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Counterfort drains – design, installation and long-term performance in soils of Greater Auckland

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ABSTRACT

Counterfort drains provide a method of improving slope stability by controlling groundwater levels via subsurface drainage; they can provide significant improvement to stability at moderate cost. Published information on the design, initial effectiveness and, importantly, the long-term performance of such drainage is limited, particularly in New Zealand soils. In the current and near future regulatory environment, the long-term performance and associated maintenance requirements of counterfort drains are a key aspect in evaluation of their suitability to a particular site and the level of risk acceptable to the designer, landowner, and territorial authority.

This paper provides comment on the design, installation, and maintenance of counterfort drains in the upper North Island, and observations of short-term measured groundwater levels following drain installation against design expectations from previous published information (e.g. Fitch 1990). Assessment is also made of long-term drainage performance based on monitoring at several sites, with regular monitoring at one site for 17 years, which shows ongoing satisfactory performance in Waitemata Group and Northland Allochthon soils.

1 INTRODUCTION

Counterfort drains, also known as buttress or trench drains, provide a method for improving slope stability through controlling groundwater pressures by subsurface drainage. They typically comprise trenches up to 6m depth, with a perforated pipe at the base, backfilled with suitable free-draining material. Where appropriately designed and constructed, they can provide significant improvement to site stability at moderate cost. However, with deep excavations in often marginally stable ground, construction difficulties are not uncommon.

Published geotechnical-specific information on design, initial effectiveness and, importantly, long-term performance is limited, particularly in New Zealand soils. Short to long-term monitoring by Riley Consultants Ltd (RILEY) of several sites in the greater Auckland area, through which counterfort drains have been installed, allows an assessment of design, effectiveness and performance comparison to be made with previous published information on counterfort drain performance in Auckland soil (Fitch 1990).

The long-term performance and associated maintenance requirements of counterfort drains is a key aspect in evaluating their suitability to a particular site and the level of risk acceptable to the designer, land owner, and territorial authority.

The following information is primarily suitable for residual fine-grained soils, derived from weathering of Waitemata Group deposits and Mangakahia Complex soils of the Northland Allochthon.

2 STABILITY IMPROVEMENT CONCEPT AND SETOUT

Site stability can be improved by reducing or maintaining satisfactorily low pore water pressures on a potential failure surface. This can be achieved by providing a high permeability preferential pathway to encourage groundwater flow from the surrounding soil. Counterfort drains present a significant surface area for drainage to occur (compared with bored drains or wells) and are typically constructed at regular spacings parallel to the slope gradient.

Counterfort drains can reduce groundwater from normal seasonal levels and storm peaks, whilst maintaining these lower levels (Cornforth 2005). Given the size of counterfort drains relative to many other drainage types, along with suitable design and construction, long-term performance with minimal degradation and maintenance is possible.

Whilst counterfort drains are typically constructed parallel or sub-parallel to the slope gradient (i.e. orthogonal to slope contour), they can be constructed across the slope as ‘interceptor drains’, often at or near the landslip headscarp to intercept subsurface groundwater flow into the affected area. Interceptor drains can be extremely effective in draining a slip feature (Cornforth 2005) and provide enhanced shear resistance across the failure surface. However, excavation across the slope can remove support from above and potentially compromise stability below due to reduction in compressional or tensile restraint, and possibly increase water ingression if not designed and constructed correctly. Due to the risks inherent with interceptor drains, these are rarely seen on current stability improvement works in the greater Auckland area, with conventional counterfort drains orthogonal to contour preferred.

Counterfort drains are most suitable for relatively shallow slips typically up to 6m depth, where trench excavation can reach the primary failure surface. Deeper drains are possible, however, these often require major earthmoving and have significant collapse risks. Counterfort drains are also most effective in gentle and moderate dipping slopes where instability can be driven by relatively large groundwater pressures, thus the drains can have a significant effect.

The depth of influence for counterfort drains can be extended below the base by bored drains (e.g. gravel-filled wells or wick drains) from the base of the trenches down to identified surfaces or zones with elevated groundwater pressures, which will drive the water upward into the trench.

3 TYPICAL DETAIL

Counterfort drain typical detail, as specified by RILEY, has changed little over the past 25 years. A cross section is presented in Figure 1. Key changes include the 110mm Novaflo pipe, now specified as ‘heavy wall’, and a Transit New Zealand F/2 drainage metal specified compared with a previous scoria material from Three Kings Quarry.

With counterfort drains in the Auckland area often excavated through fine-grained soils there is a risk of soil migration into the drainage medium leading to eventual clogging and significant reduction in the drain performance. To minimise the chance of this occurring, an all-passing drainage medium with significant fines content (sand) is required. Gap-graded materials, such as 20/40 are not specified and are liable to rejection on-site due to their poor filter suitability.

Use of a high-quality drainage aggregate with sufficient fines content to act as a suitable filter negates the need for a filter fabric wrap within the trench or wrapping the Novaflo, although if the contractor wishes to use a filter sock on the perforated collection pipe this is allowed (design criteria are available relating to the required hole size to prevent excess ingress of fines fraction of the drainage material). This approach avoids unnecessary risk with time involved placing a filter cloth in trench excavation of dubious stability.

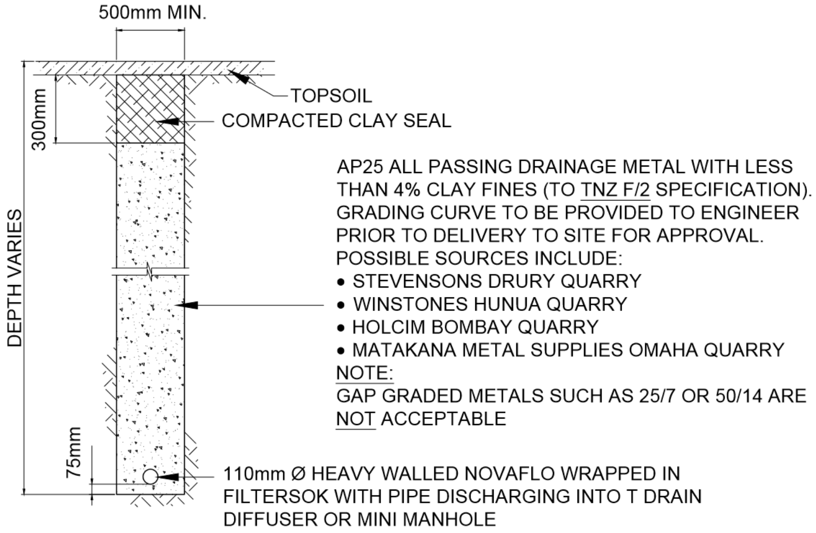

Figure 1: Current typical counterfort drain detail adopted by RILEY

4 DESIGN

4.1 Theory

Drainage design based on theoretical evaluation can be found in several published papers around the world (e.g., Hutchinson 1977, Stanic 1984, and Bromhead 1992) to determine drainage spacing and effective groundwater drawdown. These semi-empirical methods are still in use today (e.g. Cornforth 2005 and MacDonald et al 2012). Following monitoring of counterfort drain performance on two road cuts in England, it was recommended for design allowance of peak water levels 1.5m above the theoretical curve of Hutchinson (MacDonald et al 2012). These methods often assume infinite slope-type situations, homogeneity of the soils, and isotropy. In some cases, estimates of vertical and horizontal permeability are required along with soil porosity. Often these values are not available to the designer, but can be estimated, however, fissuring in Auckland soils can make permeability estimates problematic.

Experience shows there is little justification in a precise mathematical solution because of the wide differences possible between idealised assumptions and actual field conditions (Fitch 1990). A notable recommendation of Stanic (1984) is that the ratio between drain spacings and their depth below the original groundwater level should not be more than 4:1 (e.g. if the drains penetrate 5m below the pre-drain groundwater level they should not be spaced more than 20m apart).

A key design target is to intercept the assessed principal failure surface, if possible, to directly relieve water pressure on this surface. Often the surface will be acting as an aquitard and excavation to and through the surface will tap groundwater pressure.

4.2 Practical experience

Based on empirical evidence gathered by these authors, for residual Waitemata Group soils, and other fine-grained soils in the Auckland area, we consider the figures in Table 1 provide a reasonable approximation for drain performance. Monitoring to date has shown the predicted average depths to groundwater of Fitch (1990) to be accurate, noting these are average depths and peak water levels can rise higher.

Table 1: Predicted average depth to groundwater following counterfort drain construction based on measured performance in greater Auckland soils (modified from Fitch 1990)

Drain depth (m)	Drain Spacing (m)	Approximate average depth to groundwater level* (m)
2	5	1.5
2	10	1.0
4	10	3.0
4	15	2.5
5	15	3.0
5	20	2.5
6	15	4.0
6	20	3.5

* Depths to groundwater are averages, and can be higher at the midpoint between the drains. For brief a period during storm events, groundwater can rise approximately 1m above stated levels.

Groundwater levels up to 1.5m above theoretical were measured between counterfort drains on a road cut in England however, instability did not result This is believed to be a result of direct drainage of the failure surface and possible reinforcing effect of the drains (MacDonald et al 2012).

4.3 Other Considerations in Design

In the subdivisional situation, attention needs to be paid to the location of future building platforms, as deep drains can significantly affect foundation design and construction of future structures spanning over or in proximity to the drains, and also allow access for drain maintenance. Often, if lot boundaries are close enough and suitably orientated, the drains are aligned with boundaries. Location of the drains on boundaries can present issues with respect to ownership and fence construction, thus careful consideration is required.

5 CONSTRUCTION

With drains typically excavated below the groundwater table they are usually built in an uphill direction from the outfall. Due to contractor preference, sometimes these are undertaken in a downslope direction, with, in the authors' experience, mixed results.

Only a short length of trench should be open at any one time, with equipment and materials co-ordinated to prevent delays. This will reduce the risk of cave-ins occurring, however, during deeper excavations without support, such collapse will likely occur and the contractor should be made aware of this and take appropriate safety precautions. Methods to minimise the risk of collapse are hydraulic propping, trench shields, and the use of multiple excavators, all with cost implications and not always successful. As personnel need not enter the excavation, the safety responses are typically not to the same level as for excavations requiring manned entry.

Where groundwater levels are high and soils are potentially susceptible to collapse, counterfort drain construction can be problematic with collapse into the trench and insufficient time to properly backfill. This can result in ground being improperly backfilled, resulting in non-specific design foundations for future structures. To reduce this risk, initial dewatering can be undertaken by less hazardous methods, such as bored drains, directional drains, and well point drainage, with counterfort drain construction then undertaken during the summer earthworks period.

It is important to undertake regular inspection from the surface of the exposed trench side walls during excavation to evaluate whether the encountered ground conditions are consistent with that expected, and whether the design requires modification to intercept potential aquifers. Due to the nature of the construction, this may require an engineer's representative to be on-site for significant periods of time.

TNZ F/2 drainage metal is only produced at a few of the quarries that service the Auckland area and is often relatively expensive, thus there is often pressure from contractors to use a more readily available and cheaper aggregate. Gap-graded drainage metals should be avoided, with all-passing materials preferred, however, none of the usual products are ideal as they are either too coarse (with respect to retention criteria) or contain too many fines (silt and clay). The selection of a suitable drainage aggregate should be site-specific to the expected ground conditions. As a general guideline, fines (75µm or less) should be <5% with the D15 suitable for the excavated soils.

To avoid issues with the forming of wells from the base of trenches in potentially unstable counterfort drain excavations, wells can be drilled first and connected by later counterfort drain construction.

6 HISTORIC MONITORING OF COUNTERFORT DRAIN PERFORMANCE

The long-term performance of counterfort drainage, along with practical maintenance requirements, is key to acceptance as long-term solutions by designers, landowners, and territorial authorities. Recently, territorial authorities have rarely required long-term or even short-term monitoring of drainage performance to prove acceptable performance, provided the design engineer can demonstrate the drainage will produce an acceptable result based upon site-specific assessment and performance in similar sites in the past. However, concerns have recently been raised in some materials (e.g. Northland Allochthon) whether counterfort drains alone are sufficient. Presented below are performance results for counterfort drains from sites in Waitemata Group and Mangakahia Group soils. It is important the monitoring period before and after drain installation be as long as possible to record the response to a range of rainfall events.

Groundwater levels are usually monitored by standpipes or piezometers installed in separate hand or machine auger boreholes. Vandalism, and damage from mowing equipment or construction is a problem for long-term monitoring sites. It is important that a device is installed in the piezometers to record maximum groundwater levels as these often occur within a 24 hour period of a storm event, when it is unlikely someone will be on-site.

6.1 Orewa – Waitemata Group soils

Monitoring has been undertaken at a site on Waitemata Group soils in Orewa since 1999 in response to ground movement that occurred in 1998, following earlier movement in 1979. Monitoring has mostly been hand dipping at regular intervals, however, higher frequency monitoring was undertaken along with installation of maximum water level recorders to verify monitoring results immediately prior to, during, and following the counterfort drain construction in 2001. The inferred depth of failure was 5m to 6m, beyond practical construction depth in these collapsible soils, however, loose sandy horizons with elevated groundwater pressures were noted between 3m and 5m and targeted for drainage. The target of the installation was to improve stability of the land to reduce risk to the land owner, rather than development. Figure 2 presents a summary of long-term monitoring results from 1999 to 2016.

High frequency piezometer monitoring indicates groundwater levels rise within 24 hours of any significant rainfall event. Whilst long-term groundwater levels are generally below 3m, water levels do spike in response to heavy rainfall, rising to between 1m and 3m of ground surface producing an evaluated FoS of approximately 1.3 for the site under transient storm conditions. No obvious reduction in performance of the counterfort drains has been detected over 15 years of operation.

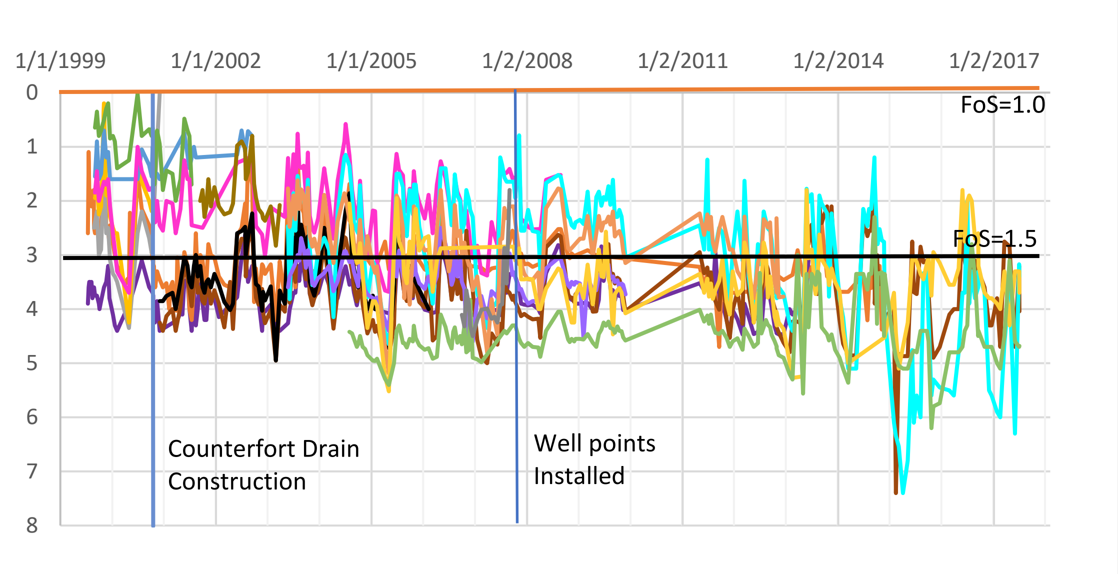

Figure 2: Summary of recorded groundwater level results from multiple piezometers across the site, prior and following counterfort drain construction from 1999 to 2017 in Waitemata Group soils, Orewa, Auckland

6.2 Hillsborough – Waitemata Group soils

Counterfort drains were excavated through weak and saturated ground between 4m to 5m depth and 10m spacing. Groundwater level monitoring was undertaken over a period of approximately 10 months; results are presented in Figure 3. Groundwater levels were maintained at a sufficient depth to achieve a minimum Factor of Safety (FoS) of 1.5 and was discussed in Fitch (1990).

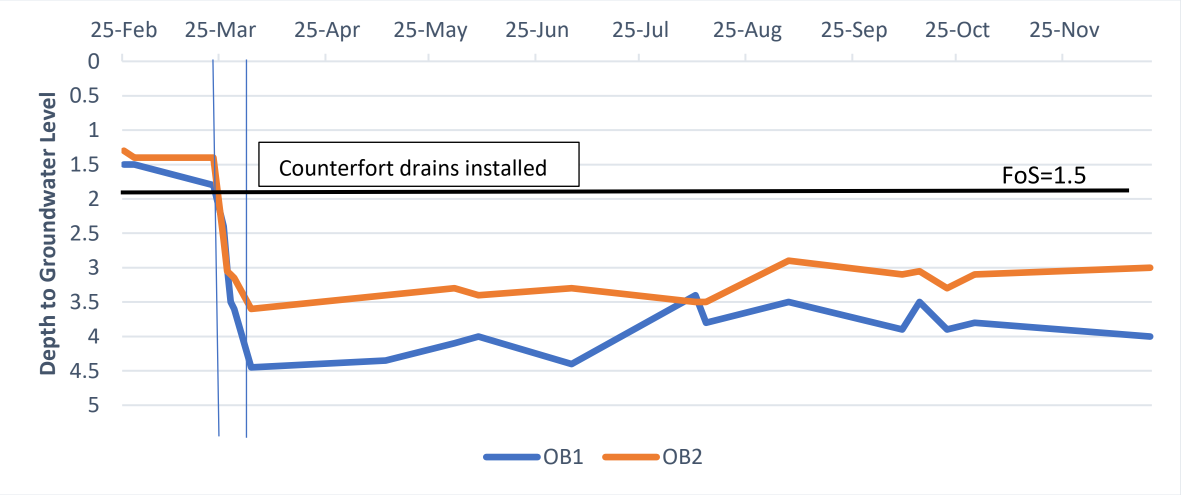

Figure 3: Summary of groundwater level results prior, during and following counterfort drain installation in Waitemata Group soils, Hillsborough, Auckland

There have been permanent dwellings constructed on the stabilised ground for a period of 27 years. A recent review, whilst not feasible to replicate the above data, indicates satisfactory land stability performance.

6.3 Waipu – Mangakahia Group, Northland Allochthon

Investigations for a proposed residential subdivision in Waipu (Northland) encountered Northland Allochthon sheared mudstones and weathered products (Mangakahia Group) subject to inferred ancient instability and evaluated as having an inadequate FoS for residential development under extreme conditions. Localised artesian water pressures were encountered above the soil-rock interface. Proof of concept was undertaken with trial counterfort drain installation in 2003 to maximum 4m depth, penetrating the soil-rock interface. Results of groundwater monitoring immediately prior and post-drain construction are presented in Figure 4. Following this trial, a more extensive array of counterfort drains was constructed.

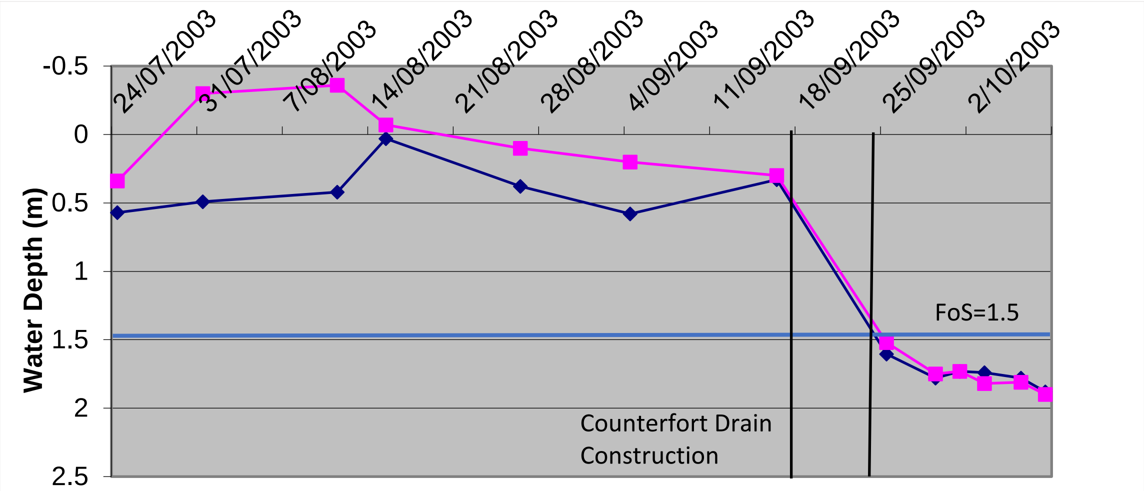

Figure 4: Summary of recorded groundwater levels prior, during, and following counterfort drain construction in Northland Allochthon materials, Waipu, Northland

The trial drain performance was reviewed in 2015 with installation of electronic logged piezometers. The recorded water levels in HA2 were relatively uniform, possibly indicating an issue with the piezometer or lack of penetration to water-bearing strata. However, this piezometer was constructed identical to the previous two in 2003 and also HA4 at the same time (which provided responses). In addition, HA2 extended to rock with groundwater typically encountered perched above the rock on a clay surface. Consequently, it is considered the monitoring results indicate satisfactory long-term performance of the drains. Results are presented in Figure 5.

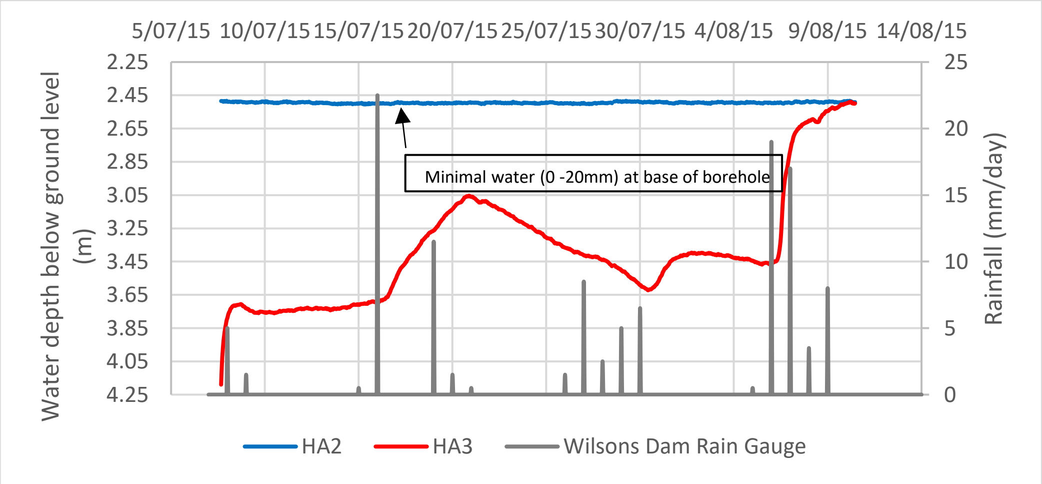

Figure 5: Summary of recorded groundwater levels during winter 2015 with HA2 (blue) within the influence zone of the drains and HA3 (red) outside the assessed key influence zone (some 20m from the nearest drain)

7 MAINTENANCE

Counterfort drains are considered relatively minimal maintenance items if constructed as outlined. The inclusion of a flushing point at the upstream end of the drain along with access from the outlet allows flushing of the drains, which is recommended on a five-yearly basis. However, with respect to the monitoring results presented in this paper, no flushing of the drains or any other regular maintenance has been undertaken.

8 CONCLUSIONS

Counterfort drains are a proven effective method to achieve slope stability improvement on sites with high groundwater levels. Typically, counterfort drains are most suitable to sites of gentle to moderate slopes, with perched groundwater and failure surfaces within 5m of ground surface. Drain spacing and depth is best assessed by a combination of analysis and practical experience. Precise mathematical solutions are not justified due to likely wide differences between idealised and actual field conditions. The drains should penetrate the failure surface.

Long-term monitoring at three sites, two in Waitemata Group soils and the third on Northland Allochthon, indicate no obvious deterioration in counterfort drain performance over the monitoring period (up to 15 years) where drains are constructed consistent with the typical design provided using a filter material similar to the TNZ F/2 envelope. Average groundwater levels as per design expectations have been recorded.

Required maintenance of well-constructed counterfort drains is minimal, however, flushing is recommended on a five-yearly basis.

REFERENCES

Bromhead, E.N. (1992). The Stability of Slopes, 2nd Edition. 242p; Taylor & Francis, London, New York.

Cornforth, D.H. (2005). Landslides in Practice – Investigation, Analysis and Remedial/ Preventative Options in Soils, John Wiley & Sons Inc, Hoboken.

Fitch, N. R. (1990). Ground Stabilisation with Counterfort Drains – Design, Installation and Monitoring of Drawdown Performance. *Proceedings NZ Geomechanics Society*, 16 1(G), 97-101.

Hutchison, J.N. (1977). Assessment of Corrective Measures in Relation to Geological Conditions and Types of Slope Movement. *Bulletin of the International Association of Engineering Geology*. No. 16:131-155, Springer, Berlin Heidelberg.

Stanic, B. (1984). Influence of Drainage Trenches on Slope Stability. *Journal of Geotechnical Engineering*, 110(11):1624-1636; American Society of Civil Engineers, Reston.

McDonald, G.J., Vooght, A.R., and Parkin, S. (2012). The use of deep counterfort drains as an effective method of stabilizing cuttings constructed in overconsolidated clays. *Earthworks in Europe*. Geological Society, London, p.115-124.