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# GROUND STABILISATION WITH COUNTERFORT DRAINS - DESIGN, INSTALLATION AND MONITORING OF DRAWDOWN PERFORMANCE

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## ABSTRACT

This paper describes the use of counterfort drainage as a method of providing ground stabilisation. Theoretical design methods are presented together with drawdown tables derived by the author for Auckland soil conditions.

Typical drainage details are given and installation techniques and costs discussed. Monitoring of performance and drawdown results from a case study are presented.

## INTRODUCTION

Counterfort drains have been used for many years as a remedial measure to achieve slope stability improvement on sites with high groundwater levels. Their effectiveness is dependent upon the amount by which the groundwater level is reduced and maintained at a lower level.

The installation of counterfort drains is one of the most effective remedial measures available for stabilising inclined plane failures. The reduction in groundwater level following the installation of the drains decreases pore water pressure which increases the effective shear strength on the failure plane.

## SLOPE STABILITY

In many parts of the Auckland area residual soils overly interbedded siltstone/sandstone of the Waitemata Group. Slope angles of 15° to 25° commonly have thick residual soil mantles of marginal stability. Residual soils developed in the Waitemata Series typically comprise clays, silts and sands, with an abrupt increase in strength frequently occurring at the interface with the less weathered Waitemata sandstones and siltstones beneath. This interface typically occurs at 5 m to 7 m depth and is usually inclined at a similar angle to the ground surface.

Investigations of failed slopes usually find that block sliding has occurred on planar surfaces parallel to the ground surface. The planes on which failure occurs can develop from weathering and ground creep, producing thin low strength silty clay horizons. Failure may also occur in the low cohesive strength silty or sandy material just above the interface with the siltstone/sandstone. Slope failures are usually observed immediately following periods of heavy rain when the phreatic surface is close to the ground surface.

## IDENTIFICATION OF PROBLEM

Many of the recent subdivisions in the Auckland area have involved sloping land where ground stability could affect housing development. Local authorities have usually required geotechnical reporting at the Scheme Plan approval stage.

Site investigations on a large subdivision where slope stability is likely to be a problem usually involve the following:

- detailed geological study of the site
- borehole drilling programme
- laboratory testing
- surveying of cross sections
- groundwater level monitoring

This will provide information for stability analysis which will usually include:

- back analysis of any existing slips
- determination of potential slip planes
- sensitivity analysis with varying soil and water parameters
- locating areas of low Factor of Safety
- assessment of remedial measures

During the assessment of remedial measures typical options which may be considered involve:

- flattening the slope
- constructing a toe embankment to buttress the slope
- the use of cantilevered pile walls
- reducing pore pressures on the slip plane

The use of counterfort drains is included in the last option above. If counterfort drains are chosen as the most appropriate remedial measure an assessment would then be made of the reduction in groundwater level required to achieve the necessary Factor of Safety. Design can then proceed.

## COUNTERFORT DRAIN DESIGN

Once the desired reduction in groundwater level has been assessed the depth and spacing of the drains can be chosen.

a) Theoretical Approach

The theoretical solution to determining the spacing and depth of drains is based on steady state or transient state analysis as shown in Figure 1.

A very extensive literature exists on the subject of subsurface drainage design. Most of the design methods are orientated towards agricultural considerations. The differences between the various mathematical solutions to the problem are related to the basic assumptions of soil homogenity, permeability, porosity, flow conditions, and boundary conditions.

Problems occur in the selection of permeability and effective porosity parameters particularly in fissured clay soils. Experience has shown that there is little justification in arriving at a precise mathematical solution because of the wide differences possible between idealised assumptions and actual field conditions.

b) Practical Experience

The author has not found the theoretical design approach to be particularly effective in practice, especially in soil strata where permeabilities can vary by a factor of 1000.

In residual clay soils, the major seepage paths are in vertical shrinkage cracks in the clay. Soil creep or slope movement may also open up tension cracks across the slope which have high permeabilities. Counterfort drains intersecting open tension cracks are very effective in extreme rainfall conditions.

For residual Waitemata Group soils and typical Auckland rainfalls the author has found that the following table gives a reasonable approximation for drain performance.

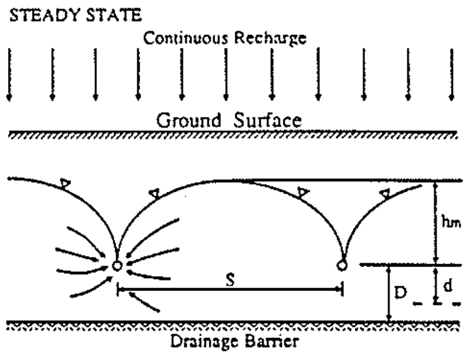
| Drain Depth (m) | Drain Spacing (m) | Approximate Average Depth to Groundwater Level (m) |
|---|---|---|
| 2 | 5 | 1.5 |
| 2 | 10 | 1 |
| 4 | 10 | 3 |
| 4 | 15 | 2.5 |
| 4 | 20 | 2 |
| 6 | 15 | 4.5 |
| 6 | 20 | 4 |

During extended dry periods water levels of 1 m or more below those given above will occur. Similarly following very heavy rain, water levels of 1 m or more above those given will occur. The presence of aquifers and aquicludes within the strata will also affect the drawdown response.

c) Other Considerations

In the subdivisional situation attention needs to be paid to the location of future building platforms to ensure that the drainage pattern provides adequate protection. Careful records of drain locations should be kept where a building platform is traversed to ensure that future foundations do not interfere with the drains.

Counterfort drains have also been used successfully at many sites in the Auckland area to stabilise slips in residual soils.




Hooghoudt Equation:

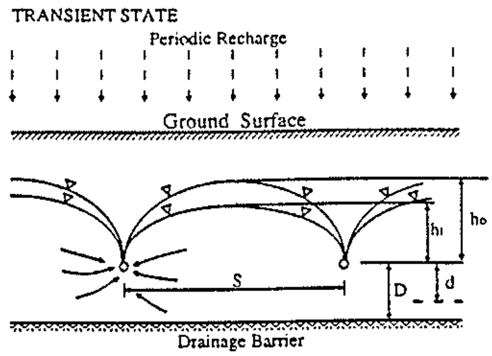
Drain Spacing, $S = \sqrt{\frac{4Khm(2d+hm)}{v}}$

where: $v$ = Recharge Rate

$K$ = Permeability

$$d = \frac{D}{1 + \frac{8D}{\pi s} \ln \frac{D}{\pi r_o}}$$

$r_o$ = Drainpipe Radius




Modified Glover - Dumm Equation:

Drawdown Ratio, $\frac{h_t}{h_o} = 1.16 e^{-\alpha t}$

where $\alpha t = \frac{\pi^2 K(d + 1/2\sqrt{h_o h_t})\, t}{N_e S^2} > 0.2$

$N_e$ = Effective Porosity

FIGURE 1 - Two-dimensional agricultural drainage with vertical recharge.

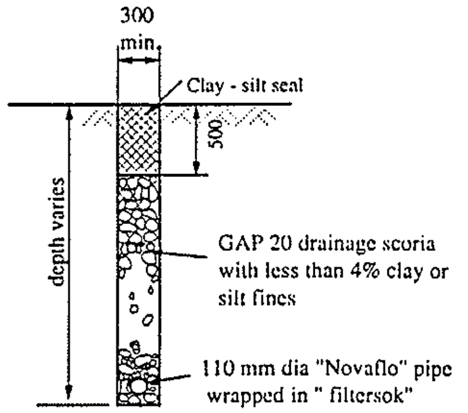
## DRAINAGE DETAILS

Figure 2 shows a typical cross section through a counterfort drain. The compacted clay-silt seal in the top of the trench is to prevent surface runoff from entering the drain. This is most important. The drain is to lower **groundwater** levels. **Surface water** should be encouraged to run off in a totally separate manner.

The choice of the filter material (in this case GAP20 scoria) is generally a compromise between the various design criteria. The filter material needs to be fine enough to prevent the soil passing through it yet coarse enough to improve the flow of water to the pipe.

A rigorous filter design procedure usually finds that two filter materials (fine and coarse) are required between the soil and the pipe to meet the various particle size ratio requirements. Alternatively the entire drain could be wrapped in filter fabric. These two options are usually impractical on site.

In practice the author has found that a single filter material with a grading similar to the NRB F/2 envelope performs adequately. If there is concern over the migration of fines a filter fabric such as 'Filtersok' should be placed around the perforated pipe to provide better filter action and prevent blocking.




NOTES
1. Trench seal to be compacted to 95% standard compaction
2. Trench to be graded to outlet so no ponding can occur. Minimum gradient 1 in 60
3. All dimensions in (mm)
4. Trench to be constructed down the line of the ground slope as detailed on drainage plans .

FIGURE 2 - Typical drainage detail

## INSTALLATION

Drains are usually installed below the groundwater level, with water seeping into the trenches as they are being dug. Consequently drains are usually, installed working in an uphill direction from the outfall.

Equipment and materials should be co-ordinated to prevent delays whilst the trenches are open. Only a short length of trench should be opened at any one time with backfilling following close behind. This will reduce the risk of cave-ins occurring. Alternatively temporary propping with hydraulic jacks can be used, but is expensive.

Inspection of trench side walls during construction is very important as soil conditions often vary from those found in the boreholes. The drainage design can then be fine tuned to the weathering profile encountered, and to intercept any deep aquifers. It is **imperative** that inspections **only be carried out from the surface.** Trenches **must not** be entered - by their very nature stability trench side walls are prone to sudden collapse.

The following table gives the approximate costs per metre length for various drain depths together with the practical construction width and typical excavation equipment used. The costs are for a site within about 40 km of Auckland requiring more than 100 m length of trench. It is assumed that excavated material will be removed and disposed of within 10 km of the site.

| Depth of Drain | Width | Total Installed Cost /m Length | Typical Excavation Equipment |
|---|---|---|---|
| 2 m | 0.3 m | $120/m | Tractor Backhoe |
| 4 m | 0.5 m | $180/m | PC 40 Excavator |
| 6 m | 0.6 m | $290/m | UHO 83 Excavator (Long Reach Boom) |

## MONITORING OF PERFORMANCE

It is often a requirement of the local authority concerned that the stability improvement be verified by monitoring of groundwater levels after the drains have been installed. It is important that the monitoring period before and after drain installation be as long as possible to record the response to a range of rainfall events.

Standpipes are installed in machine or hand auger boreholes to allow monitoring of groundwater levels. Particular care should be taken to seal the standpipes in place to prevent surface runoff from influencing results.

Standpipes are usually wrapped in filter fabric to prevent blockages and the anulus surrounding them packed with sand or gravel. The upper portion of the hole is sealed with bentonite pellets and powder. A large diameter pipe with a cap is installed at the surface as protection to the standpipe. In areas where vandalism could be a problem the large diameter pipe can be concreted in place and mounted flush with the ground level or padlocked.

It is often useful to install devices in strategic standpipes to record the maximum height to which the groundwater level rises during an extreme rainfall event. It is most unlikely that anyone will be on site during such an event.

## TYPICAL RESULTS

Figure 3 shows monitoring results from a site in Hillsborough, Auckland on which over 400 m of counterfort drains were recently installed. The soils comprise residual Waitemata Group clays, silts and sands overlying siltstone/sandstone. The drains were installed to stabilise a large slip whose failure plane occurred at the interface with the underlying materials. The slip material was saturated and generally soft. Hydraulic jacks were used to hold the trenches open.

The monitoring results plotted are from two observation bores on a cross section down a slope located halfway between two drains. The counterfort drains were spaced 10 m apart with depths of between 4 m and 5 m.

During drain installation groundwater levels dropped dramatically and remained at a low level throughout the monitoring period. In mid May a rain gauge was set up on site and daily rainfall records taken. This allowed a more accurate study of the relationship between rainfall and groundwater level rise.

It should be noted that the monitoring period plotted on Figure 3 does not include any extreme rainfall events. A 24 hour storm with a 2 year return period at the site would produce about 70 mm of rain. At the end of the May the records show a storm giving about half of that intensity. Other periods of wet weather lasted several days but only produced a maximum of about 25 mm on any given day.

Our conclusions for the area being monitored were that the counterfort drainage installation had been successful. Groundwater levels were maintained at a sufficient depth to achieve a minimum Factor of Safety of 1.5 under normal conditions, and 1.25 under extreme conditions.

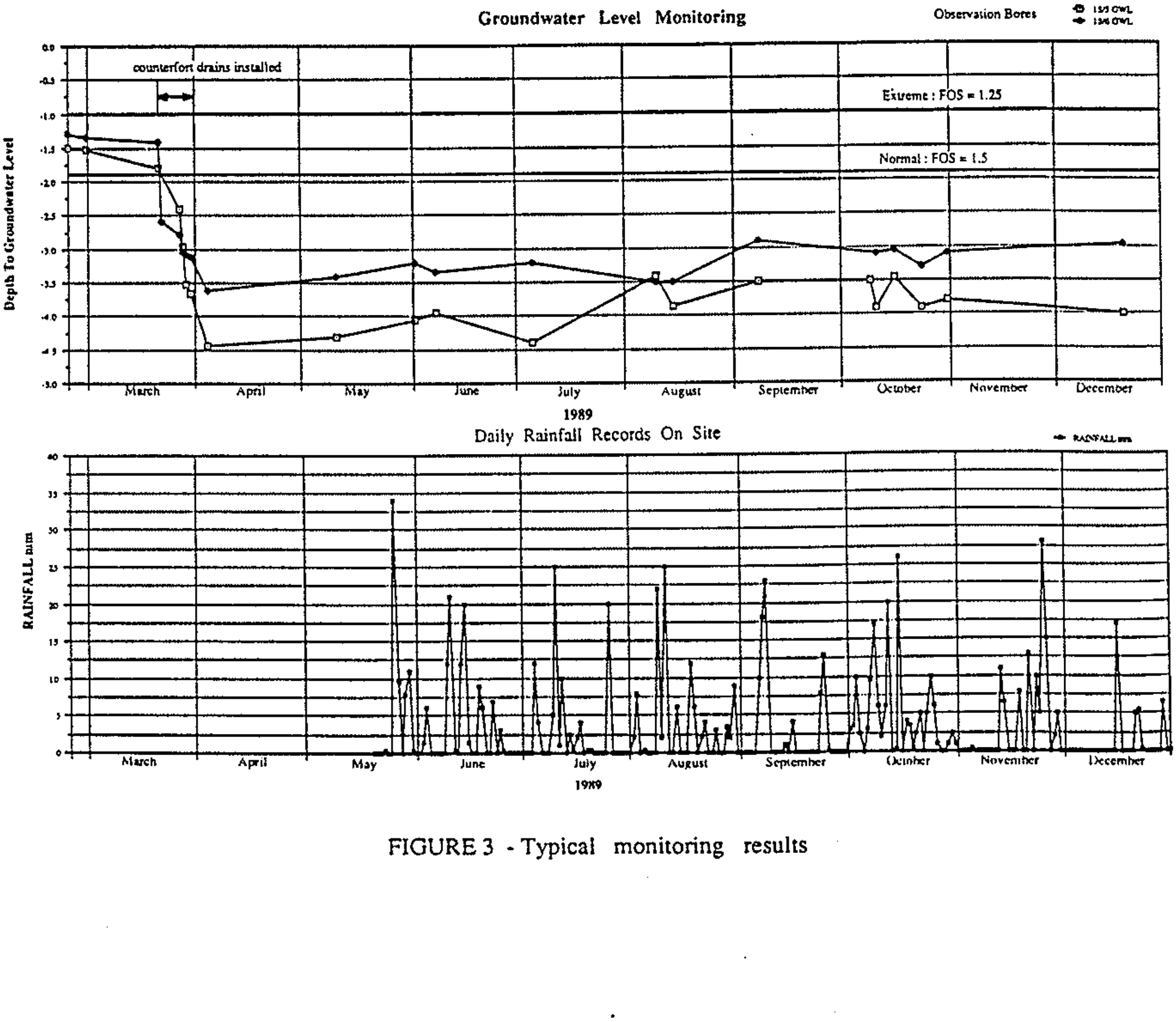



FIGURE 3 - Typical monitoring results

## CONCLUSIONS

Counterfort drains can be used to achieve effective slope stability improvement on sites with high groundwater levels. Drainage design should be preceded by a detailed site investigation to assess the required reduction in groundwater level. Drain spacing and depth is best assessed by a combination of analysis and practical experience. A precise mathematical solution is not justified because of the wide differences possible between idealised assumptions and actual field conditions.

The author has found that backfilling of trenches with a single filter material of grading similar to the NRB F/2 envelope gives adequate performance. If there is concern over the migration of fines a filter fabric such as 'Filtersok' can be placed around the perforated pipe.

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