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Counterfort Drain Performance in the Auckland Area

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ABSTRACT

Counterfort drains are a method of lowering groundwater levels in soils and subsequently reducing pore water pressures on possible failure planes that can induce slope instability. This paper discusses the typical detail of counterfort drains employed and whether counterfort drains continue to be effective in reducing groundwater levels as has been demonstrated in Fitch (1990). Maintenance issues, monitoring and performance over time is outlined. Up to date costs of construction of counterfort drains are also given. The appropriateness of counterfort drain use in different types of Auckland Region Northland Allochthon geology is investigated. Counterfort drains are shown to generally have a demonstrable effect on groundwater levels. Their effectiveness is dependent on site specific geology rather than the overall geological unit present. Provided site specific factors are fully considered they can routinely be considered as a slope stability improvement option in the Auckland region.

Keywords: counterfort drain, buttress drain, trench drain, groundwater, slope stability, piezometers.

1 INTRODUCTION

Counterfort drains, also known as trench or buttress drains, are a method of lowering groundwater levels in soils and subsequently reducing pore water pressures on possible failure planes related to slope instability and thus improves the effective shear strength along such a plane. Counterfort drains have been used in New Zealand for a number of years, however, little analysis of their performance in recent projects along with their performance over time has been presented. Performance over time is important as generally counterfort drains are constructed to increase a slope's stability (quantified by a Factor of Safety (FOS)) to a sufficient level for a council to permit land development. The majority of structures and infrastructure in land development is intended to have a 50 or 100 year design life and therefore the stability of the land should also be assessed for this time.

2 TYPICAL DETAIL

The typical detail of a counterfort drain, as specified by Riley Consultants Ltd (RILEY), has had very limited changes made to it over the last 25 years. Figure 1 shows the typical cross section through a counterfort drain as specified by RILEY currently.

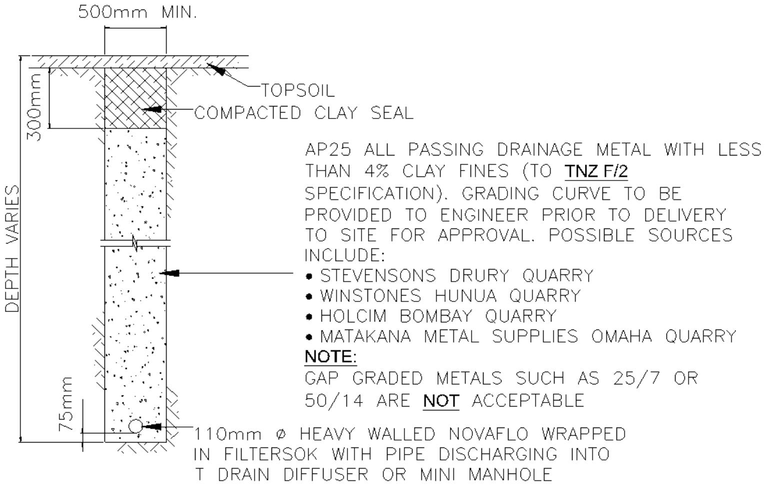

Figure 1. Typical Counterfort Drain Detail 2016 (RILEY)

The main changes to the RILEY counterfort drain detail over time as compared to Fitch (1990) are that the 110mm diameter “Novaflo” (perforated plastic pipe) is specified as heavy wall and, although the filter material is similar in composition the scoria specification is no longer used. Instead a general all passing material to Transit New Zealand F2 specification is stipulated. The appropriate scoria material typically was sourced from Three Kings Quarry in Auckland. However, the output of this material from the quarry (in particular low fines content) has now ceased as the quarry is economically at the end of its life. It is important that the grading curve of the filter material is specified by the engineer and that of the acquired material is checked before the material is delivered to site. The criticality of the low fines content is often not understood by the contractor. From some quarries a blended material or a builder’s mix can produce a material similar to the F2 grading envelope.

3 THEORY AND DESIGN

A counterfort drains system’s ability to reduce groundwater levels from both normal seasonal levels and storm related spikes is dependent on their depth and spacing (Cornforth, 2005). Cornforth (2005) states that theoretical research by Hutchinson (1977), Stanic (1984) and Bromhead (1986) to determine the required spacing to attain a certain drawdown is based on a number of assumptions: the infinite slope model applies, the landslide mass is homogeneous and isotropic (Bromhead’s method allows some anisotropy in permeability). To encounter such conditions in the field is unlikely.

The three authors’ drain spacing-depth-drawdown relationships are not dependent on landslide mass permeability coefficients with Stanic (1984) summarising that the recommended drain spacing is short enough in a trench drain system that the drainage path is of a length that allows consolidation to occur very quickly and thus pore pressure change with time to not been considered. Therefore, Stanic has not included the coefficient of permeability is the derived relationship. A notable recommendation by Stanic (1984) is that the ratio of spacing between drains relative to their depth below the original groundwater level should not be more than 4:1 as experience has indicated that sliding can occur within the landslide mass between the drains when the ratio is exceeded.

4 SPACING AND DEPTHS

Local authorities have become less stringent in recent years regarding stipulating that monitoring of groundwater must occur post counterfort drain construction. Therefore, there are limited case studies within the RILEY job records to undertake a thorough review of recent performance of the drain spacing and depths required for particular levels of groundwater drawdown in Waitemata Group soils as detailed in Fitch (1990).

Review of a counterfort drain system designed by RILEY on land at 67 to 73 and 77 to 81 West Hoe Heights Road, Orewa (Figure 2) known as West Hoe Homes (WHH) site for which an extensive period (over 15 years) of groundwater monitoring has occurred post drain construction provides insight into how counterfort drains in the wider Auckland area perform, beyond Waitemata Group geology, and allows assessment of performance over time. The WHH site is located near the east coast in the northern Auckland Council area (formerly known as Rodney District). The Rodney District has areas underlain by Northland Allochthon (historically known as Onerahi Chaos Breccia). Toan (1980), on behalf of Beca, Carter, Hollings and Ferner, provided a summary of Northland Allochthon/ Onerahi Chaos Breccia. Toan outlines that the Northland Allochthon is irregularly bedded rocks found both below and above Waitemata Group material. Toan explains that there is often a cohesive, low permeability skin of residual mudstone or siltstone in the allochthon, particularly on gentle slopes and ridges. This is different to Waitemata Group residual clays; Fitch (1990) outlines will often have major seepage path in vertical shrinkage cracks or soil creep may also open tension cracks across the slope which have high permeability’s.

The 1:50,000 New Zealand Geological Survey’s Geological Map shows Post Miocene Chaos Breccia underlying the WHH site. Typically this is comprised of displaced blocks of Miocene Flysch (interbedded sandstone and siltstone of the Pakiri Formation). Investigation at the WHH site in 1980 identified a sequence of deeply weathered sandstones and siltstones apparently dipping at about 10º in an easterly direction. The site was subject to instability in 1979 following earthworks in 1977 and 1978 near the toe of the slope. Heavy rainfall in 1998 triggered a secondary slip and reactivated the original instability. Post the 1998 movement groundwater monitoring was installed and approximately two years later a system of counterfort drains was constructed along with new standpipe piezometers.

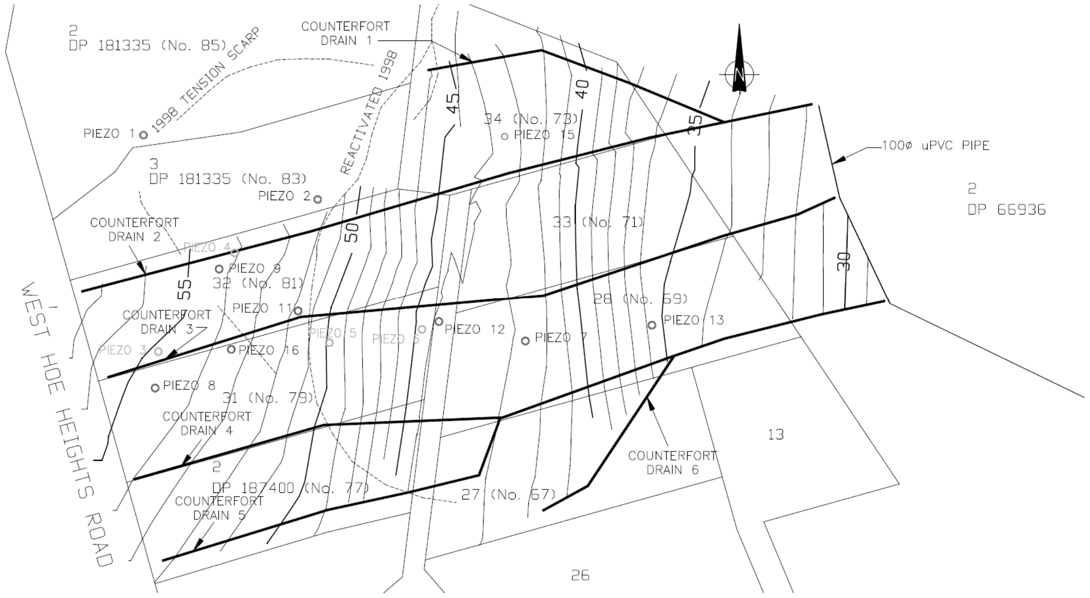

Figure 2. West Hoe Homes Site Plan

Table 1 list the counterfort drain sets at the WHH site along with their depths and spacing's. Table 2 indicates the average (over the record length) groundwater depths in standpipe piezometers (with response zones across their full depth) at WHH three drainage sets. Table 3 outlines the approximation of groundwater level for selected counterfort drain depths and spacing's calculated by Fitch (1990) based on number of case studies.

Table 1. West Hoe Homes, Orewa Counterfort Drain Performance

Drain Set	Depth (m)	Spacing (m)	Spacing/Depth
2 to 3	5	16	3.2
3 to 4	5	19	3.8
4 to 5	5	15	3.0
4,5 & 6 Lower to 3 Lower	4	18	4.5
3 Lower to 2 Lower	4	21	5.3
1 Lower to 2 Lower	4	20	5.0

Table 2. West Hoe Homes, Orewa Counterfort Drain Performance

Drain Set	Groundwater Depth Prior to drain installation (m)	Depth to groundwater with drains installed (m)	Groundwater Drawdown[a] (m)
2 to 3	1.24 (P3), 1.60 (P4)	2.86 (P11[b]), 3.32 (P9[b]),	1.7
3 to 4	0.82 (P5), 0.91 (P6)	3.65 (P8[b]), 2.56 (P12s[bc])	2.2
4,5 & 6 to 3 Lower	2.09 (P7)	2.03 (P7), 2.25 (P13s[g]), 1.84 (P14s)	0.0

[a] Difference between average groundwater levels at piezometer location before & after drain construction between drain sets
[b] P8, P9, P11 and P12s are replacement piezometers for P5, P4, P3 and P6 respectively
[c] s = the shallow screen portion at the subject piezometer location

Table 3. Fitch (1990) Counterfort Drain Performance- Reasonable approximation

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
4	20	2.0
6	15	4.5
6	20	4.0

The WHH site results agree somewhat with the Fitch (1990) and the WHH case study for the depth to groundwater level achieved by certain drain spacing's and depth's is made if linear interpolation made between the 4m and 6m drain depths in Table 3. However, given what is known about the geology at the WHH site and that the Fitch (1990) paper is focused on drains in Waitemata Group material this is assessed to be coincidental only.

5 MAINTENANCE

Counterfort drains, if designed and constructed appropriately, are considered as generally low to no maintenance items. However, there is little evidence published the author is aware of to substantiate this. Maintenance of counterfort drain typically involves ensuring that outlets are kept clear and that flushing is undertaken at regular intervals. In general maintenance is not something that is regularly undertaken, as counterfort drains are often constructed at subdivisional stage and the lots sold soon after, with dwelling construction then following within months to a year. Thus it is assumed that the drainage is working adequately as it has typically had testing undertaken that has allowed the subdivision to be approved. Once the drains are built there is often no statutory requirement to maintain them and the lot owner is unlikely to understand the importance of the drainage to the stability of their site. Flushing of the drains via ports can occur every 5 years. There should be no sediment emanating from the drains. The effort required in flushing a counterfort drain will be dependent on whether a flushing port has been installed and whether it is easily locatable along with ability to access water for flushing.

Maintenance is often embarked on when there is redevelopment occurring on the site or the site has remained undeveloped since subdivisional stage. To gain building consent for the proposed structure(s) a geotechnical report is then required to satisfy that the stability of the site meets the required FOS (typically 1.5 for residential development). Analysing the stability of the site requires comprehension of the groundwater regime and this can be assessed by installing piezometers. If the piezometers do not show favourable groundwater levels in line with the counterfort drains performing as expected then flushing of the counterfort drains may be undertaken. The outlets would also be located, cleared of any obstructions, flow rates assessed and any remediation to ensure scouring does not occur performed so that possible de-stabilising effects such as loss of toe support do not transpire. Monitoring well maintenance issues are discussed in the following section.

6 MONITORING

As previously mentioned, its is occasionally a requirement of the local authority or a recommendation of the design engineer or peer reviewer that monitoring of groundwater levels occur post counterfort drain construction, so as to demonstrate adequate performance. Standpipes installed in boreholes allow for monitoring. The monitoring is undertaken by a range of methods depending on budget, site location and monitoring period. The most common option is to manually visit the site and use a dip meter to record the groundwater level at the time of the visit. Alternatively installation of a system of custom made devices that allow ground water level rises during extreme precipitation events between technician visits' to be captured and recorded later on a technician returns. In remote locations or large budget projects, electronic water level data loggers are installed in the piezometers to provide measurements at consistent, prescribed intervals and which can be downloaded onsite or with more sophisticated equipment transferred via wireless and internet connections.

There are a number of issues with monitoring groundwater level in piezometers that make review of the performance of counterfort drains difficult. Protection of the standpipe is often difficult as vandalism from trespassers on vacant lots can occur and destruction from mowers or vehicles is regularly a problem. Piezometers can become blocked which may necessitate new piezometers being installed. With regard to manual monitoring by dipping at the site in an extreme rainfall event it can be too dangerous to access the site at the time and therefore groundwater peaks may be missed. The more sophisticated methods of manual measurement such as customised manual devices to capture extreme events are time consuming to make. Furthermore electronic data loggers are expensive and if they do not have remote monitoring there is no way to know whether adequate data has been recorded until a visit to the site is undertaken, often after the event in question. In addition, due to their cost, often electronic monitoring cannot be left in the ground for long periods of time, although with cost reductions this is becoming more economic. A secondary issue besides the measurement technique for the water level in the piezometer is that using standpipes without selective response zones can give inaccurate reading of the true hydrostatic pressures at the critical depth as the standpipe will potentially intercept or penetrate through perched groundwater tables. WHH case study is an example of the perched groundwater phenomenon influencing modelling and is reviewed in the next section.

7 PERFORMANCE

The performance of counterfort drains is often critical to maintaining the required margin against instability. The WHH site provides invaluable data on long term counterfort performance and performance in Northern Allochthon material due to the period of groundwater monitoring that has occurred.

7.1 Background and Initial Performance

Groundwater levels were first monitored at the WHH site after instability occurred following a heavy rainfall event in 1998 when groundwater was inferred to be close to ground surface as outlined in Section 4. Two piezometers (P1 and P2) were installed on the neighbouring adjoined properties at 83 and 85 West Hoe Heights in 1999 concurrent with installation of counterfort drains within the properties. These piezometers have been monitored since July 1999. Five piezometers (P3 to P7) were installed on the WHH site in July 1999 with monitoring commencing in August 1999. All groundwater levels have been manually dipped. After a period of six months the groundwater levels were reviewed and it was shown that groundwater levels on WHH land were on average 1.8m below the ground surface and the water level was 1.0m to 1.5m higher than at 83 and 85 West Hoe Heights Road. Furthermore certain piezometers on the WHH site showed rapid response to rainfall and this was inferred to be a result of these piezometers intercepting a permeable sand horizon between approximately 3.9 and 5.0m encountered in the boreholes before standpipe installation. The back analysis of the 1979 and 1998 failures assessed that depth of failure plane were between 6-7m and around 5m respectively. Soft soils in general were found between 3m to 5m depth. Draining the permeable sand horizon(s) was considered essential to improving stability of the site.

To improve site stability counterfort drains were installed on the site with layout and characteristics outlined shown in Figure 2 and Table 1 respectively. The groundwater levels in Table 3 indicate that the counterfort drains had a demonstrable effect on groundwater levels. Stability review of the slope from the groundwater levels recorded post construction to early 2003 indicated that under extreme levels the FOS of the slope was 1.30. Although the counterfort drainage system was primarily installed for land stabilisation purposes future development for residential dwellings was being considered. For this it would be necessary to prove that a FOS of 1.50 for the site had been attained. To clarify whether perched groundwater was potentially giving an exaggerated result of the hydrostatic pressure at failure plane level it was recommended that multiport piezometers be installed. Confirmation of such a phenomenon would indicate that the FOS in the land was higher than had been modelled under observed extreme groundwater.

7.2 Multiport Piezometers and Extended Performance

Four multiport piezometers were installed at the site; two in May 2003 (P12 and P13) and two in April 2004 (P14 and P15). Each piezometer had an upper screen from ground level to approximately 3.5 – 4.0m depth and a lower screen from below the depth of the shallow piezometer to the base of the drilled boreholes which were 6m deep. Figure 3 shows results from multiport piezometer 12 (over time period where both shallow and deep parts of the piezometers remained operational) clearly show that a downward groundwater gradient does exist at the site and hydrostatic pressure at the inferred failure surface level is less than indicated by a standpipe piezometer without a targeted response zone and may reflect a separate aquifer, a downward gradient in flow or a combination of both.

A selection of deep screen piezometers currently still in operation on site is shown in Figure 4 to assess the performance of counterfort drains on hydrostatic pressure at the depth of the inferred failure surface. No obvious trend is shown in these groundwater levels from when monitoring commenced that would indicate that the groundwater levels have risen over time. There does however appear to be some increased activity with P15/1 Deep and P16 over 2013 and winter spring 2014. However, peak groundwater levels for these piezometers coincided with their lowest recorded levels in the same period. For this period the rainfall does not follow any atypical trend. Observations on site, such as of concrete driveways and kerbings do not indicate any ground movement, however, an up to date survey of monitoring points has not recently been undertaken.

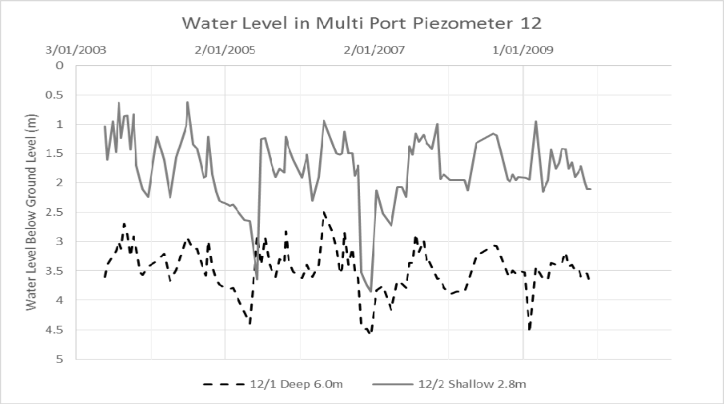

Figure 3. Multi Port Piezometer Performance

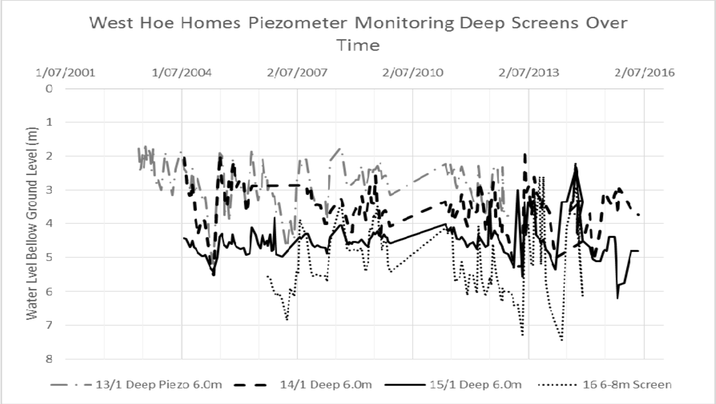

Figure 4. Ground water levels of deep screen piezometers over time

8 CONSTRUCTION COSTS

Recent (2014) costs for counterfort drain construction in Auckland is outlined in Table 4.

Table 4. Counterfort drain construction costs from 2014

Drain depth (m)	Cost (NZD)/m length of drain
0-3m	$270
Up to 5m	$480
5m to 6m depth	$780

9 CONCLUSION

Counterfort drains are shown to generally have a demonstrable effect on groundwater levels. Their effectiveness is dependent on site specific geology rather than the overall geological unit present. Understanding the response zone in a piezometer is necessary. Provided site specific factors are fully considered they can routinely be considered as a slope stability improvement option in Auckland.

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