly and thoroughly inspected to help determine their performance.

Where the determination of the location and extent of Counterfort Drains, and other forms of slope drainage, is problematical then techniques such as LiDAR, orthoimagery and hyperspectral scanning can be used to identify the location and extent of Counterfort Drains and other forms of slope drainage (Arup, 2017). For critical Counterfort Drain installations remote monitoring (Arup, 2020) such as piezometers, soil moisture probes or water level sensors could be utilised to detect a build-up of water in the drain. However, such installations are likely to require specific design detailing to be effective. Techniques such as Ground Penetrating Radar have also been used to determine the degree of fouling of drains (Stylianides et al. 2015a, 2015b). These areas of monitoring and investigation are rapidly evolving

The drainage aggregate and filter materials in Counterfort Drains are likely to need replacing or refurbishment following around 15 to 25 years' service. The drainage media is likely to have to be either removed, cleaned and reinstated to the trench, or removed and replaced with fresh material. The need to replace the geosynthetic filter, or otherwise, is likely to be dependent upon both its condition in service and the process used to remove and replace the aggregate and the degree of damage that occurs to the filter during that process.

Where Counterfort Drains are required to intercept surface water then there is a significant potential for clogging of the surface (Section 2.1 and Figure 14) and it is likely that the surface of such drains will require periodic scarification. Stylianides et al. (2015a) suggest a frequency of five years.

5.3 Competence

It is recommended that the inspection of SGMs should be certified by a Geotechnical Advisor in accordance with CD 622.

6 Recommendations

Counterfort Drain SGMs cannot meet the required design life for slopes of 60 years without significant intervention, as the filter/separator and drainage aggregate element are likely to need refurbishment or replacement. There is a body of evidence that suggests that this will be required at between 15 and 25 years assuming that the Counterfort Drains are maintained. There is substantial evidence that in the UK, counterfort drain design, specification and construction is frequently not at a level that would promote longevity of this nature.

6.1 Guidance

Recommendation 1: There is confusion within the industry regarding the different types of slope drains, their function, form, design, construction and potential performance. There is a corresponding lack of specific and consolidated guidance. It is considered that the provision of such guidance is a matter of some significant need, and it is strongly recommended that this be taken forward through the auspices of the Geotechnical Asset Owners Forum.

6.2 Design

Recommendation 2: It has been identified that there is a lack of official design guidance for Counterfort Drains. It is important that an appropriate opportunity is sought to produce a guidance document for the design of Counterfort Drains and that the outcomes are incorporated in appropriate standard(s).

Recommendation 3: It is recommended that the design of Counterfort Drains must clearly identify, assess and account for the following features and functions:

- Slope failure mechanism(s) and depth(s) of slip planes to be treated by the drains and/or buttresses.
- Whether the drains treat groundwater only or a combination of surface and ground water. If the latter is the case, then they must be specifically designed to cope with that combination. The specific issues that must be addressed are inter alia clogging of the drain surface and the higher flows implicit where surface water is additionally collected.
- In addition, consideration must be given to ensuring that the drain can be effectively maintained so that water does not back up and enter the slope, thereby decreasing stability and compromising the drain filter cake.
- Potential for the drain to receive significant surface/groundwater flows which may mobilise and transport the drainage aggregate causing a debris flow type failure onto the asset below.
- Careful consideration of the velocity of surface water flow and the slope gradient are critical, and interlinked factors, in ensuring that washout of the drainage aggregate does not occur. Such considerations should form an integral part of the design by determining appropriate limits on surface water flow velocity.

Recommendation 4: Given the potential for a variety of drainage systems to interact it is vital that the often-competing requirements of the various systems are clearly understood and accounted for in the design.

Recommendation 5: Carrier and collector drain functions should remain separate and where necessary a particular Counterfort Drain construction may incorporate the usual collector pipe and a carrier pipe to transport water from (say) the Crest Drain and/or Interceptor Drains to a suitable outfall at the toe.

Recommendation 6: The geotechnical designer should coordinate their design with the relevant landscape/environmental designer to ensure compatibility on planting schemes.

6.3 Construction

Recommendation 7: Regardless of flow rates a perforated collector pipe should be installed in a Counterfort Drain which outfalls into a catchpit at the toe. The catchpit at the the toe should also assist with locating the Counterfort Drains for inspection and maintenance purposes.

Recommendation 8: Mineral filters or, more commonly, geosynthetic filters/separators are required at the trench boundaries.

Recommendation 9: Significant changes in vertical and/or horizontal alignment, in particular towards the base of steep slopes, should be made wholly within a catch pit designed to resist the forces and flow transition resultant from the flows.

Recommendation 10: Following construction of the Counterfort Drains they should be physically marked on site to allow easy identification in the field. They should have the top and bottom coordinates located in the GFR and be provided in BIM format or similar. Maintenance.

Recommendation 11: The service life of filter drains, including Counterfort Drains, is likely to be in the range 15 to 25 years. Specific provision should be made for the appropriate inspection of such drains in order that they can be refurbished or replaced before their lack of functionality increases instability to an unacceptable level.

Recommendation 12: It is recommended that maintenance procedures are specifically targeted at ensuring that trees and shrubs do not grow adjacent to Slope Drains of any type. The distance between the drain boundary and such growth should be specified in the GFR.

Recommendation 13: In addition, it is recommended that vegetation maintenance precludes the deposition of vegetation debris on drain surfaces or on the surface of a slope where it can migrate onto the surface of drains.

Recommendation 14: Where Counterfort Drains and/or Slope Drains are designed to intercept surface water flows then scarification will be required to prevent clogging of the surface of the aggregate. Clearly the frequency will depend upon the site location and the environs; however, a frequency of every four years could be a reasonable starting point as this can be tied in with the maintenance required every two years.

6.4 Overarching Issues

It is considered that a move to cease Contractor self-certification and revert to a more conventional client-led Construction Quality Assurance scheme in order to ensure quality of execution of Works is strongly indicated.

Also strongly indicated is, earlier and more extensive operational and maintenance geotechnical input to Major Works in order to ensure specification compliance, acceptability for use and handover to the operator.

The effective implementation of these two recommendations increases the likelihood that Works are built correctly first time and greatly reduces the risks associated with future defects and deterioration. This becomes even more critical in the light of predicted climate change which is expected to exacerbate geotechnical asset deterioration.

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Appendix A Counterfort Drain Site Locations

SGM Type	SGM ID	Area	Road	Location	Eastings	Northings	Date	Approximate Date of Construction
Counterfort Drains	NA	7	A14	Elkington	462408	277609	Oct-20	1994
Counterfort Drains	1924	SW	A30	Pathfinder Village	284326	93113	Jan-21	Post 1976
Counterfort Drains	2053	SW	A30	Pathfinder Village	285307	92785	Jan-21	1970s
Counterfort Drains	2065	SW	A30	Nr Exeter	287064	92536	Jan-21	1970s
Counterfort Drains	1280	SW	A303	Horton	332272	114244	Jan-21	2001
Counterfort Drains	3329	SW	A303	Horton	332272	114244	Jan-21	2000
Counterfort Drains	NA	SW	A38	Liskeard	222625	65042	Jan-21	2015
Counterfort Drains	NA	NW	M6 J34	Lancaster	349701	465325	Mar-21	2015
Counterfort Drains	9685 (classed as slope drain)	9	M42	MP 54/2 to 54/3	425053	302348	Feb-22	Unknown

Forensic Examination of Critical Special Geotechnical Measures: Counterfort Drain Information Note

The effective design, specification and construction of Special Geotechnical Measures (SGMs) is critical to the efficient operation of the National Highways Strategic Road Network (SRN). Given the required performance of the SRN in terms of resilience, reliability, redundancy and recovery it is essential that SGMs are themselves reliable in terms of performance and life; resilient to external conditions such as earthworks deterioration and extraordinary conditions (e.g. climate change). Around 100 different types of SGMs are used on the SRN and the early installations of some SGMs are approaching the end of their design life and the design, specification and application of many of these techniques is based on limited studies. This Information Note on Counterfort Drains is part of a series that reports on investigations of specific SGMs and makes recommendations on their future use.

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