Progressive Underslip Stabilisation Using Gravel Columns

Transfund New Zealand Research Report No. 208

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GHD Ltd

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Keywords: underslip stabilisation, graded gravel column drains, high pore water pressure, inclinometer, piezometer, deep-seated road failure, cost effectiveness, Snake Hill, SH1

An Important Note For The Reader

The research detailed in this report was commissioned by Transfund New Zealand.

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Contents

cont.

APPENDICES

Executive Summary

Transfund NZ commissioned GHD Ltd to monitor the performance of an innovative stabilisation method designed and implemented by GHD's Geotechnical Team. The stabilisation method consisted of the construction of deep *graded gravel columns* to provide positive subsurface drainage to the failure planes within a slip site. This monitoring was undertaken as a part of the stabilisation of a road embankment slip at Snake Hill (SH1 RP 144/11.34).

The report finds that *graded gravel column drains* are a suitable cost-effective method for the stabilisation of deep-seated road failures driven by high pore water pressures. The graded gravel column drain stabilisation method was evaluated on the basis of performance and cost against conventional methods such as piled retaining walls, counterfort drains and spider drains. The column drain method of stabilisation offers up to 35% savings over more conventional methods. The advantages and limitations associated with this technique are discussed.

The monitoring program undertaken indicates that the elevated pore water pressures at the site have generally been reduced to target levels, and the site deformation has progressively decreased. Following installation of the graded gravel column drains, computer simulated stability back-analysis was conducted for this site. The analysis returned an acceptable Factor of Safety of 1.6. Based on this the inclinometer readings GHD has concluded that further reinstatement of the road pavement, as a result of progressive failure will not be required.
Dr Laurie Wesley, a Senior Lecturer, undertook an External Independent Peer Review of this report at the University of Auckland. GHD concur with his recommendation that further surveillance should be undertaken.

Abstract

This report presents the findings of the monitoring programme undertaken by GHD at Snake Hill (SH1 RP 144/11.34), a road slip site which was stabilised using graded gravel column drains. Monitoring of pore water pressures was undertaken using piezometers, inclinometers were monitored to determine deformation, and computer simulated back analysis was undertaken. This report discusses the results of the monitoring programme, and asserts that the column drains have provided effective positive subsurface drainage to the failure planes, resulting in the stabilisation of the site. It also discusses the typical cost of methods for the stabilisation of deep-seated road failures driven by high pore water pressures, and finds that column drains are comparatively cost-effective.

1 Background

In March 1999 Transit New Zealand commissioned Manukau Consultants Limited (now GHD Ltd) to undertake contract PN 1774. The commission involved the geotechnical investigation, design and construction supervision for the reinstatement of the following road slips:

- Snake Hill Underslip SH 1 (RP 144/11.34)
- Tangiteroria Underslip SH 14 (RP 15/13.35)
- Goose Camp Overslip SH 1 (RP 32/7.70)

The Snake Hill Underslip was stabilised using graded gravel column drains, an innovative method designed by GHD's geotechnical team. Transfund New Zealand agreed to fund a research project for GHD to monitor the effectiveness of this methodology and to submit a report. This report discusses:

- The methodology implemented for the stabilisation of the Snake Hill Underslip site;
- The subsurface investigation;
- The remedial measures undertaken;
- The post construction monitoring;
- The effectiveness of graded gravel column drains in site stabilisation;
- The cost in comparison to conventional stabilisation measures;
- Suitable conditions and limitations for the use of graded gravel column drains;
- An assessment of the risks associated with the method.

2 Site Description

2.1 Location

The site at Snake Hill is located on SH1 at RP 144/11.34 (approx. 12km north of Whangarei). The slip is located along the fill embankment on the southbound lane of this dual carriageway (*see* Appendix A.)

2.2 Site Observations

The following on site observations were made prior to the subsurface investigation (by, V. Jairaj, principal geotechnical engineer):

- The road embankment was located across a deeply incised natural gully. The southbound lane curved to the right and sloped down in a southerly direction;
- A 45m wide failure headscarp (visible through the road seal), extended to the road centreline;
- A rubble-lined concrete water table drain was located adjacent to the northbound lane. This drain flowed in an east to west direction;
- A culvert was located beneath the fill embankment. This directed the surface drainage water from the water table drain to the toe of the failed slope;

- The batter slope of the fill embankment in the southbound lane varied from 1(V):2.5(H) and 1(V):3(H);
- A stock pond, fed by surface drainage from the road culvert, was located immediately south of the embankment.

3 Site Geology

Thompson, B. N. 1961. Sheet 2A Whangarei. (1st Ed.) Geological Map of New Zealand. 1:25 000. Department of Scientific and Industrial Research, Wellington, New Zealand, suggests that the site is underlain by:

Material	Description	Age
Alluvium	• Undifferentiated deposits in streams and river valleys.	Quaternary
Overlying:		
Greywacke & Argillite	• Intensely deformed, jointed and sheared, hard argillites and massive greywacke sandstones; • Of the Waipapa Group.	Paleozoic to Mesozoic
And / or:		
Basalt	• Lava flow deposits, in terraces; • Of the Horeke Basalts.	Quaternary

See Appendix B.

4 Site Investigation

4.1 Subsurface Investigation

A drill hole, BH 1, was positioned on the southbound shoulder in order to determine the nature of the subsurface material, and the depth of the failure plane(s). A wireline rotary-core drilling rig was used by Drillwell Exploration NZ Ltd to recover core. The core was logged and photographed by Ormiston Associates Ltd. The position of BH 1 is shown on the "As Built" drawing in Appendix E.

The *insitu* materials from the recovered core are summarised in the top table on the next page (page 13).

4.2 Failure Mechanism

4.2.1 Location of failure planes

The construction details and as-built data pertaining to this embankment were not readily available for reference during the investigation. Three potential failure planes were identified during the subsurface investigation: these varied in depth from 3.5m to 6.7m below the road level.

Depth	Material	Description
0-1.0m	**Basecourse**	
1.0-7.6m	**Fill**	• Consisting of SILT and CLAY, various intermixed materials, including some large wood organics; • Three potential failure planes consisting of saturated clays and clayey silts, with organic material, occurred between 3.5-4.5m, 4.8-5.0m, and 6.0-6.7m depth.
7.6-9.45m (EOB)	**Mudstone**	• Inferred to be argillite of the Waipapa Group (see Geology, Section 3.0); • Highly weathered and highly sheared; • Very stiff soil to very weak rock; • Frequent calcite deposits and occasional calcite veining in joints.

See Bore log and photographs, Appendix D.

4.2.2 Drivers

The following drivers are considered to have contributed to the instability at this location:

- Subsurface materials containing highly plastic saturated CLAYS and silty CLAYS with organic inclusions may have contributed towards a preferential failure plane;
- Basecourse material more than one metre thick, located along the headscarp of the failure plane;
- Poor subsurface drainage has contributed to elevated pore water pressures along the failure plane. The water sources are:
  - Groundwater percolating through more permeable horizons within the road formation;
  - The location of the stock pond at the toe of the embankment.

5 Design

5.1 General Options

Options for the stabilisation of a slip can be broadly classified into the following groups:

Method	Options	Limitations
Change in slope geometry	• Reduce driving force i.e. regrade slope; • Increase resisting forces i.e. toe loading or retaining walls.	Effective when slope geometry is the only driver of the failure, and competent material exists for founding retaining structures.
Change in soil parameters	Excavate below failure plane and backfill with competent material.	• Labour intensive; • Expensive
Reduction of pore water pressure	Subsurface drainage	Effective when failure is driven by high pore water pressures.

5.2 Retaining Walls

The suitability of retaining walls to stabilise the underslip was evaluated as tabled as follows:

Retaining Method	Limitations of Options	At Snake Hill
Gravity retaining walls i.e. Gabion baskets/ "Massblock"	These measures require a suitable foundation. If no suitable foundation exists these measures can become a head load for further instability.	No suitable foundation was identified. These measures were likely to exacerbate the instability in this location.
Reinforced concrete pile retaining wall	This option requires the presence of a suitable thickness of stable material to act as passive resistance to movement of the slope, and may require keying into the underlying bedrock horizon.	A failure plane was identified at 6.7m below ground level. This solution is unlikely to be cost-effective, as piles need to be very robust.

5.3 Drainage Options

Conventional drainage methods and their limitations with respect to the Snake Hill site were evaluated as follows:

Drainage Method	Limitations of Options	At Snake Hill
Counterfort drains	Depth of excavation is limited to a maximum of 4m, beyond which this method is uneconomical and cumbersome.	Failure planes identified to depth of 6.7m.
Spider drains	Horizontal drains can miss the failure plane and therefore may not provide effective subsurface drainage. Spider drains require regular maintenance of the drainage pipes.	Three potential failure planes were identified. Drainage of all three would require separate spider drain systems.

Drainage improvement was chosen as the preferred option to stabilise the underslip for the following reasons:

- At this location the batter slope of the embankment was approximately 1(V): 3(H). The geometry of this slope was considered to be adequately stable for an engineered fill;
- High pore water pressures were exhibited by the subsurface strata immediately below the embankment;
- Based on this, it was inferred that the failure was driven by high pore water pressure, and a cost-effective deep drainage system was required.

Lack of confidence in the conventional options for the stabilisation of this site led GHD to explore for alternative drainage methods.

5.4 Graded Gravel Column Drains

The development of an effective method to stabilise deep-seated progressive underslip failures was recognised as a priority by GHD. Graded gravel column drains provided a means for long term stabilisation of deep-seated road failures. The stabilisation method developed by GHD consisted of the provision of deep positive subsurface drainage to the existing failure planes.

5.4.1 Design methodology

Seventeen strategically located 900mm diameter vertical columns were drilled through the failure surface at the Snake Hill underslip to a stable underlying formation. The columns were then back-filled with a graded aggregate material. The drainage water from the base of the columns was directed to a manhole, through a 63mm diameter HDPE sub horizontal pipe grouted to the base of the column.

The column drains provide long-term, positive subsurface drainage through the failure planes at this site. (*See* Appendix C for the construction drawings.)

5.4.2 Comparison to conventional methods

The following are some of the advantages of using the graded gravel column drain over other (widely used) methods:

- It provides an effective mechanism to reduce high porewater pressures in deep seated slips and thereby stabilising them;
- The graded nature of the backfill limits migration of fines and thereby ensures that positive drainage is maintained;
- The method is cost-effective and requires minimum long-term maintenance.

5.4.3 Research team

The stabilisation of the Snake Hill underslip employed an innovative method developed by GHD's geotechnical team. This was lead by V. (Raj) Jairaj, who was responsible for the investigation, design, monitoring and evaluation of this project. The project was administrated by Mark Smith of GHD.

Dr Laurie Wesley (University of Auckland) undertook an external peer review (*see* Appendix J) of the reinstatement works at the following stages:

- Investigation and design;
- Review of post reinstatement works;
- Review of monitoring information and the completion report.

6 Construction

6.1 General

The contract was awarded to Ken Rintoul Cartage & General Contractors Ltd. Construction began in April 2000 and was completed in June 2000. The works involved in the construction of the graded gravel column drain system can be summarised as follows:

- The vertical columns were drilled at pre-selected locations at this site;
- Sub horizontal directional drilling was undertaken to intercept the pre-drilled vertical shafts at the specified invert levels;
- 63mm diameter MDPE pipes were threaded through the sub-horizontal holes to connect the vertical shafts to the drainage manholes. The inlet end of the pipe was wrapped in approved geofabric;
- The vertical shafts were backfilled with graded gravel;
- The existing basecourse was excavated and removed from the southbound lane. The lane was rebuilt with approved aggregate reinforced with geogrid.

6.2 Construction Details

- Directional drilling was undertaken from a pre-excavated pit. Appropriately sized drainage manholes were erected at each of these pit locations. During construction the pit walls require temporary support to prevent collapse.
- The construction of the column drains was undertaken using a 900mm diameter auger rig. The drilled shafts were supported with temporary steel casing. This facilitated man access to complete installation of drainage inlet details.
- The directional drilling was completed in most locations with ease; however, when the drill head encountered unweathered greywacke sandstone, progress of drilling was slow.
- Engineer's representative inspected each column drain connection. This necessitated additional supervision time. Construction observation costs were $2K – $3K more than migth have been expected for conventional retaining wall construction.
-

Although the column drain stabilisation method is a new technique, the physical construction work was completed easily in accordance with the construction specifications. (*See* Appendix E for the "As Built" drawing.)

7 Pre and post Construction Monitoring

7.1 General

GHD's original proposal was to install monitoring instruments prior to the commencement of stabilisation works. However, site conditions at this location precluded accessibility of drilling equipment to do this. However, during the latter stages of the construction three inclinometers and five piezometers were installed.

During the post construction period the column drains were seen to continuously discharge large volumes of water into the manhole. This confirmed that they were draining subsurface water, which is considered to have contributed to progressive failure of the slip at this site.

7.2 Piezometers

Five piezometers were installed in two drillholes located midway down the slope and at the toe. Refer to the "As Built" drawing (Appendix E) for the piezometer positions.

Drillhole Number	Piezometer Identity	Response Level (mRL)	Top of Piezo Tube (mRL)
H1	**P_1**	84.151	95.061
	P_2	88.601	95.061
	P_3	91.431	95.061
H2	**P_4**	83.764	93.764
	P_5	88.184	93.764

The piezometers were monitored from June 2000 to April 2001 at approximately monthly intervals. The monitoring information has been transferred to a spreadsheet format. The graphical representation of this information is included in Appendix F.

Post construction monitoring indicates that:

- Generally the porewater pressures registered by the piezometers were at or slightly above the column drain outlet elevation.
- Piezometers **P_4** and **P_5** register porewater pressure below the outlet level of Row 1 of the column drains. This is due to the influence of deeper drainage outlets from the column drains in Row 2, which are in the immediate vicinity of these piezometers.
- Immediately after construction, piezometers **P_2** and **P_5** show sensitivity following rainfall events. However after allowing the site to drain and stabilise further rainfall events appear to have had insignificant influence on the piezometric levels.
- Piezometers **P_2** and **P_3** are installed within the same drillhole and are isolated by a bentonite plug to measure pore pressures within two separate zones. However their readings show identical signatures. The observed pattern in the readings suggests that the bentonite plug make not have been effective i.e. short-circuiting of porewater pressure.

- Piezometers **P_2** and **P_3** show porewater pressure approximately 1.5m above the drainage outlet. This may be due to

  either

  partially blocking by algae growth of the the outlet to some of the columns at the manhole,

  or

  during the drilling of the vertical columns the walls of the columns could have been smeared with fine silty CLAYS. The clay would restrict the passage of water into the columns. The columns were spaced at 4m C/C and there is thus a possibility that some of the groundwater is finding its way along the original drainage paths between the columns. Over time the soil particles on the inside of the columns will be rearranged and subsurface water will be drawn into the lower permeable graded gravel of the column. By this time the piezometer levels will progressively be drawn down to the outlet level.

7.3 Inclinometers

Two inclinometer tubes were installed at the site by Drillwell Exploration Ltd, and monitored by Geotechnics Ltd. The locations of the inclinometers, **I_1** and **I_2**, are shown on the "As Built" drawing in Appendix E. **I_1** and **I_2** were installed to depths of 12m and 10m respectively.

The base readings were taken on 13 June 2000, and further readings were taken on 30 October 2000 and 18 April 2001. The results are summarised in the following table.

Inclinometer	30/10/00	18/04/01
I_1	Deflection of 8mm @ 7m depth	Deflection of 13mm @ 7m depth
I_2	Deflection of 8mm @ 8-9m depth	Deflection of 12mm @ 8-9m depth

The inclinometer monitoring data, shown in Appendix G, suggests that:

- Minor movement associated with post-construction settlement has occurred during the initial 5 months period following construction however this has not compromised the integrity of the road surface at this location.
- Movement during the latter six-month period is within the order of accuracy of the instrument (± 5mm). It is therefore likely that no movements have occurred in the later 6-month period. Additional readings should however,be undertaken to confirm this.
- The instability at the site has been resolved as a result of positive subsurface drainage.

7.4 Stability Analyses

Computer simulated slope stability analyses of the site have indicated a sufficiently improved factor of safety of 1.6 following construction of the graded gravel column drains. Stability analyses were conducted at both pre and post construction stages, using the Geoslopes modelling program SLOPE/W. The post-construction analysis was modelled using the piezometer and inclinometer readings taken throughout the monitoring programme. The results of the stability analyses are shown in Appendix H.

7.5 Post Construction Surveillance and Maintenance

Generally the site instability at Snake Hill is driven by high porewater pressure during prolonged wet periods – typically during winter. Surveillance monitoring undertaken at Snake Hill to date has only been undertaken over one winter period. In order to confirm the ongoing effectiveness of this solution it is recommended that the surveillance and maintenance programme continue at this site as follows:

- The piezometers are measured on a monthly basis for the next two years. Logistics may require that this be reduced to a minimum frequency of three-monthly for two years;
- The inclinometers should be monitored annually for the next two years;
- The drainage outlet pipes should be cleaned at six-monthly intervals, in order to maintain the free flow of subsurface water.

8 Cost Analysis

Detailed costs for various stabilisation options have been estimated (Appendix I). The cost analysis also includes the maintenance cost for each option, over a 25-year period.This is summarised in the following table.

Stabilisation Option	Estimated Cost (PV)	Advantages	Disadvantages
Pile Retaining Wall	$228K	• Minimal maintenance • Conventional, well understood construction methodology	• Principal instability driver (porewater pressure) not removed • Visual impact • Expensive
Counterfort Drains	$231K	• Removes principal instability driver (porewater pressure) • Conventional, well understood construction methodology	• Limited to 4-5m depth • Prohibitively expensive for deep-seated failures
Spider Drains	$126K	• Removes principal instability driver (porewater pressure) • Low cost	• Uncertainty associated with intersection of failure planes does not ensure positive subsurface drainage • Bad track record for instability stabilisation • Cost of maintenance is considered to be greater than any other option
Graded Gravel Column Drains	$111K	• Removes principal instability driver (porewater pressure) • Intersection and drainage of failure planes is assured • Gravel grading controls mitigation of soil particles and hence ensures long-term effectiveness • Visually pleasing • Can be used under roads to transfer some pavement loads to a more competent horizon • Becomes a shear key although this property is subordinate compared to the lowered pore-water pressure • Low cost	• Limited maintenance required in ensuring that pipes remain clear. However, under certain conditions unblocking of pipes may be required due to laminite build-up on inside of drainage pipes

9 Suitability of Graded Gravel Column Drains

9.1 Suitable Conditions

The graded gravel column drain method is suitable for the following land stabilisation works:

- Deep-seated land instabilities driven primarily by high porewater pressures;
- Can easily be adapted to suit instabilities in relatively steep topographical terrain;
- Provides positive drainage to all water bearing strata encountered throughout the entire depth of the column. This reduces porewater pressures in these strata and thereby provides stability to the site;
- An appropriate level of site investigation is required to determine failure planes and parameters. If the drivers and the extent of failure can be ascertained with confidence prior to conducting subsurface investigations, then the site investigation can be scaled down, without adversely affecting the reliability of the stability achieved.

9.2 Unsuitable Conditions

The graded gravel column drain solution is not suitable for the following situations:

- Where the failure is not driven by high porewater pressures but other factors such as geometry of the slope or the soil parameters;
- In situations where failures are shallow seated and driven by high porewater pressures, conventional methods such as counterfort drains may well be more cost effective, as conventional machinery, such as hydraulic excavators etc., can be used.

10 Risk Assessment

10.1 Construction of Graded Gravel Column Drains

The following risks are associated with construction of the column drains:

- Temporary steel casings should be provided for support of the drilled shafts in all cases. This addresses the following issues:
  - collasing holes
  - soft ground
  - high water tables
  - safety before man access is permitted;
- Excavation for thrust pits and manholes at the base of an unstable slope requires carefully designed temporary support to protect workers at these locations. Construction works should preferably be undertaken during dry summer months, when the porewater pressures are low and hence risk of failure is at a minimum;
- Working on a road requires adequate traffic control. However, generally one side of the road may remain open;
- Elastic contraction of MDPE drainage pipes during post installation periods should be given cognisance. Such contraction may discharge drainage water

to the outside of manholes and thereby exacerbate existing site instability. The MDPE pipe should therefore be extended adequately through the manhole to allow for any elastic contraction movement. The pipe should only be grouted into the manhole once all contraction movement has ceased.

- Undulating bedrock horizons may pose a limitation to directional drilling.

10.2 Long Term

The following risks may affect the long-term function of the column drains:

- Graded gravel has been used within the column to filter drainage water and prevent long-term blockage within the drainage medium. Inadequate care in the selection of gravel grading may result in serious failure of this system;
- The MDPE pipes selected were greater in size than would be required under normal operational conditions. This is to allow for any unexpected blockages within the 63mm diameter pipes. Inspections of the manhole outlets of the 63mm diameter pipes are required on a six-monthly basis. Any laminite build-up needs to be cleared immediately;
- Subsurface water may track along the annulus of the 63mm diameter MDPE pipe and the directionally drilled hole. Over a prolonged period, the resultant irrigation of the failure plane will exacerbate instability. Application of an adequate quantity of bentonite grout at the column drain inlet is imperative to the success of this method.

11 Response to Peer Review

Dr Laurie Wesley (University of Auckland) undertook an external peer review of the reinstatement works. His peer review is included in Appendix J. GHD's response to the peer review is as follows:

- Point 3 – We agree with Dr Wesley's statement and have outlined our recommended program for further post construction surveillance and maintenance in section 7.5.
- Point 4 – We agree with his statement that, uncertainty exists in the increase in the value of factor of safety (FOS) since completion of stabilisation works. However given the limitations to the pre-construction information of the site, the results of the computer stability analysis presents the best comparison model of the pre and post construction FOS.
- Point 5 – We concur that allowance should be made for monitoring of porewater pressures following prolonged heavy rainfall. This will enable the response to rainfall events to be determined.
- Last Paragraph – Other sites where the graded gravel column drains have been used and where pre and post construction surveillance was undertaken all show very positive results and appear to be well stabilised.

12 Conclusions

From the geotechnical investigation, monitoring program and construction of the project, the following conclusions can be made:

- The observed instability along SH1 at Snake Hill (RP 144/11.34) can be attributed to the poor quality of fill within the road embankment, combined with elevated pore water pressures driven by poor surface and subsurface drainage;
- Conventional drainage methods were unsuitable for the site conditions and a purpose designed, deep subsurface drainage system was devised by GHD to stabilise the slope;
- Graded gravel column drains are a suitable method for dealing with a deep-seated instability driven by high pore water pressures. Minor settlement may occur, but this is unlikely to cause distress to the road surface in this location;
- The impact of the stabilisation works on the environment has been minimal;
- The cost of the graded gravel column drain stabilisation method has been significantly less than the typical cost of conventional stabilisation methods.

13 Recommendations

Through the construction and surveillance of the column drains at the Snake Hill site the column drain stabilisation method has been proved to be cost effective at stabilising deep seated instability at this site.

It is therefore recommended that this stabilisation method be adopted as a suitable stabilisation method for similar sites.

14 Scope and Limits of Geotechnical Investigation

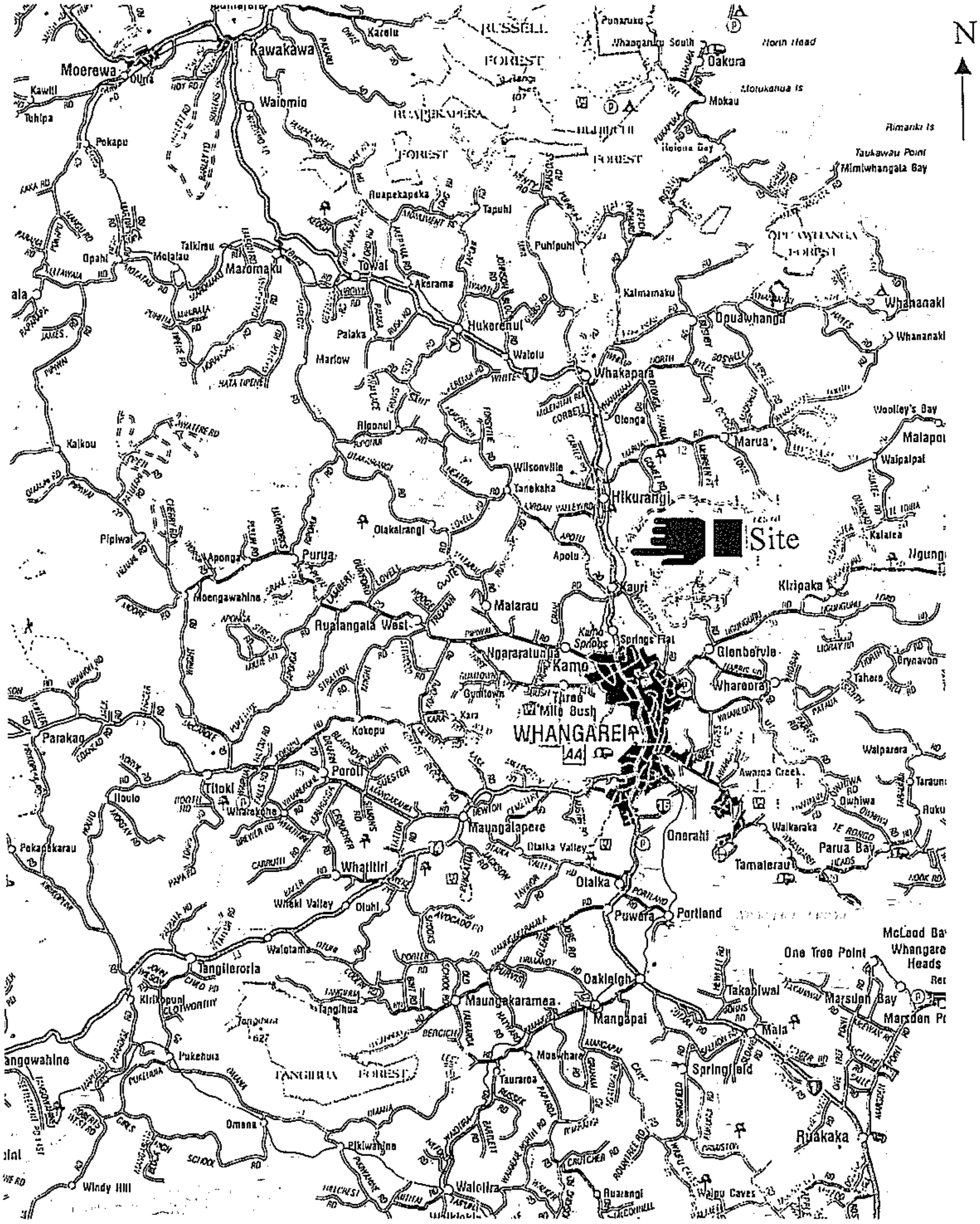
An understanding of the geotechnical site conditions depends on the integration of many pieces of information, some regional, some site specific, some structure specific and some experienced based.

The advice tendered in this report is based on information obtained from the investigation locations tests points and sample points and is not warranted in respect to the conditions that may be encountered across the site at other than these locations. It is emphasised that the actual characteristics of the subsurface materials may vary significantly between adjacent test points and sample intervals and at locations other than where observations, explorations and investigations have been made. Subsurface conditions, including groundwater levels and contaminant concentrations can change in a limited time. This should be borne in mind when assessing the data.

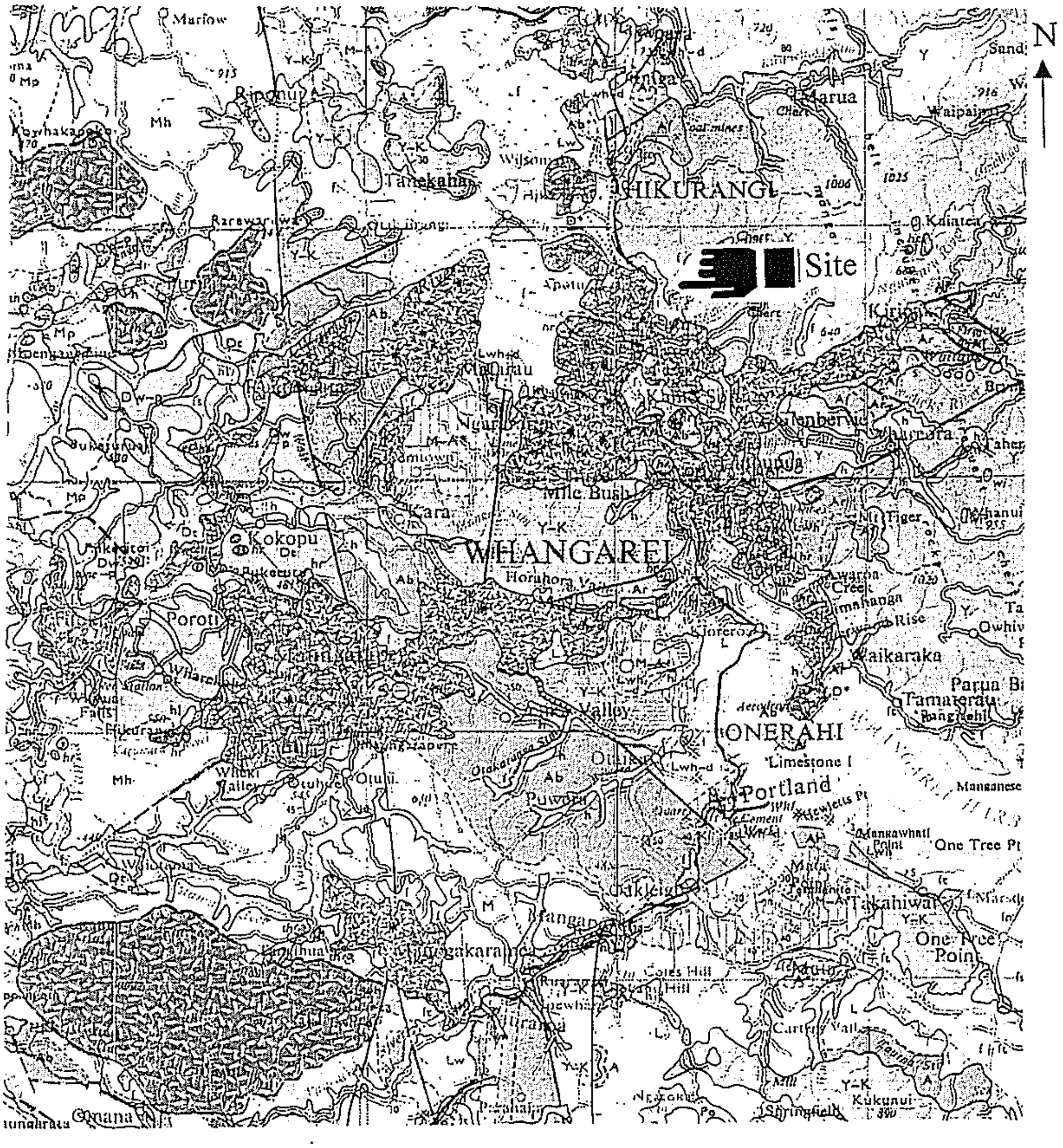
It should be noted that because of the inherent uncertainties in subsurface evaluations, changed or unanticipated subsurface conditions may occur that could affect total project cost and/or execution.

The subsurface and surface earthworks, excavations and foundations should be examined by a suitably qualified and experienced engineer to judge whether the revealed conditions accord with both the assumptions in this report and/or the design of the works. If they do not, the engineer needs to modify advice in this report and/or design of the works as necessary.

Appendix A
Location Map



Appendix B
Site Geology

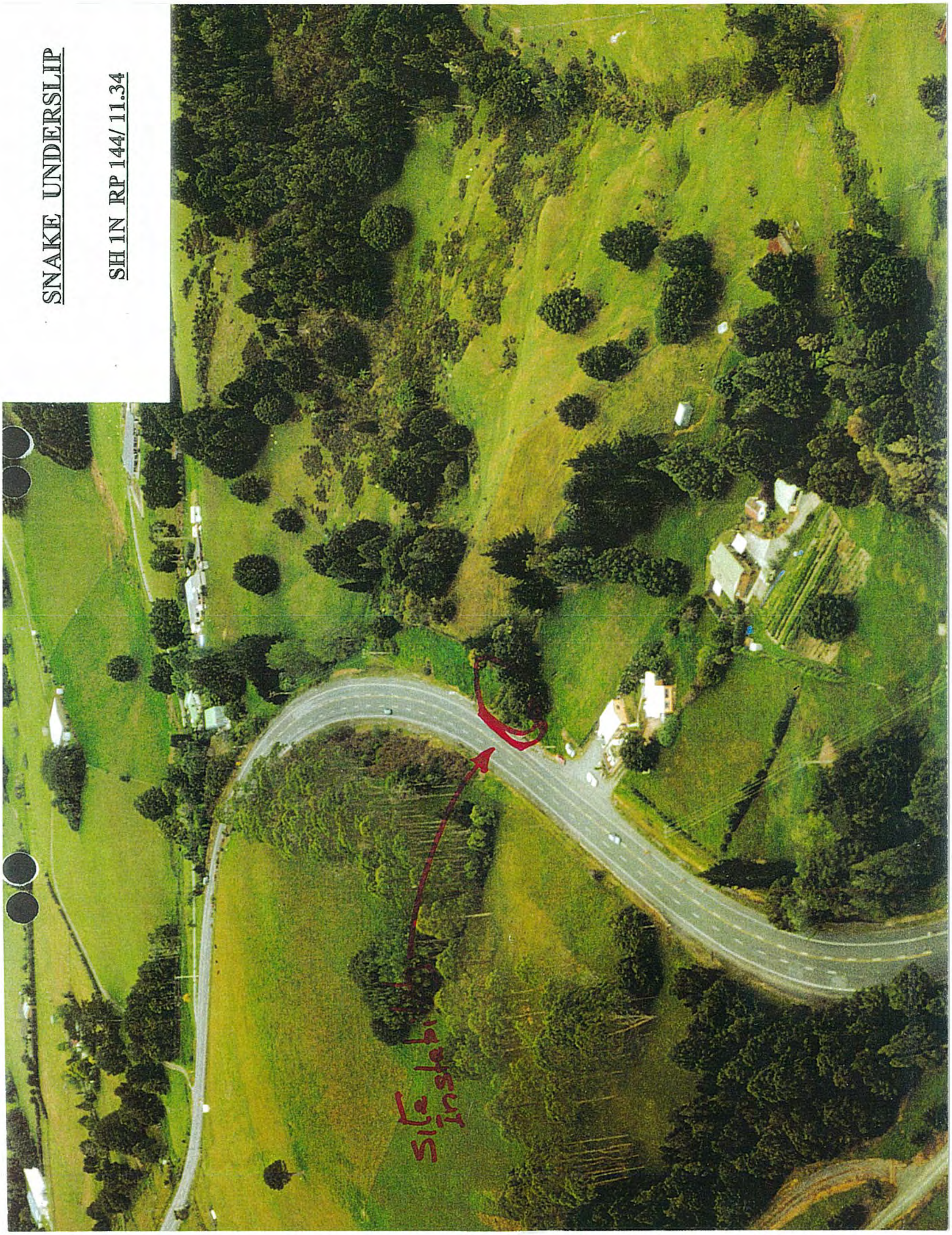


f ALLUVIUM: Undifferentiated stream and river valley deposits, of Quaternary Age.

Y GREYWACKE & ARGILLITE: Highly weathered, deformed, jointed and sheared, hard arkosic argillites and massive greywacke sandstones, with chert and associated manganese, and secondary silica or calcite veining. Of the Waipapa Group, of Permian to Jurassic age.

hr BASALT: Basalt flows without scoria cones, now forming terraces up to 600ft above sea level. Of the Horeke Basalts, of Pliocene to Pleistocene age.

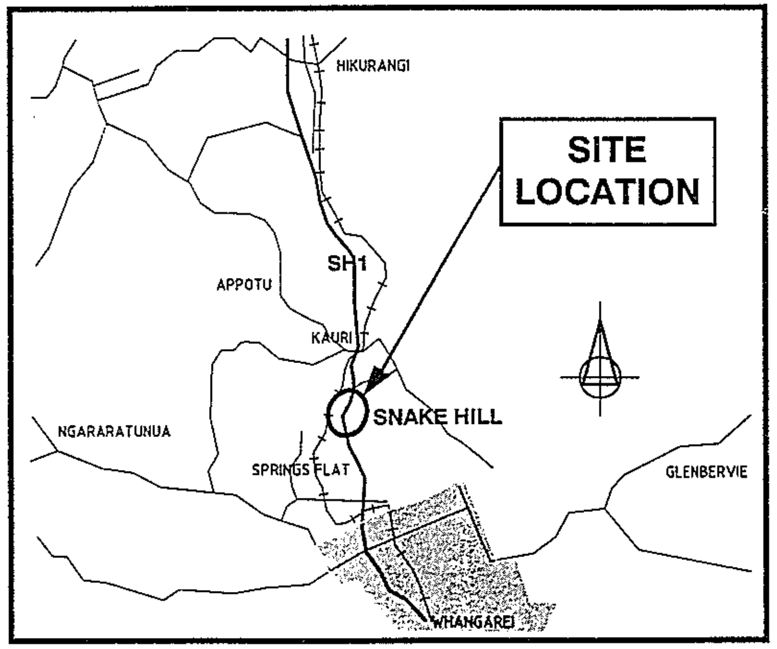
Appendix C
Construction Drawings and Photograph



SNAKE HILL UNDERSLIP
SH1N, RP144/11.34 (LHS)
For
Transit New Zealand

Locality Plan

Not to Scale



Drawing List

Plan No.	Revision	Title
52027903/03/01	-	LIST OF DRAWINGS AND LOCALITY PLAN
52027903/03/02	-	PROPOSAL TO UPGRADE BASE PLAN
52027903/03/03	-	CROSS SECTIONS
52027903/03/04	-	SETTING OUT PLAN
52027903/03/05	-	STANDARD DETAILS

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LIST OF DRAWINGS AND
LOCALITY PLAN
PLAN No 52027903/03/01
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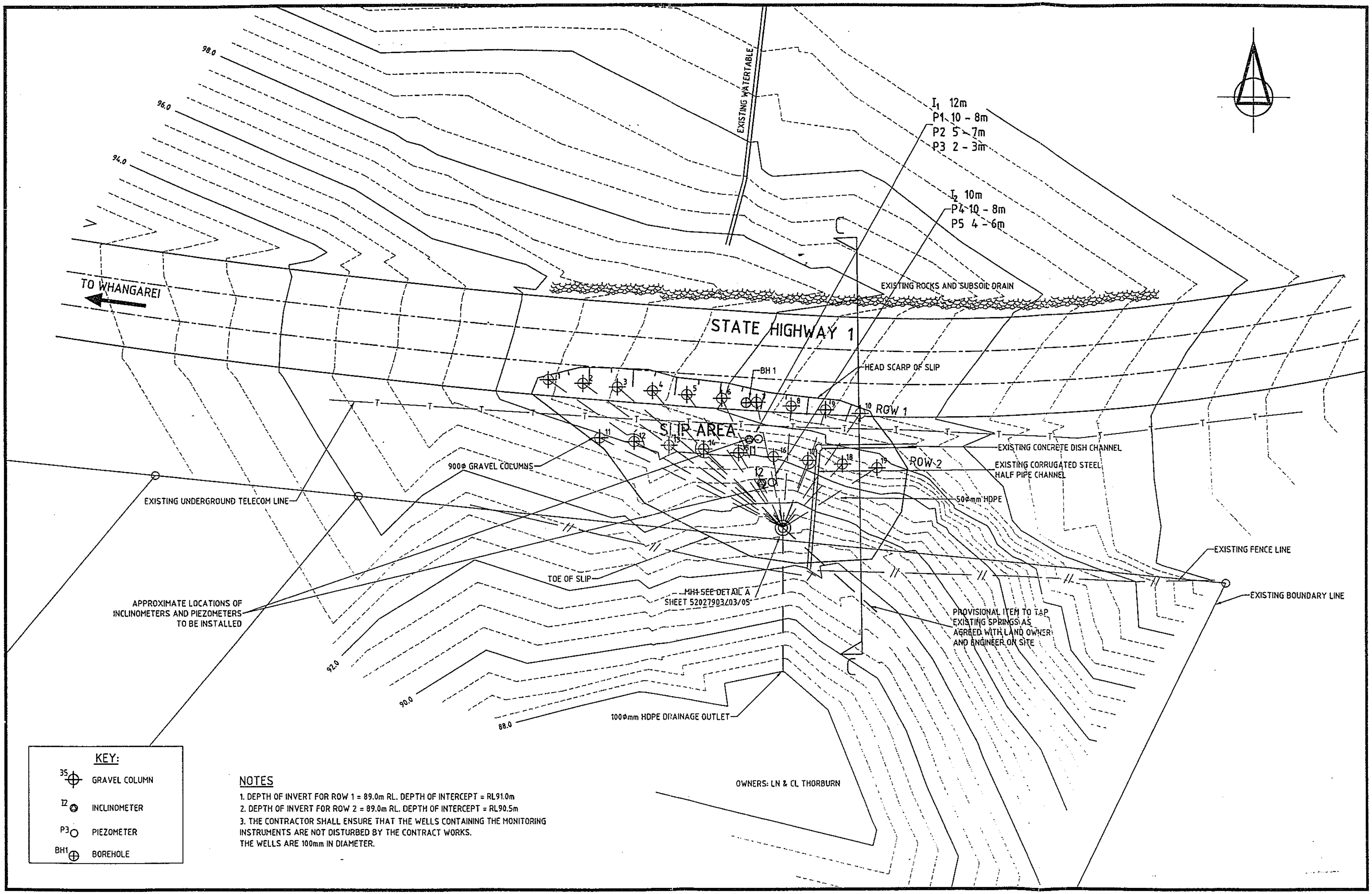

NOTES

1. DEPTH OF INVERT FOR ROW 1 = 89.0m RL. DEPTH OF INTERCEPT = RL91.0m
2. DEPTH OF INVERT FOR ROW 2 = 89.0m RL. DEPTH OF INTERCEPT = RL90.5m
3. THE CONTRACTOR SHALL ENSURE THAT THE WELLS CONTAINING THE MONITORING INSTRUMENTS ARE NOT DISTURBED BY THE CONTRACT WORKS.
THE WELLS ARE 100mm IN DIAMETER.

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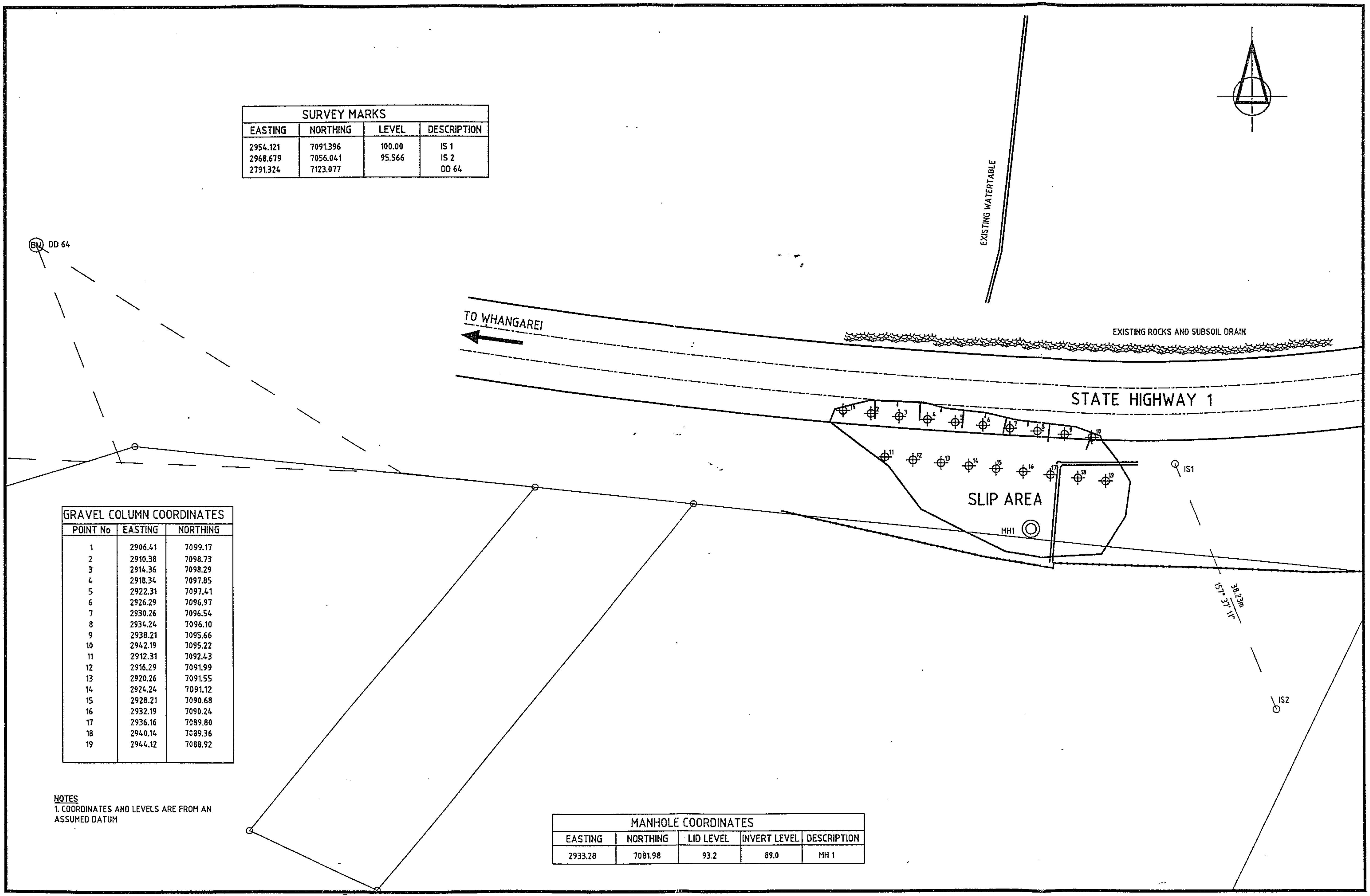
REV	BY	DATE	CHK	AMENDMENT

PROJECT NAME
SNAKE HILL UNDERSLIP
SH1N, RP144/11.34 (LHS)
For
TRANSIT NEW ZEALAND

	SIGNED	DATE		SIGNED	DATE
SURVEYED			DRAWING CHECKED		17/9/99
DESIGNED	R.Jairaj	6/99	M.C. APPROVED		23/9/99
DRAWN	T.Baker	6/99	XREF NAME		VIEW 1
FILE NAME	R:\52027903\ACAD\03\PLAN01				
CLIENT DWG. REFERENCE			SCALE: 1:200 @ A1, 1:400 @ A3		

TITLE
PROPOSAL TO UPGRADE
BASE PLAN

PLAN NO. 52027903/03/02
REVISION --



SURVEY MARKS

EASTING	NORTHING	LEVEL	DESCRIPTION
2954.121	7091.396	100.00	IS 1
2968.679	7056.041	95.566	IS 2
2791.324	7123.077		DD 64

GRAVEL COLUMN COORDINATES

POINT No	EASTING	NORTHING
1	2906.41	7099.17
2	2910.38	7098.73
3	2914.36	7098.29
4	2918.34	7097.85
5	2922.31	7097.41
6	2926.29	7096.97
7	2930.26	7096.54
8	2934.24	7096.10
9	2938.21	7095.66
10	2942.19	7095.22
11	2912.31	7092.43
12	2916.29	7091.99
13	2920.26	7091.55
14	2924.24	7091.12
15	2928.21	7090.68
16	2932.19	7090.24
17	2936.16	7089.80
18	2940.14	7089.36
19	2944.12	7088.92

NOTES

1. COORDINATES AND LEVELS ARE FROM AN ASSUMED DATUM

MANHOLE COORDINATES

EASTING	NORTHING	LID LEVEL	INVERT LEVEL	DESCRIPTION
2933.28	7081.98	93.2	89.0	MH 1

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Consulting Civil & Structural Engineers,
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Contract Documentation & Supervision,
Surveying.

Telephone (09) 262 8999
Fax (09) 262 5131

REV	BY	DATE	CHK	AMENDMENT

PROJECT NAME

SNAKE HILL UNDERSLIP
SH1N, RP144/11.34 (LHS)
For
TRANSIT NEW ZEALAND

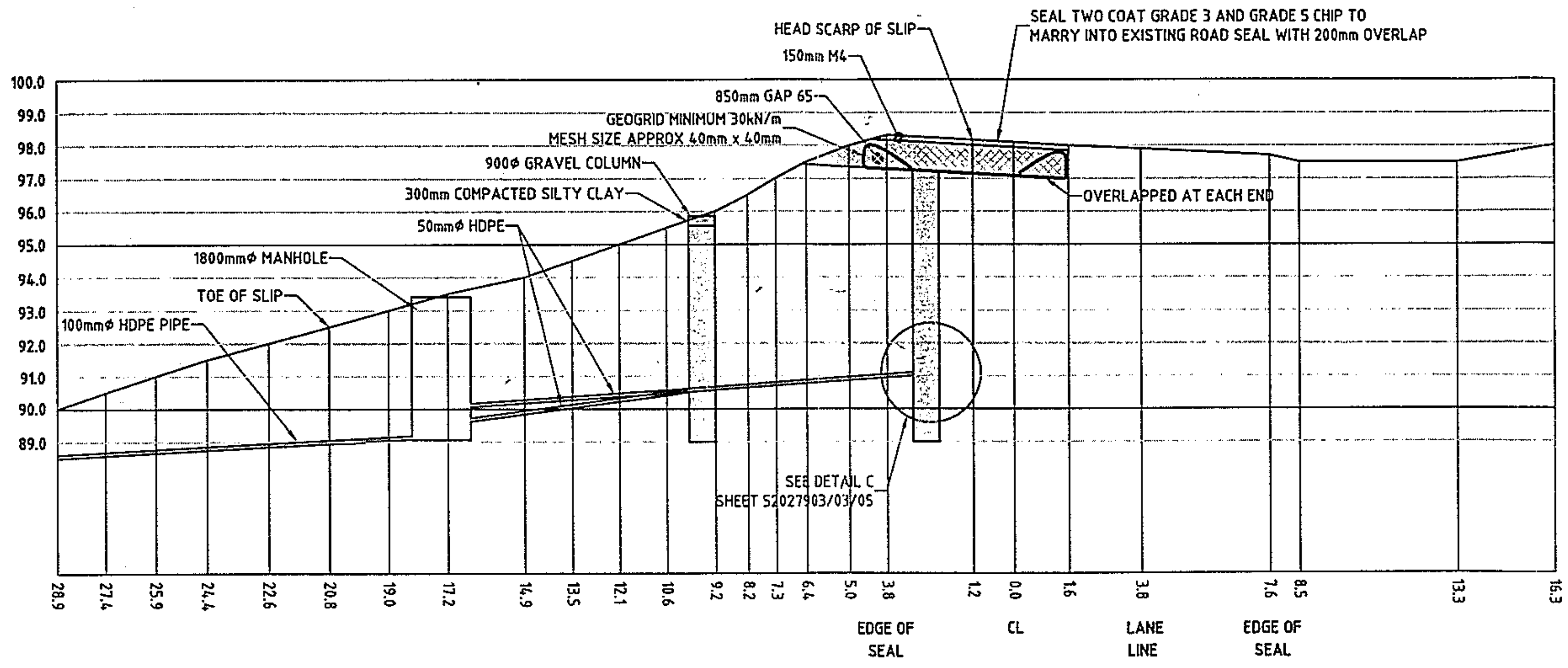
	SIGNED	DATE		SIGNED	DATE
SURVEYED			DRAWING CHECKED		17/9/99
DESIGNED	R.Jairaj	6/99	M.C. APPROVED		23/9/99
DRAWN.	T.Baker	6/99	XREF NAME		VIEW 1
FILE NAME	R:\52027903\ACAD\03\SETOUT				
CLIENT DWG. REFERENCE			SCALE: 1:250 @ A1, 1:500 @ A3		@A1

TITLE

SETTING OUT PLAN

PLAN NO. 52027903/03/04

REVISION —



CROSS SECTION C-C

TYPICAL CROSS SECTION

SCALE = 1:100

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REV	BY	DATE	CHK	AMENDMENT

PROJECT NAME

SNAKE HILL UNDERSLIP
SH1N, RP144/11.34 (LHS)
For
TRANSIT NEW ZEALAND

	SIGNED	DATE		SIGNED	DATE
SURVEYED			DRAWING CHECKED	Jwh.	23/9/99
DESIGNED	R.Jairaj	6/99	M.C. APPROVED	D. Payne	23/9/99
DRAWN.	T.Baker	6/99	XREF NAME		VIEW 1
FILE NAME	R:\52027903\ACAD\03\XSEC01				
CLIENT DWG. REFERENCE			SCALE: 1:100 @ A1, 1:200 @ A3		

TITLE

TYPICAL CROSS SECTION

PLAN NO. 52027903/03/03

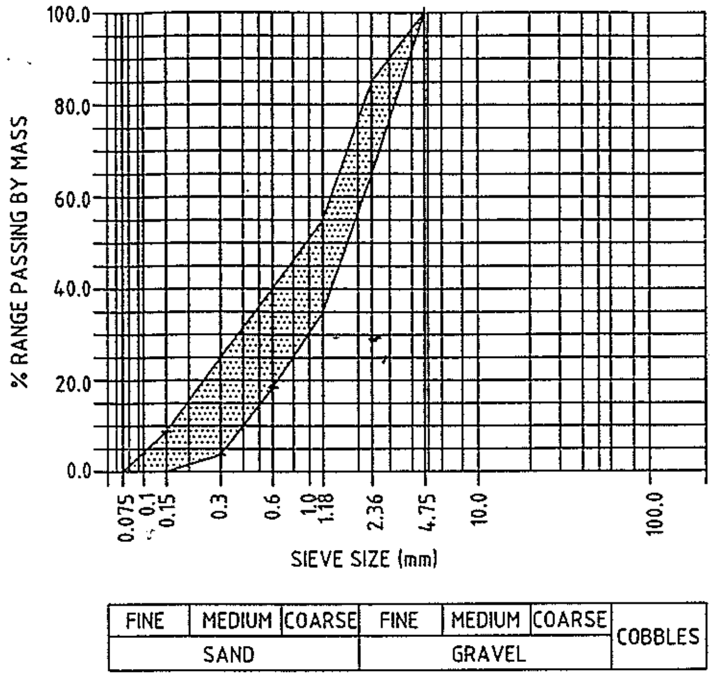
REVISION --

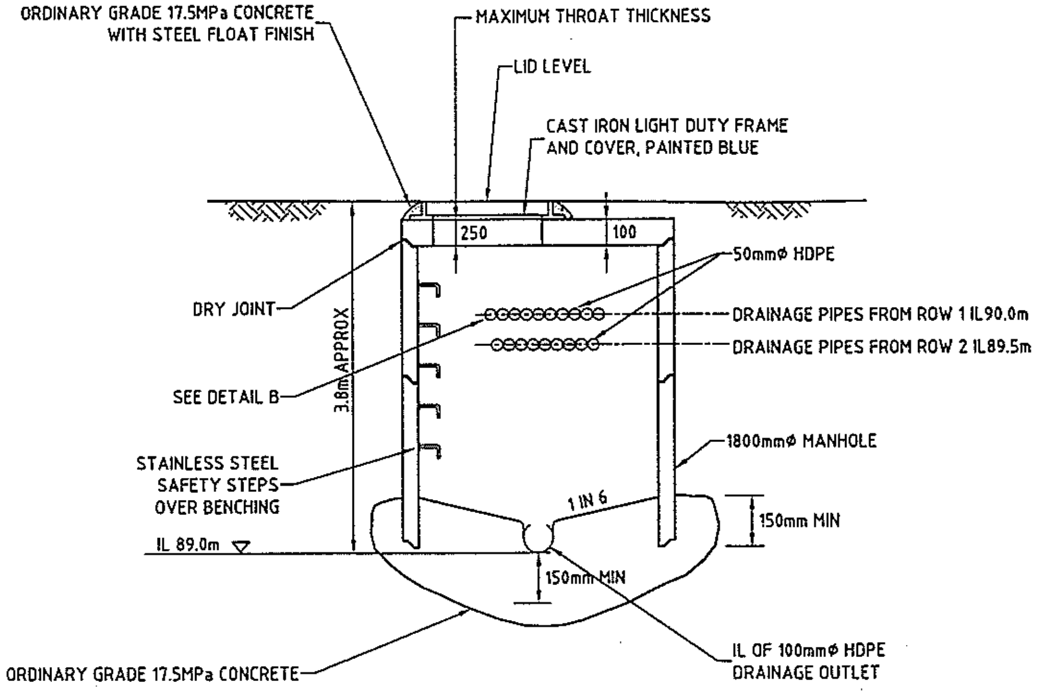
GRADING CURVE FOR GRAVEL FILTER

TESTED IN ACCORDANCE WITH NZS 4407 : 1991

GRADING RESULTS

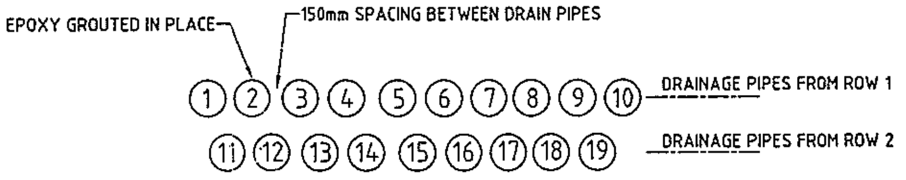
SIEVE SIZE	% RANGE PASSING BY MASS
4.75mm	100
2.36mm	55 - 85
1.18mm	35 - 55
600mic	18 - 40
300mic	3 - 25
150mic	8 max
75mic	0





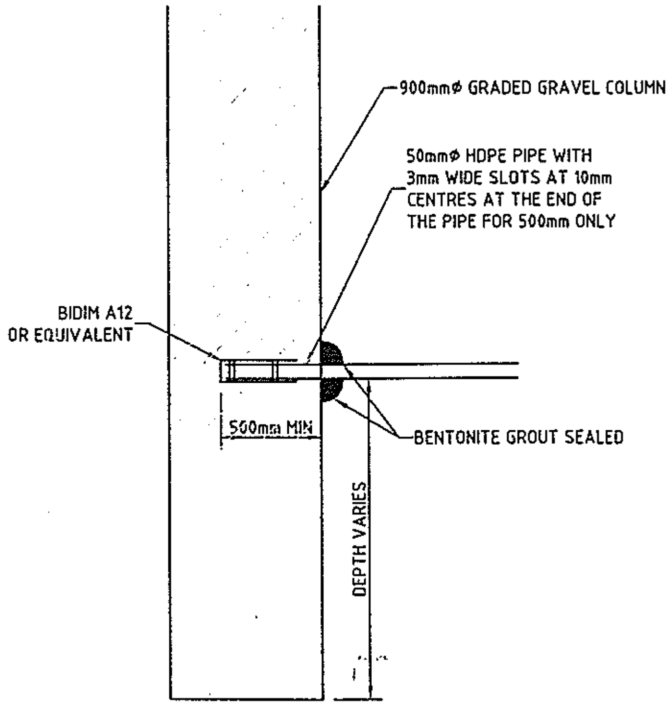
DETAIL A - MH 1

NOT TO SCALE



DETAIL B - DRAINAGE ARRANGEMENT

NOT TO SCALE



DETAIL C

NOT TO SCALE

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Fax (09) 262 5131

REV	BY	DATE	CHK	AMENDMENT

PROJECT NAME

SNAKE HILL UNDERSLIP
SH1N, RP144/11.34 (LHS)
For
TRANSIT NEW ZEALAND

	SIGNED	DATE		SIGNED	DATE
SURVEYED			DRAWING CHECKED		17/9/99
DESIGNED	R.Jairaj	6/99	M.C. APPROVED		23/9/99
DRAWN	T.Baker	6/99	XREF NAME		VIEW 1
FILE NAME	R:\52027903\ACAD\03\DETAILS				
CLIENT DWG. REFERENCE			SCALE: NOT TO SCALE		

TITLE

STANDARD DETAILS

PLAN NO. 52027903/03/05

REVISION --

Appendix D
Borelog and Photographs

Job No: 22/1003

Project: Snake Hill RP 144/11.34 - SH1

Borehole Location:

Surface Elevation: Datum:

Surface Conditions:

LOG OF BOREHOLE BH 1

Sheet 1 of 2

					SAMPLE DATA			FIELD TESTS		
Geol. Unit	Soil / Rock Description	Graphic Log	Depth (m)	Drilling Method	Condition	Type	Sample Recovery (%) 20 80	Shear Strength (kPa)	Groundwater	SPT
FILL	Basecourse									
	SILT, slightly clayey, stiff, wet, slightly to moderately plastic, intermixed light grey, orange, brown.		1					159/28		
	Frequent weakly cemented clasts (1-2mmØ)									1 1 1 N=2
	Clayey, firm, saturated, highly plastic, light grey, orange									
	Slightly clayey, firm, wet, slightly plastic, light grey, orange									
			2							
	Occasional clayey SILT lenses									
	Clayey, firm, wet, highly plastic, grey, brown		3					43/14		0 1 1 N=2
	CLAY, soft, saturated, highly plastic, grey, brown, occasional partly decomposed organic matter and gravel (fine)									
			4							
	SILT, slightly clayey, stiff, wet, slightly plastic, grey, brown							46/18		0 2 2 N=4
	200mm CLAY lense, saturated, highly plastic, greenish grey		5							

Date Started ....9 March 1999..........
Date Finished....9 March 1999..........
Driller ....
Type of Rig ....
Shear Vane No. ..DR 1749..................
Logged by ....Ormiston Associates Ltd

DRILLWELL EXPLORATION
N.Z. LIMITED
Ph : (09)2679100 Fax : (09)2678100

Job No: 22/1003
Project: Snake Hill RP 144/11.34 - SH1
Borehole Location:
Surface Elevation: **Datum:**
Surface Conditions:

LOG OF BOREHOLE BH 1

Sheet 2 of 2

Geol. Unit	Soil / Rock Description	Graphic Log	Depth (m)	Drilling Method	SAMPLE DATA Condition	Type	Sample Recovery (%) 20 80	FIELD TESTS Shear Strength (kPa)	Groundwater	SPT
FILL	SILT, stiff, wet, non plastic, dark brown/grey, large wood fragments, frequent roots (2-3mmØ)									
			6					113/28		2 2 3 N=5
	Slightly clayey, soft, saturated, slightly plastic, intermixed light grey, dark grey and brown, frequent organic matter Becomes grey, orange									
	SILT, stiff, wet, non plastic, grey, orange, frequent black flecks Faint rock fabric		7							
	Occasional carbonaceous material									
HIGHLY SHEARED MUDSTONE (ONERAHI CHAOS?)	SILT, very stiff, wet, non plastic, dark grey									7 9 12 N=21
			8							
	Frequent calcite deposits									
	Dark grey, highly weathered, homogeneous, very weak, MUDSTONE, highly sheared nature									
	Occasional calcite veining		9							10 22 27 N=49
	E.O.B. 9.45 m (Target Depth)									
			10							

Date Started 9 March 1999
Date Finished 9 March 1999
Driller
Type of Rig
Shear Vane No. DR 1749
Logged by Ormiston Associates Ltd

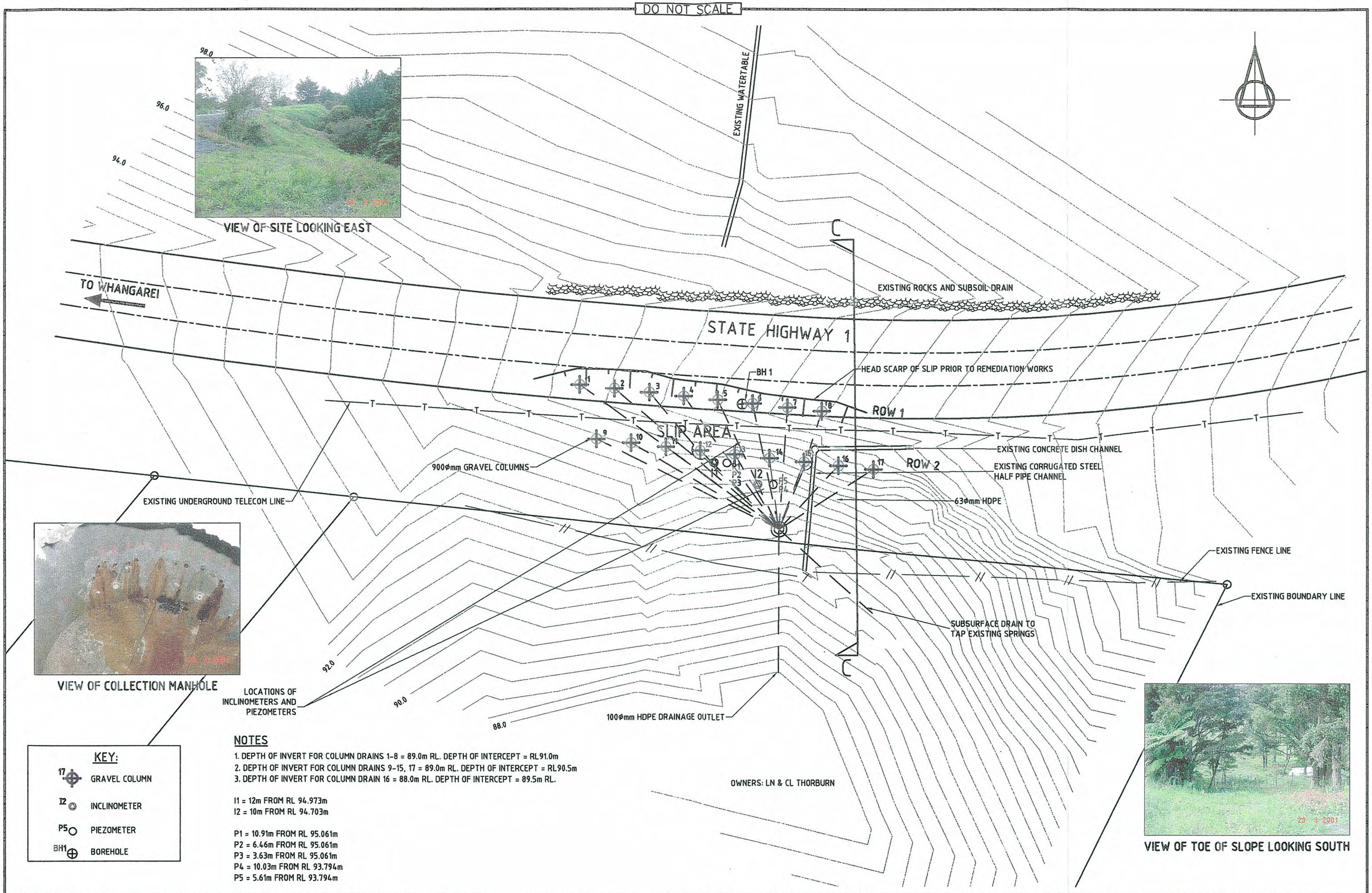
DRILLWELL EXPLORATION N.Z. LIMITED
Ph : (09)2679100 Fax : (09)2678100

SNAKE HILL RP 144/11.34 - SH1
BOREHOLE 1

Box 1 0.00m - 7.50m
Box 2 7.50m - 9.45m EOB

Appendix E
“As Built” Drawing

DO NOT SCALE



VIEW OF SITE LOOKING EAST

VIEW OF COLLECTION MANHOLE

VIEW OF TOE OF SLOPE LOOKING SOUTH

KEY:

17 ✚ GRAVEL COLUMN
I2 ◎ INCLINOMETER
P5 ○ PIEZOMETER
BH1 ⊕ BOREHOLE

NOTES

1. DEPTH OF INVERT FOR COLUMN DRAINS 1-8 = 89.0m RL. DEPTH OF INTERCEPT = RL91.0m
2. DEPTH OF INVERT FOR COLUMN DRAINS 9-15, 17 = 89.0m RL. DEPTH OF INTERCEPT = RL90.5m
3. DEPTH OF INVERT FOR COLUMN DRAIN 16 = 88.0m RL. DEPTH OF INTERCEPT = 89.5m RL.

I1 = 12m FROM RL 94.973m
I2 = 10m FROM RL 94.703m

P1 = 10.91m FROM RL 95.061m
P2 = 6.46m FROM RL 95.061m
P3 = 3.63m FROM RL 95.061m
P4 = 10.03m FROM RL 93.794m
P5 = 5.61m FROM RL 93.794m

No.	Revision — Revise on CAD do not amend by hand	Checked	Approved	Date	M/Film

Drawing File

MANAGEMENT
ENGINEERING
ENVIRONMENT

1 Campbell Road, Takapuna, North Shore City
Telephone (09) 488 0003 Facsimile (09) 488 0008
Email: northmail@ghd.co.nz

GHD Limited

Scale 1:200

Drawn/Traced CF 05/01
Engineer Design R.J 06/99
Draft Check
Engineer Check
Approved

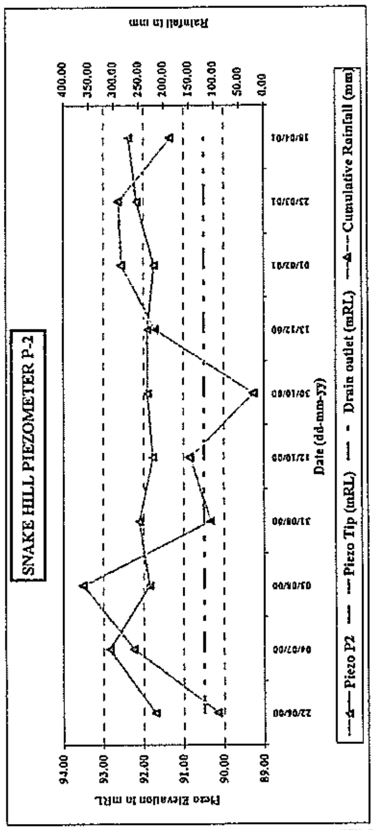
This Drawing must not be used for Construction unless signed as Approved

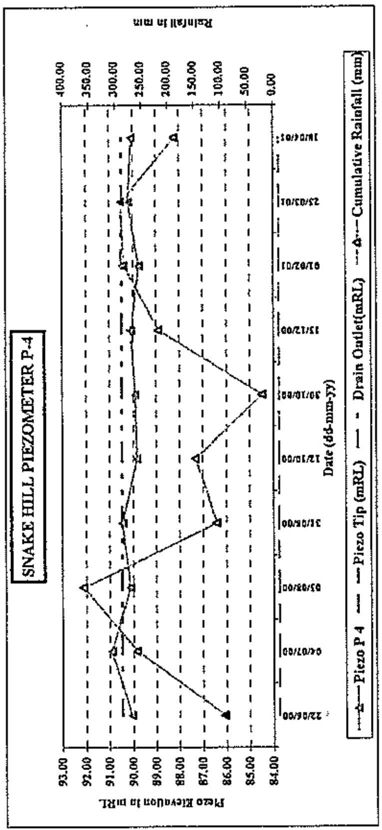
Client and Job TRANSIT NEW ZEALAND
SNAKE HILL UNDERSLIP

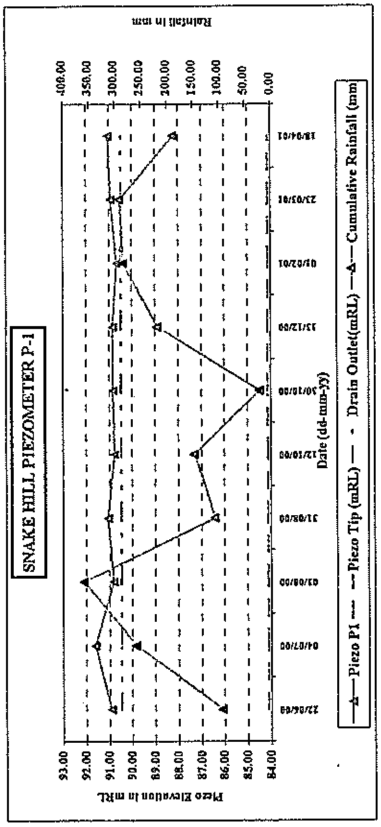
Title AS-BUILT PLAN

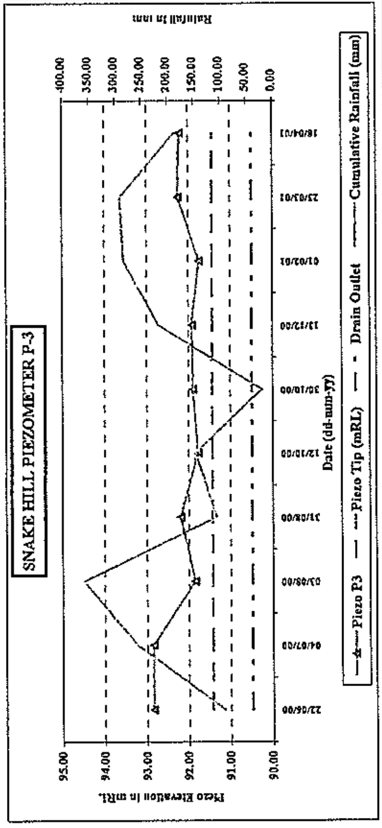
Size A1
Drg. No.
Rev

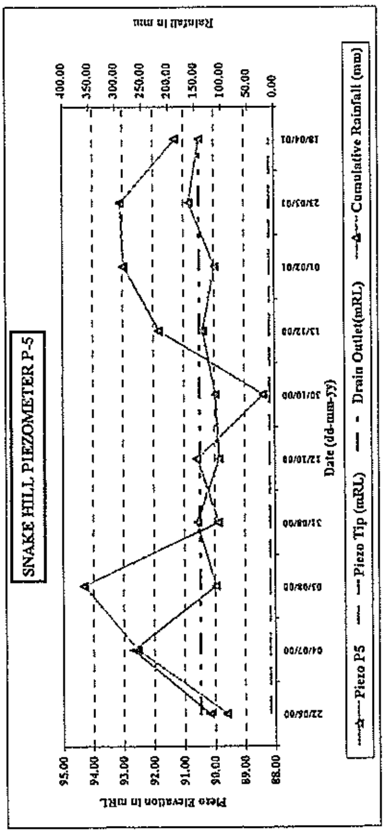
Appendix F
Piezometer Monitoring Data





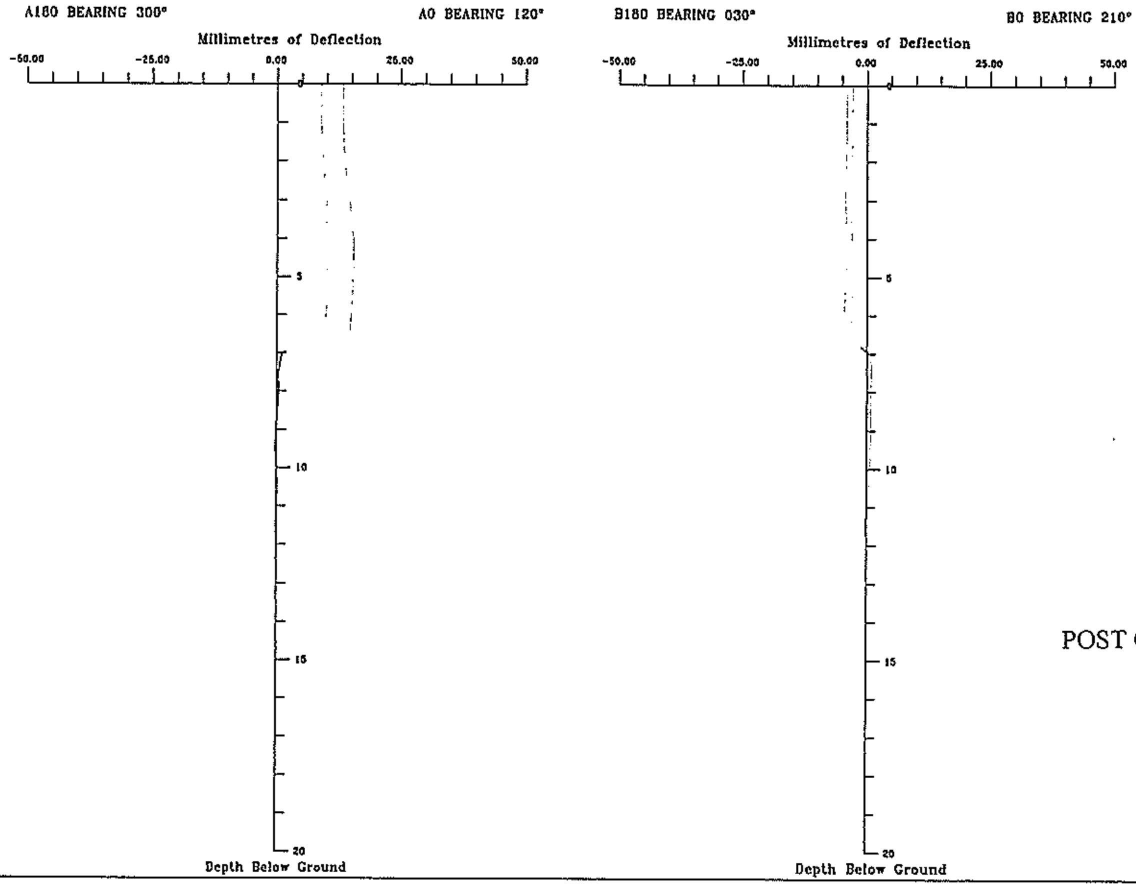






Appendix G
Inclinometer Monitoring Data

GEOTECHNICS LTD
INCLINOMETER MONITORING - CUMULATIVE



Page 4 of 5

CLIENT:
GHD LTD

PROJECT:
SNAKEHILL UNDERSLIP

LOCATION:
SH1N,RP144/11.3

JOBNO: 613818.3

BORE: I1

DATE: 18/04/01

ClientRef:

R.L.:
Datum:

East:
North:

Operator: LIT
Base: 13/06/00

POST CONSTRUCTION

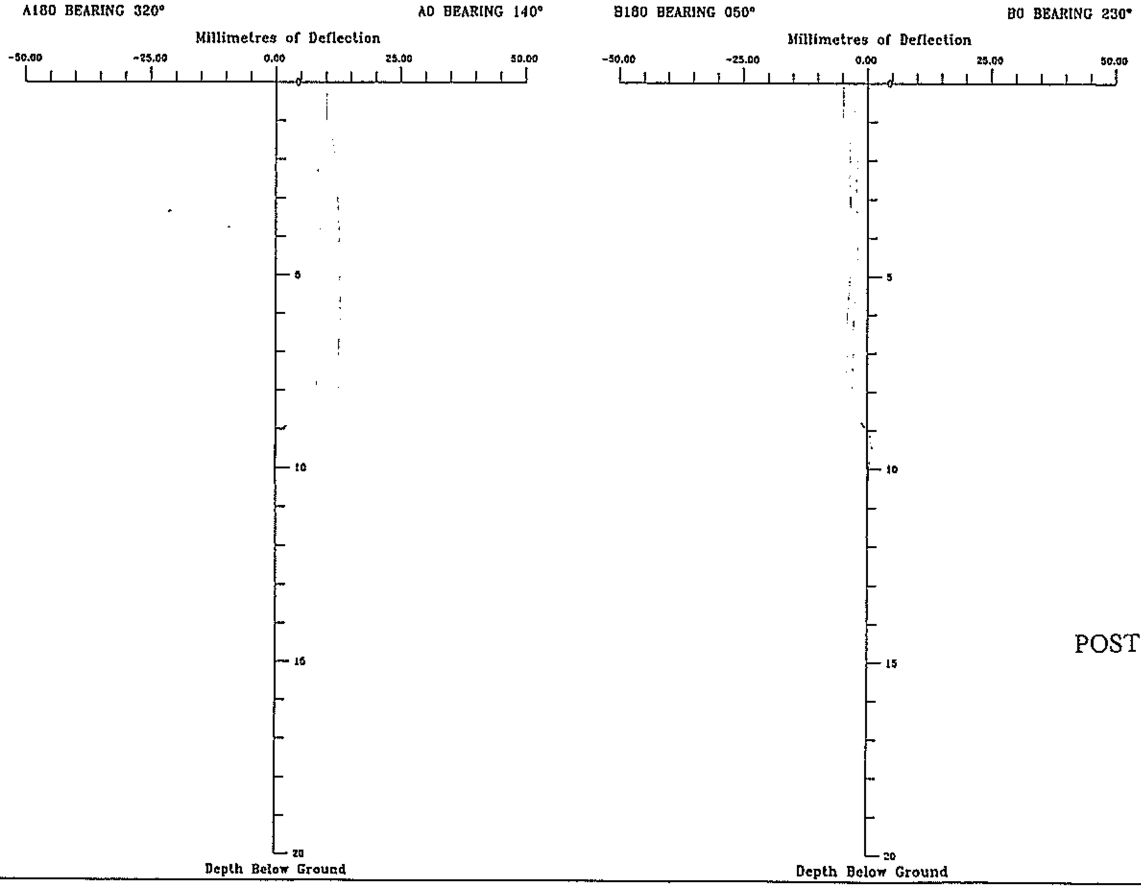
31/10/00-->SH1112
18/04/01-->SH1113

Software by Tonkin & Taylor Ltd

COMMENT:

SH1113-SH1111

GEOTECHNICS LTD
INCLINOMETER MONITORING - CUMULATIVE



Page 5 of 5

CLIENT:
GHD LTD

PROJECT:
SNAKEHILL UNDERSLIP

LOCATION:
SH1N,RP144/11.3

JOBNO: 613818.3

BORE: I2

DATE: 18/04/01

ClientRef:

R.L.:
Datum:

East:
North:

Operator: LIT
Base: 13/06/00

POST CONSTRUCTION

31/10/00-->SH1122
18/04/01-->SH1123

Software by Tonkin & Taylor Ltd

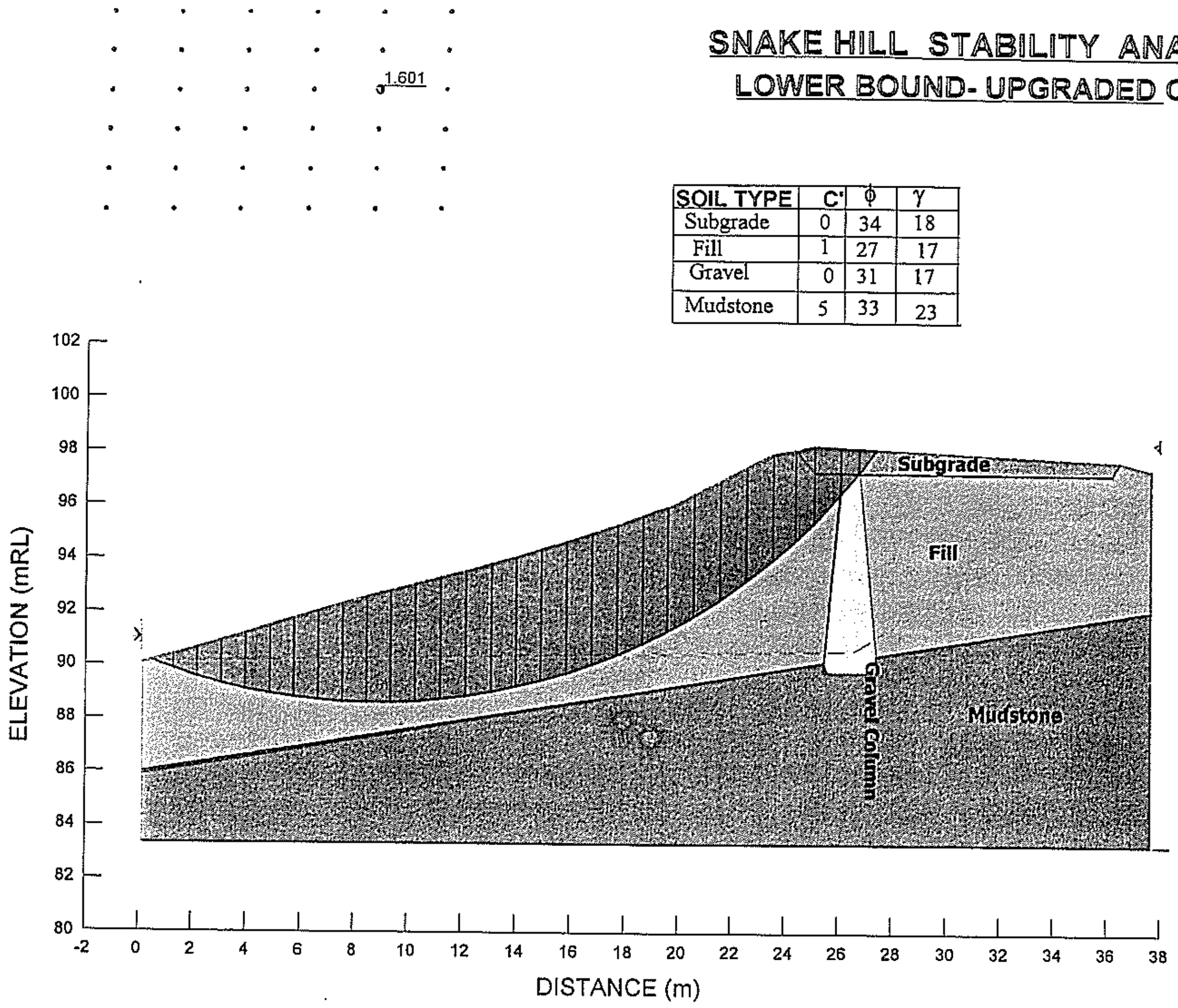
COMMENT:

SH1123-SH1121

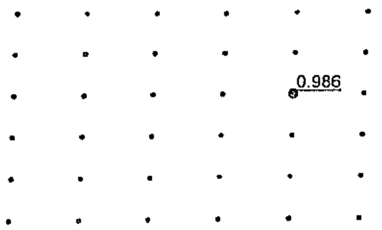
Appendix H
Stability Analyses

SNAKE HILL STABILITY ANALYSIS
LOWER BOUND- UPGRADED CASE

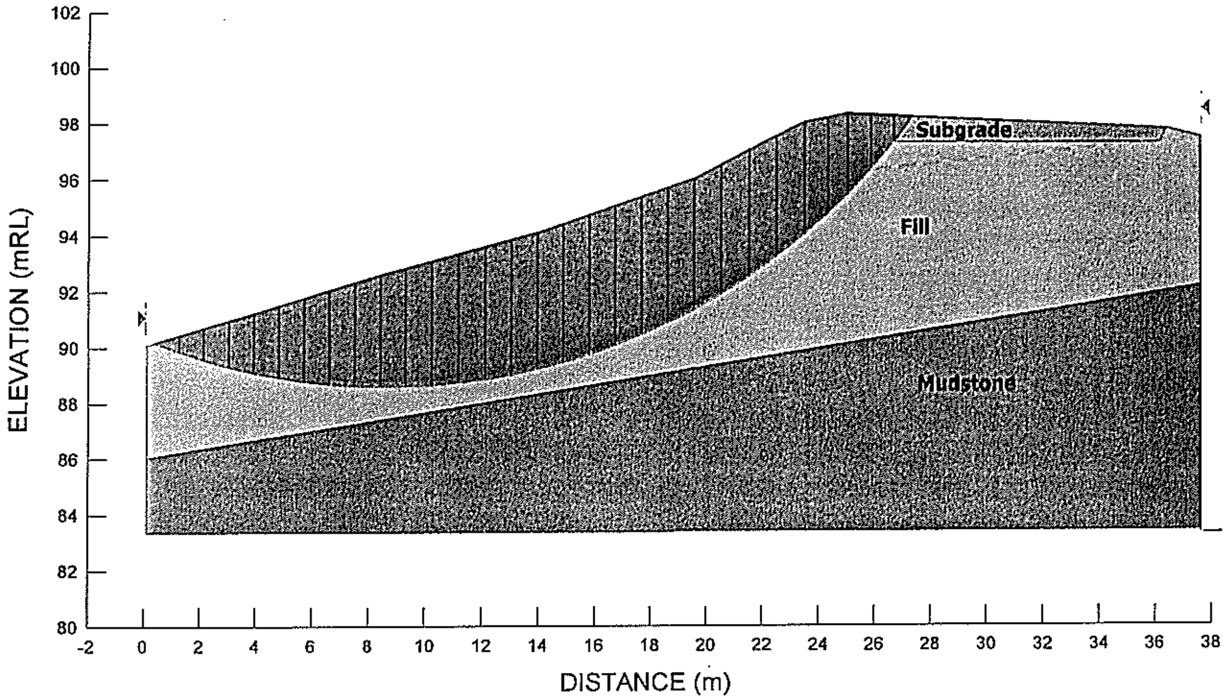
SOIL TYPE	C'	φ	γ
Subgrade	0	34	18
Fill	1	27	17
Gravel	0	31	17
Mudstone	5	33	23



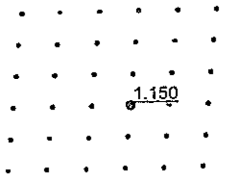
SNAKE HILL STABILITY ANALYSIS
LOWER BOUND CASE



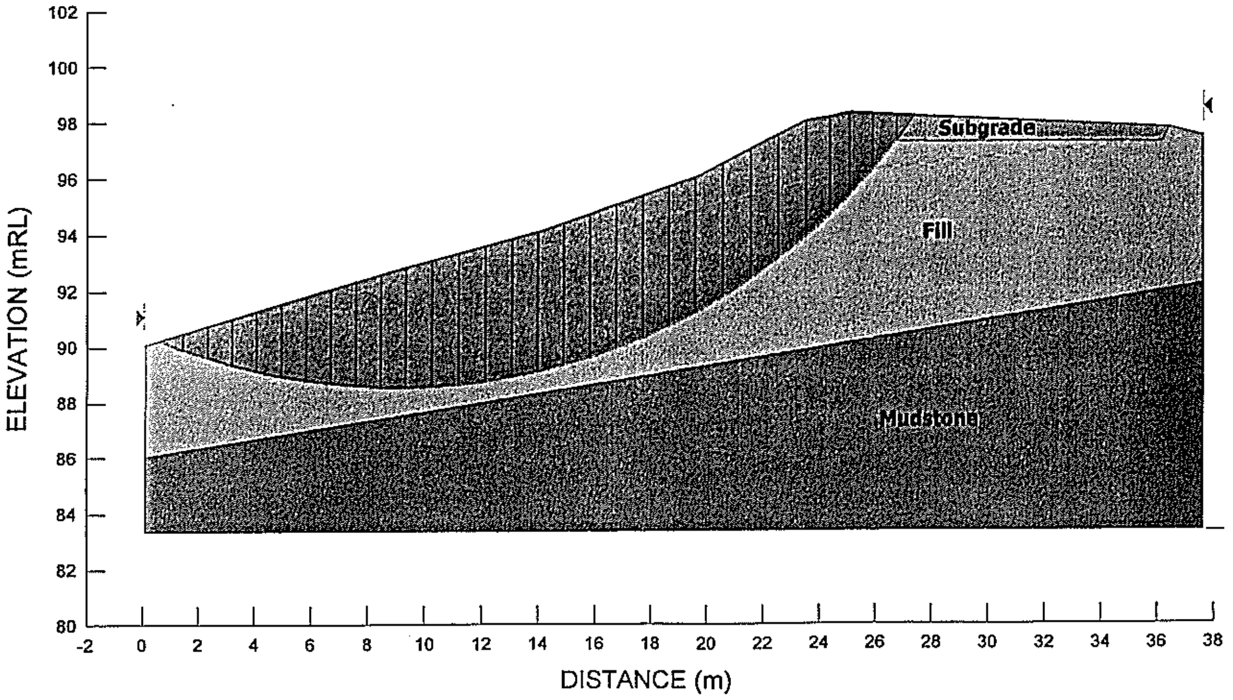
SOIL TYPE	C'	ϕ	γ
Subgrade	0	34	18
Fill	1	27	17
Mudstone	5	33	23



SNAKE HILL STABILITY ANALYSIS
UPPER BOUND CASE



SOIL TYPE	C'	ϕ	γ
Subgrade	0	34	18
Fill	3	28	17
Mudstone	5	33	23



Appendix I
Cost Analysis

SITE STABILISATION OPTION: Column Drains
COST ANALYSIS

1.1 Cost of works as per attached estimate sheets = **$111,123** (a)

$111,123 (a) x 0.91 = **$101,122** (b)

1.2 Estimated PV of maintenance costs in year 1 = **$1,000** (c)

1.3 Estimated PV of maintenance costs in years 2 to 25 following completion of works

= **$1,000** x 8.57 = **$8,570** (d)

(b) + (c) + (d) = **TOTAL B** **$110,692**

---

2. Describe how the option will improve site stability:

Elevated porewater pressure is the principal driver for the failure at this site. Therefore the provision of positive subsurface drainage improves the long-term stability. Drainage of multilevel failure planes is achieved through the provision of deep vertical graded gravel columns. The grading of the gravel columns controls migration of fine soil particles and thereby ensures long-term, maintenance free site stabilisation.

SITE STABILISATION OPTION: Counterfort Drains
COST ANALYSIS

1.1 Cost of works as per attached estimate sheets = **$243,084** (a)

$243,084 (a) x 0.91 = **$221,206** (b)

1.2 Estimated PV of maintenance costs in year 1 = **$1,000** (c)

1.3 Estimated PV of maintenance costs in years 2 to 25 following completion of works

= **$1,000** x 8.57 = **$8,570** (d)

(b) + (c) + (d) = **TOTAL B** **$230,776**

2. Describe how the option will improve site stability:

Elevated porewater pressure is the principal driver for the failure at this site. Therefore the provision of positive subsurface drainage improves the site stability. However, the construction of Counterfort Drains with trenches greater than 4m deep is difficult. The cost of this option is therefore prohibitive when applied to deep-seated failures.

SITE STABILISATION OPTION: Spider Drains
COST ANALYSIS

1.1	Cost of works as per attached estimate sheets	=	**$101,910**	(a)
	$101,910 (a) x 0.91	=	**$92,738**	(b)
1.2	Estimated PV of maintenance costs in year 1	=	**$3,500**	(c)
1.3	Estimated PV of maintenance costs in years 2 to 25 following completion of works			
	= **$3,500** x 8.57	=	**$29,995**	(d)

(b) + (c) + (d) = **TOTAL B** **$126,233**

2. Describe how the option will improve site stability:

The option consists of drilling and installing sub horizontal pipes to provide drainage to the failure planes. Interception of failure plane is never certain. This is reflected in the lack of effectiveness of Spider Drains at many sites. The consequence of this is the high cost of ongoing maintenance, monitoring, and additional reinstatement at these sites.

SITE STABILISATION OPTION: Pile Retaining Wall
COST ANALYSIS

1.1 Cost of works as per attached estimate sheets = **$250,047** (a)

$250,047 (a) x 0.91 = **$227,543** (b)

1.2 Estimated PV of maintenance costs in year 1 = **$0** (c)

1.3 Estimated PV of maintenance costs in years 2 to 25 following completion of works

= **$0** x 8.57 = **$0** (d)

(b) + (c) + (d) = TOTAL B **$227,543**

---

2. Describe how the option will improve site stability:

The option consists of the construction of a bored pile wall to stabilise the site. The retaining wall requires minimal maintenance over a long period of time. Construction is expensive, necessitates disruption of the highway, and the visual impact of the structure on the environment is evident.

SCHEDULE OF PRICES
SNAKE HILL COST OPTIONS

Date :	20-May-01
Revision no :	A
Contract Number :	PA1774
File Name :	S:\10161\Snake Hill.xls
Plan Nos :	
Prepared By/Checked By :	Ellen/ Raj

				Column Drain		Counterfort Drain		Spider Drain		Pile Retaining Wall	
ITEM	DESCRIPTION	UNIT	QUANTITY	RATE	AMOUNT	RATE	AMOUNT	RATE	AMOUNT	RATE	AMOUNT
A	PRELIMINARY AND GENERAL										
A1	Establishment	L.S.	1.00	2,450.00	2,450.00	2,450.00	2,450.00	2,450.00	2,450.00	2,450.00	2,450.00
A2	Contractor Setting Out, Supervision, Location of Existing Services	L.S.	1.00	1,850.00	1,850.00	1,850.00	1,850.00	1,850.00	1,850.00	1,850.00	1,850.00
A3	Traffic Control by Contractor (TNZ G1)	Days	30.00	250.00	7,500.00	250.00	7,500.00	250.00	7,500.00	250.00	7,500.00
A4	Temporary Power and Water supply	L.S.	1.00	1,260.00	1,260.00	1,260.00	1,260.00	1,260.00	1,260.00	1,260.00	1,260.00
A5	Testing by Contractor	L.S.	1.00	1,840.00	1,840.00	1,840.00	1,840.00	1,840.00	1,840.00	1,840.00	1,840.00
A6	Testing by Others (Provisional)	P S	1.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00
A7	As Built by Contractor	L.S.	1.00	420.00	420.00	420.00	420.00	420.00	420.00	420.00	420.00
A8	Liaise with Others	L.S.	1.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00
				SUBTOTAL A	$16,570.00	SUBTOTAL A	$16,570.00	SUBTOTAL A	$16,570.00	SUBTOTAL A	$16,570.00
B	EARTHWORKS										
B1	Clearing and cut benching for construction equipment	L.S.	1.00	240.00	240.00	240.00	240.00	240.00	240.00	240.00	240.00
B2	Fencing										
B2.1	Dismantle and move fences	m	20.00	14.00	280.00	14.00	280.00	14.00	280.00	14.00	280.00
B2.2	Temporary safety fence (provisional quantity)	m	70.00	5.20	364.00	5.20	364.00	5.20	364.00	5.20	364.00
B2.3	Reinstate fencing	m	20.00	7.40	148.00	7.40	148.00	7.40	148.00	7.40	148.00
B2.4	Temporary stock proof fence (provisional quantity)	m	70.00	12.60	882.00	12.60	882.00	12.60	882.00	12.60	882.00
B2.5	Reinstatement and removal of temporary fences	L.S.	1.00	210.00	210.00	210.00	210.00	210.00	210.00	210.00	210.00
B3	Reinstatement after installation of monitoring equipment by others	L S	1.00	210.00	210.00	210.00	210.00	210.00	210.00	210.00	210.00
				SUBTOTAL B	$2,334.00	SUBTOTAL B	$2,334.00	SUBTOTAL B	$2,334.00	SUBTOTAL B	$2,334.00
C	CARRIAGEWAY CONSTRUCTION										
C1	Removal of Existing Pavement	m^3	200.00	6.50	1,300.00	6.50	1300.00	6.50	1300.00	6.50	1300.00
C2	Supply and place Manukau Consultants Sb 65 subbase	m^3	170.00	43.50	7,395.00	43.50	7,395.00	43.50	7,395.00	43.50	7,395.00
C3	Supply and place TNZ M/4 basecourse	m^3	30.00	58.80	1,764.00	58.80	1,764.00	58.80	1,764.00	58.80	1,764.00
C4	Two Coat Chipseal (T.N.Z P/3, P/4) grade 3 and grade 5 chip	m^2	200.00	13.60	2,720.00	13.60	2,720.00	13.60	2,720.00	13.60	2,720.00
C5	Supply and place geogrid (provisional quantity)	m^2	240.00	14.60	3,504.00	14.6	3504	14.6	3504	14.6	3504
				SUB TOTAL C	$16,683.00	SUBTOTAL C	$16,683.00	SUBTOTAL C	$16,683.00	SUBTOTAL C	$16,683.00
D	STORMWATER DRAINAGE										
D1	Manhole 1800mm dia. 4m deep Iinclusive of excavation and removal of material from	LS	1.00	11,140	11,140.00	11,140.00	11,140.00	11,140.00	11,140.00	11,140.00	11,140.00
				SUB TOTAL D	$11,140.00	SUBTOTAL C	$11,140.00	SUBTOTAL C	$11,140.00	SUBTOTAL C	$11,140.00
E	TRAFFIC SIGNS/ ROADMARKING										
E1	ROADMARKING - Supply and install										
E1.1	White continuous reflectorised line - WC100R	m	50.00	7.20	360.00	7.20	360.00	7.20	360.00	7.20	360.00
E1.2	White Intermittent Reflectorised continuity line - WI 100R (3-7)	m	30.00	3.00	90.00	3.00	90.00	3.00	90.00	3.00	90.00
E1.3	White bidirectional RRPM's	each	2.00	20.00	40.00	20.00	40.00	20.00	40.00	20.00	40.00
				SUB TOTAL E	$490.00	SUBTOTAL H	$490.00	SUBTOTAL H	$490.00	SUBTOTAL H	$490.00
F	COLUMN DRAIN CONSTRUCTION										
F1	Installation of 900mm dia Vertical Gravel Column Drain	m	183.00	164.00	30,012.00						
F2	Supply and Install 63mm dia HDPE pipe	m	410.00	43.80	17,958.00						
F3	Supply and Install 100mm dia HDPE pipe	m	20.00	32.20	644.00						
F4	Connection of 63mm dia HDPE pipe to Gravel Drain	each	19.00	42.00	798.00						
				SUB TOTAL F	$49,412.00						
G	COUNTERFORT DRAINS										
G1	Exavation of trenches with shields	m^3	550.00		0.00	212.50	116,875.00				
G2	Remove material to approved dump site	m^3	770.00		0.00	18.00	13,860.00				
G3	Place 110Dia Nova coil wrapped in geofabric	m	140.00			65.00	9,100.00				
G4	Supply fill trench to 600mm below ground level with approved graded material	m^3	500.00		0.00	48.00	24,000.00				
G5	Backfill balance trench with approved clay	m^3	50.00		0.00	6.50	325.00				
						SUB TOTAL G	164,160.00				
H	SPIDER DRAINS										
H1	Directionally drill holes to a length of 20m		600.00		0.00			52.00	31,200.00		
H2	Insert slotted 50mm dia PVC pipes		600.00		0.00			17.00	10,200.00		
								SUB TOTAL H	41,400.00		
I	PILE RETAINING WALLS										
I1	Drill 600mm dia vertical shafts place steel caissions as support	m	275.00		0.00					365.00	100,375.00
I2	Remove material to approved dump site	m^3	120.00		0.00					18.00	2,160.00
I3	Place approved steel caging and pour concrete	m^3	80.00		0.00					720.00	57,600.00
I4	Place approved steel caging and pour concrete for the Capping beam	m^3	14.00		0.00					720.00	10,080.00
										SUB TOTAL I	$170,215.00
	SUMMARY										
A	PRELIMINARY AND GENERAL				16,570.00		16,570.00		16,570.00		16,570.00
B	EARTHWORKS				2,334.00		2,334.00		2,334.00		2,334.00
C	CARRIAGEWAY CONSTRUCTION				16,683.00		16,683.00		16,683.00		16,683.00
D	STORMWATER				$11,140.00		$11,140.00		$11,140.00		$11,140.00
E	TRAFFIC SIGNS/ ROADMARKING				490.00		490.00		490.00		490.00
F	COLUMN DRAIN CONSTRUCTION				49,412.00		0.00		0.00		
G	COUNTERFORT DRAIN						164,160.00				
H	SPIDER DRAIN								41,400.00		
I	PILE RETAINING WALL										170,215.00
				Const Total	96,629.00		211,377.00		88,617.00		217,432.00
				Contingency 15%	14,494.35		31706.55		13292.55		32,614.80
	TOTAL CONSTRUCTION COST (exclusive GST)				$111,123.35		$243,083.55		$101,909.55		$250,046.80
				Column Drain		Counterfort Drain		Spider Drain		Pile Retaining Wall	

Appendix J
External Peer Review

Auckland UniServices Limited

4 June 2001

GHD Limited
PO Box 33 216
Takapuna.

Private Bag 92019
Auckland 1 New Zealand
Visitors' address:
UniServices House
58 Symonds Street.

Phone: + 64-9-37 37 522
Fax: + 64-9-37 37 412

Attention Mr V. Jairaj

Dear Mr Jairaj,

Snake Hill Underslip: Peer Review Report

As requested, I have read your report on the remedial and monitoring work carried out to stabilise the above slip, and am herewith forwarding my comments. These comments are based on the information in the report as well as discussions with yourself and our site visit together last year.

1. My general agreement and support for your initial proposal of deep bored drains as a stabilising measure was expressed in a letter to you (then Manukau Consultants) dated 8 June, 1999; I am pleased that you have been able to have the concept implemented on several sites, including Snake Hill.
2. The installation of the drainage measures and the accompanying monitoring measures appear to have been carried out in a workmanlike manner.
3. The performance of the slip since the measures were installed, and the monitoring information so far gained, appear to confirm that the measures have been effective. The water table appears to have been drawn down to a depth approximately the same as the base of the vertical drains as intended. However, it is barely a year since the work was done; this is a relatively short period from which to draw firm conclusions, so conclusions should be regarded as tentative at this stage.
4. I note the implied increase in safety factor from about unity to 1.6 on the basis of slip circle stability calculations. I understand the basis for this is an assumed initial water table depth fairly close to the ground surface. While this is reasonable, it was not firmly established by monitoring prior to the installation of the drainage measures, so the increase in safety factor could be somewhat optimistic.
5. I am in general agreement with your monitoring proposals, but I think that allowance should be made for additional monitoring following any periods of particularly heavy and prolonged rainfall. This would be in addition to the monitoring at regular intervals proposed in your report.

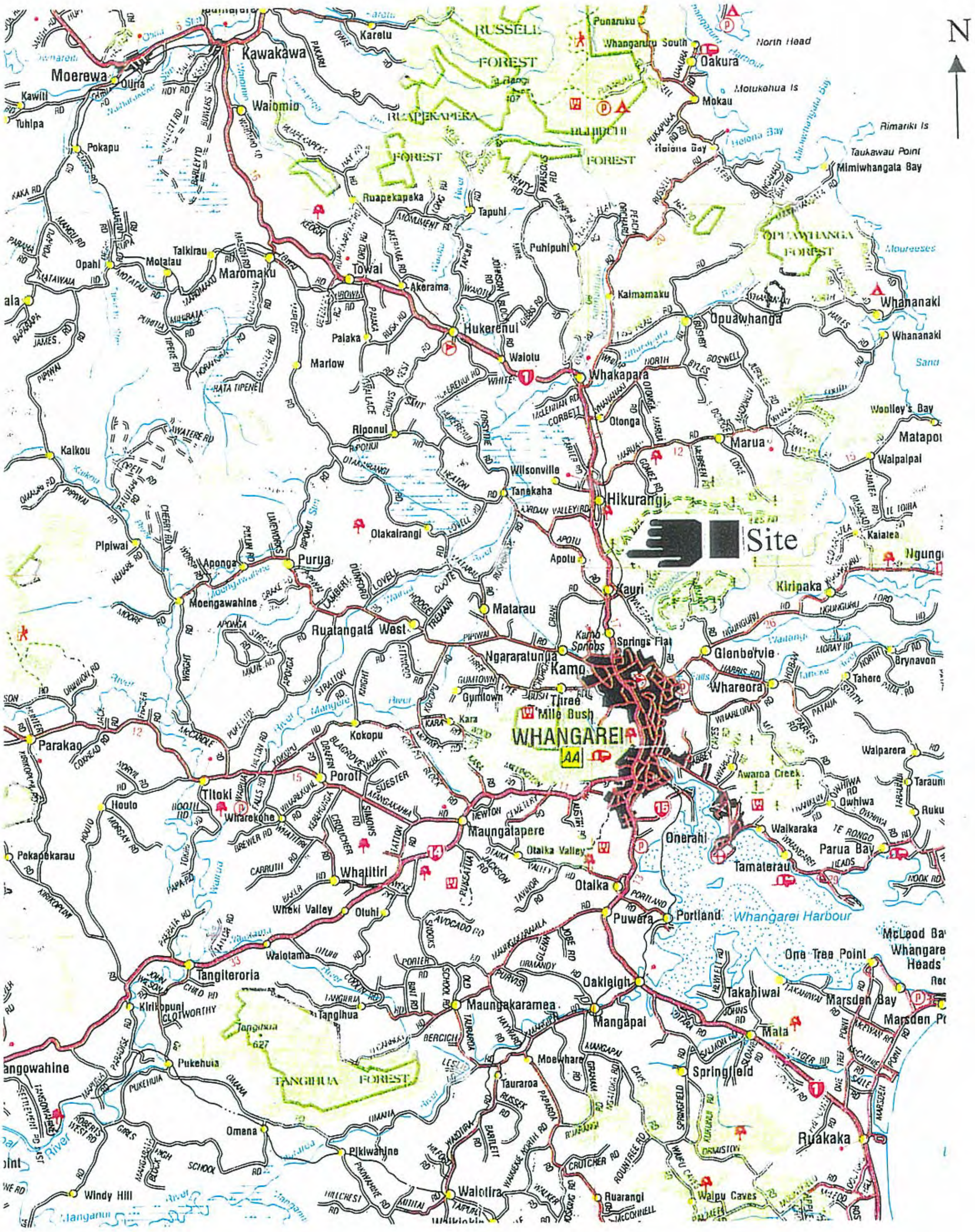
I understand that for several reasons it was not possible to install piezometers at this site prior to the installation of the drainage measures, and thus obtain firm data on the initial groundwater conditions. As indicated above, this is something of a disadvantage in evaluating the effectiveness of the drains. However, I understand also that there are other sites that you are involved in where you have been able to obtain such information. This should be particularly valuable in providing a firmer picture of the performance of the drains.

Yours sincerely,

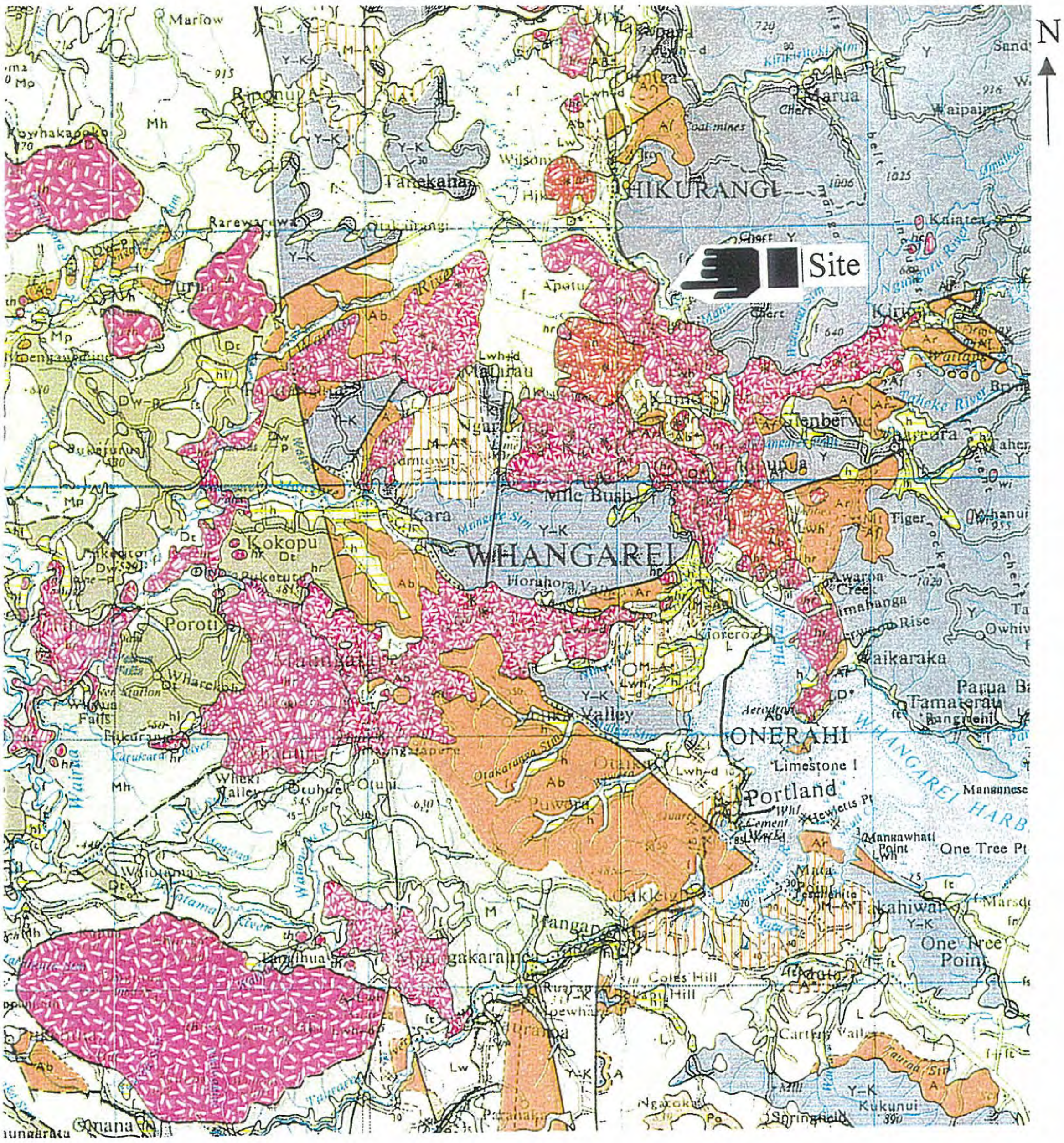
Laurie Wesley

Laurie Wesley
Senior lecturer in geotechnical engineering.

Appendix A
Location Map



Appendix B
Site Geology



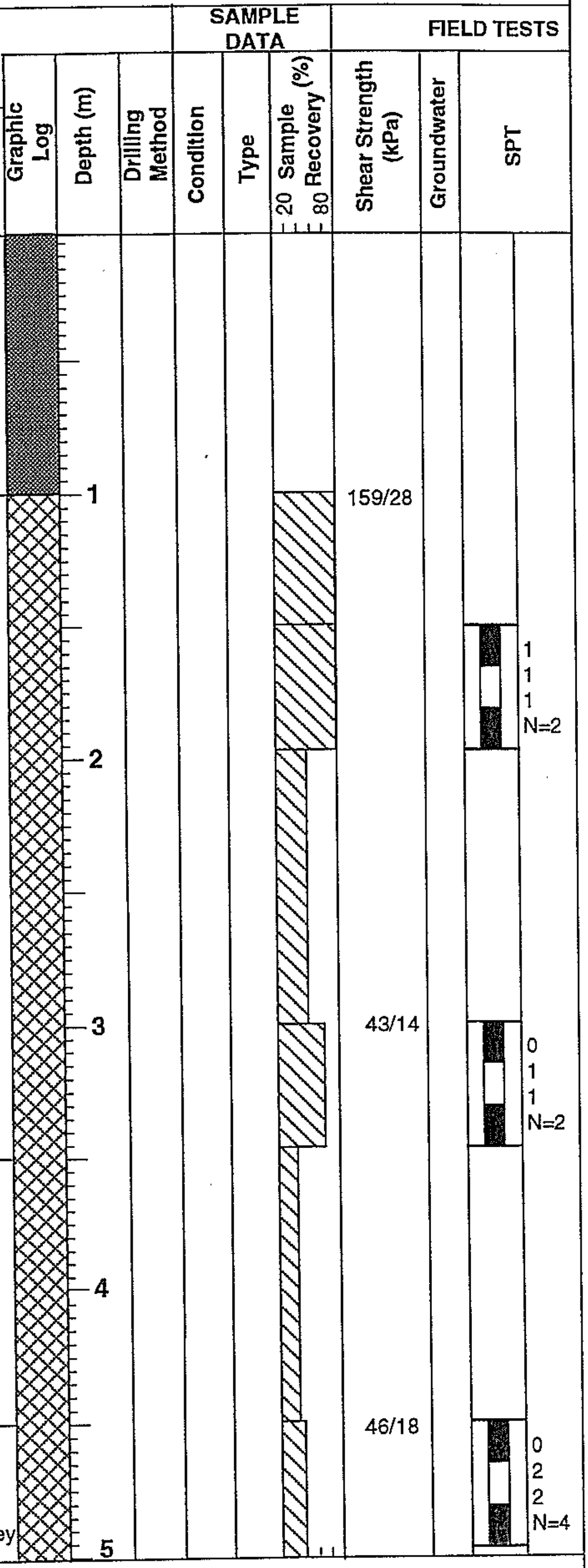
f	ALLUVIUM: Undifferentiated stream and river valley deposits, of Quaternary Age.
Y	GREYWACKE & ARGILLITE: Highly weathered, deformed, jointed and sheared, hard arkosic argillites and massive greywacke sandstones, with chert and associated manganese, and secondary silica or calcite veining. Of the Waipapa Group, of Permian to Jurassic age.
hr	BASALT: Basalt flows without scoria cones, now forming terraces up to 600ft above sea level. Of the Horeke Basalts, of Pliocene to Pleistocene age.

LOG OF BOREHOLE BH 1

Sheet 1 of 2

Job No: 22/1003
Project: Snake Hill RP 144/11.34 - SH1
Borehole Location:
Surface Elevation: **Datum:**
Surface Conditions:

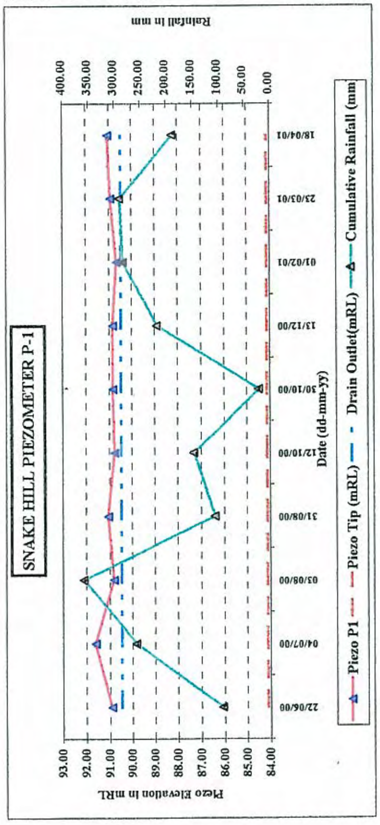
Geol. Unit	**Soil / Rock Description**
FILL	Basecourse
	SILT, slightly clayey, stiff, wet, slightly to moderately plastic, intermixed light grey, orange, brown.
	Frequent weakly cemented clasts (1-2mmØ)
	Clayey, firm, saturated, highly plastic, light grey, orange
	Slightly clayey, firm, wet, slightly plastic, light grey, orange
	Occasional clayey SILT lenses
	Clayey, firm, wet, highly plastic, grey, brown
	CLAY, soft, saturated, highly plastic, grey, brown, occasional partly decomposed organic matter and gravel (fine)
	SILT, slightly clayey, stiff, wet, slightly plastic, grey, brown
	200mm CLAY lense, saturated, highly plastic, greenish grey

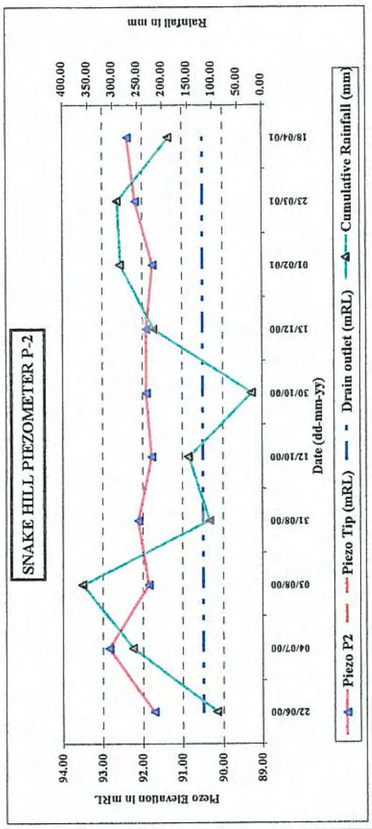


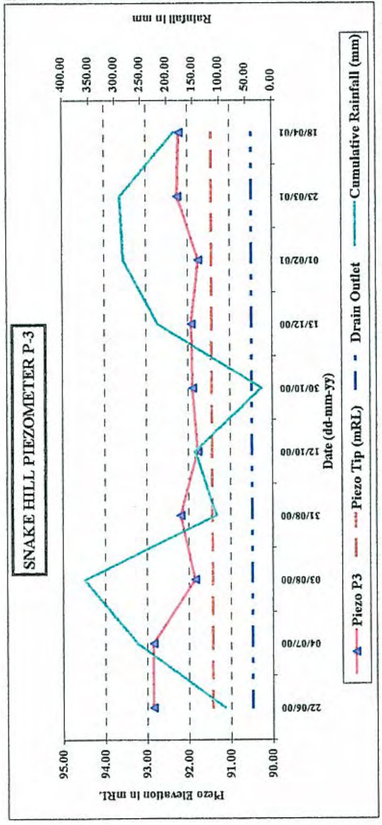
Date Started 9 March 1999
Date Finished 9 March 1999
Driller
Type of Rig
Shear Vane No. DR 1749
Logged by Ormiston Associates Ltd

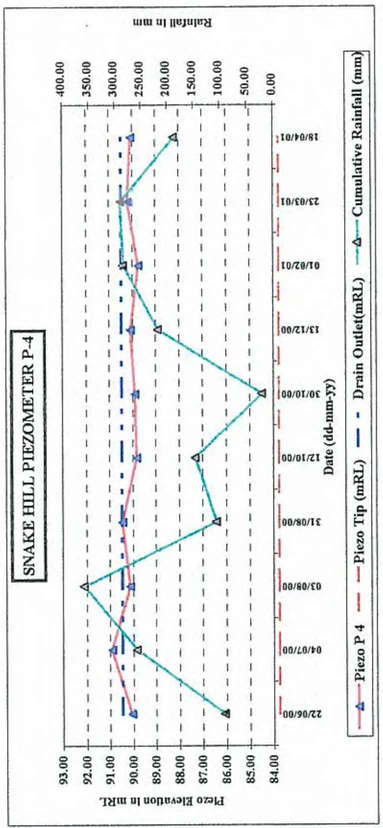
DRILLWELL EXPLORATION N.Z. LIMITED
Ph : (09)2679100 Fax : (09)2678100

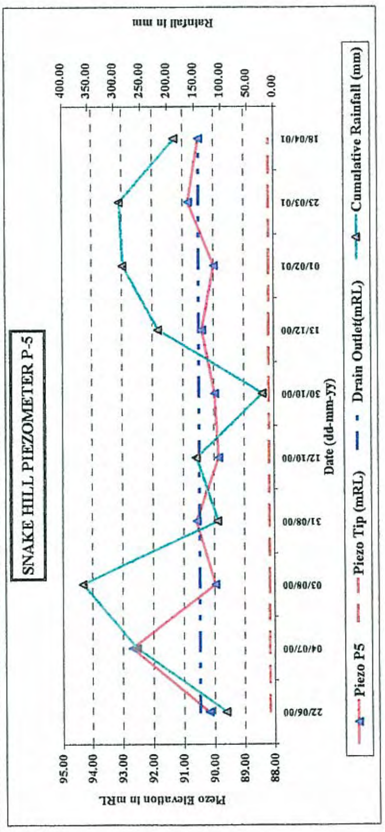
Appendix F
Piezometer Monitoring Data



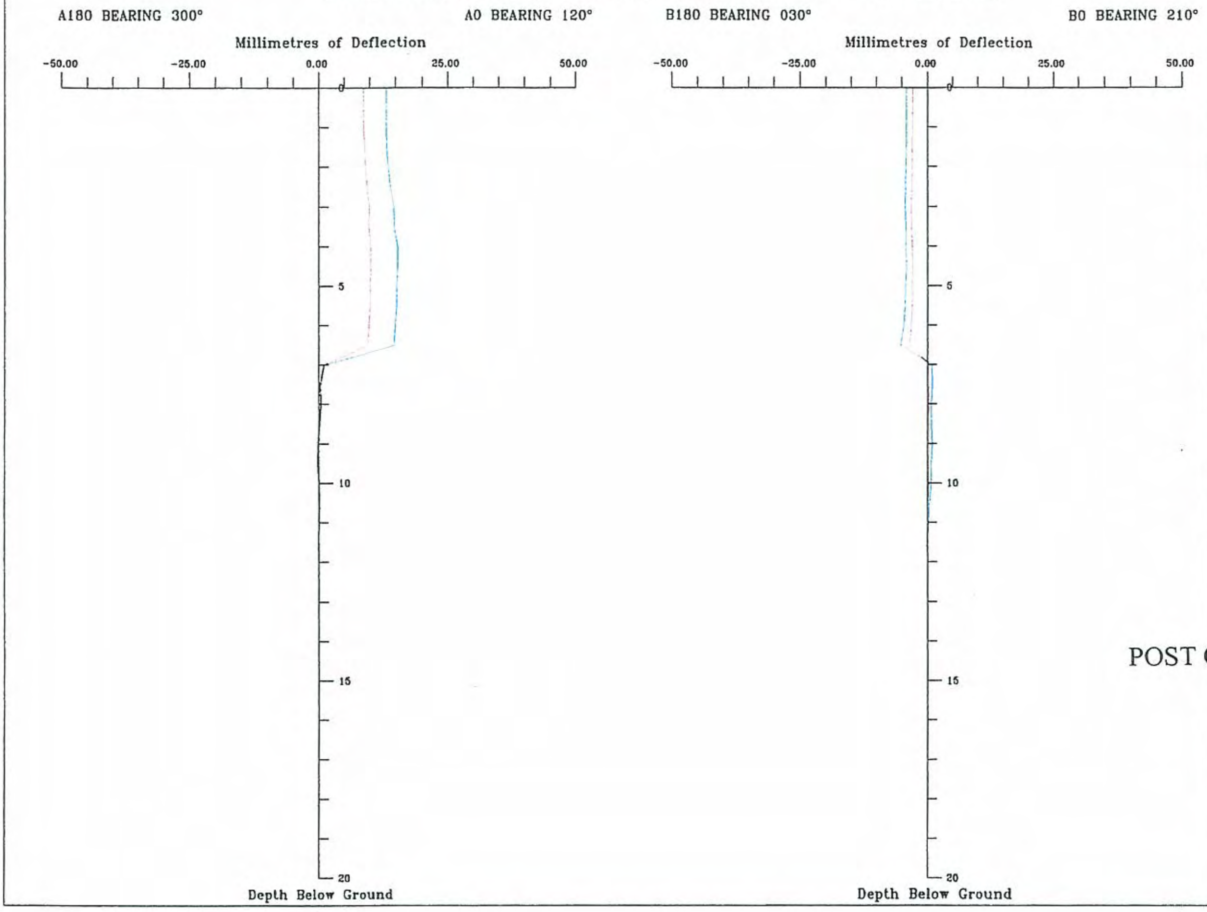








GEOTECHNICS LTD
INCLINOMETER MONITORING - CUMULATIVE



Page 4 of 5

CLIENT:
GHD LTD

PROJECT:
SNAKEHILL UNDERSLIP

LOCATION:
SH1N,RP144/11.3

JOBNO: 613818.3

BORE: I1

DATE: 18/04/01

ClientRef:

R.L.:
Datum:

East:
North:

Operator: LIT
Base: 13/06/00

POST CONSTRUCTION

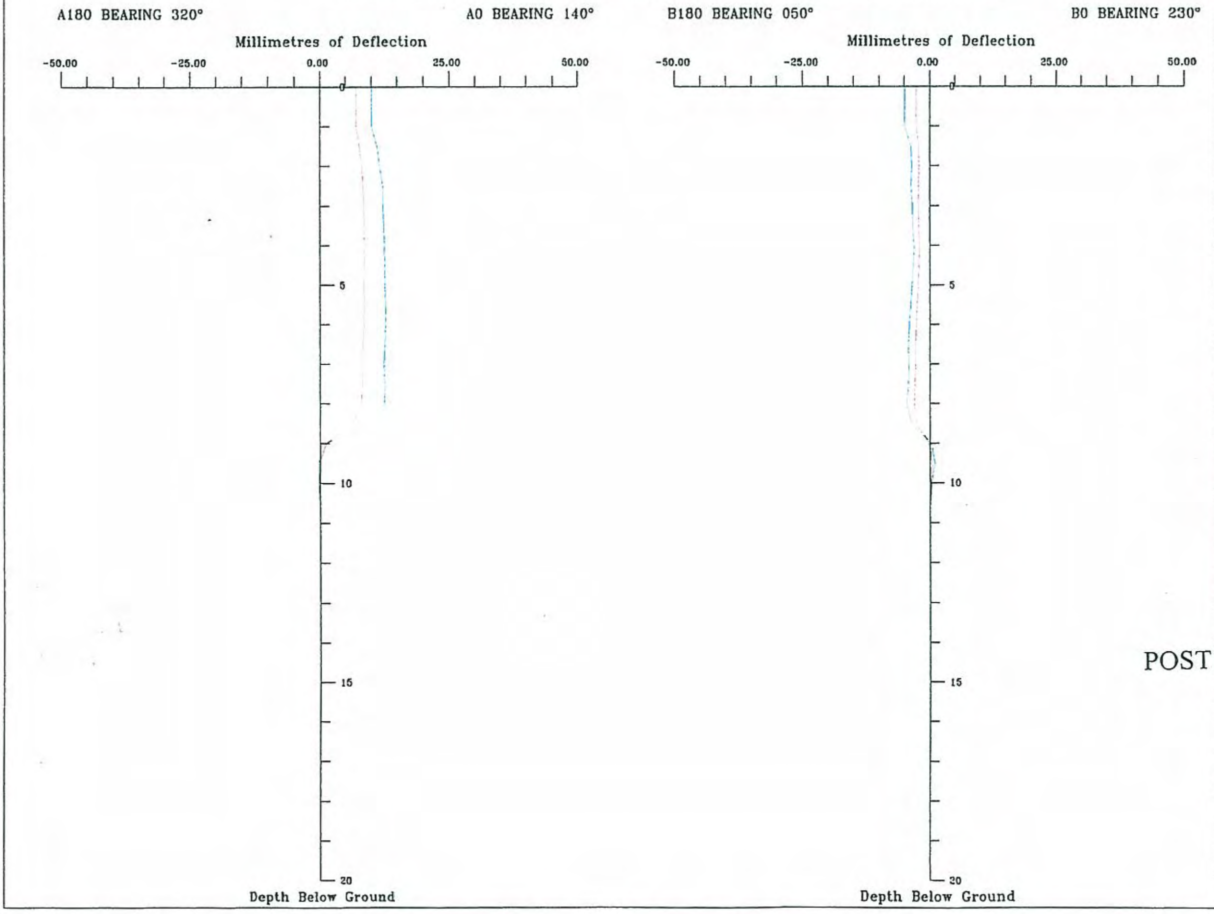
31/10/00-->SH1112
18/04/01-->SH1113

Software by Tonkin & Taylor Ltd

COMMENT:

SH1113-SH1111

GEOTECHNICS LTD
INCLINOMETER MONITORING - CUMULATIVE



Page 5 of 5

CLIENT:
GHD LTD

PROJECT:
SNAKEHILL UNDERSLIP

LOCATION:
SH1N,RP144/11.3

JOBNO: 613818.3

BORE: I2

DATE: 18/04/01

ClientRef:

R.L.:
Datum:

East:
North:

Operator: LIT
Base: 13/06/00

POST CONSTRUCTION

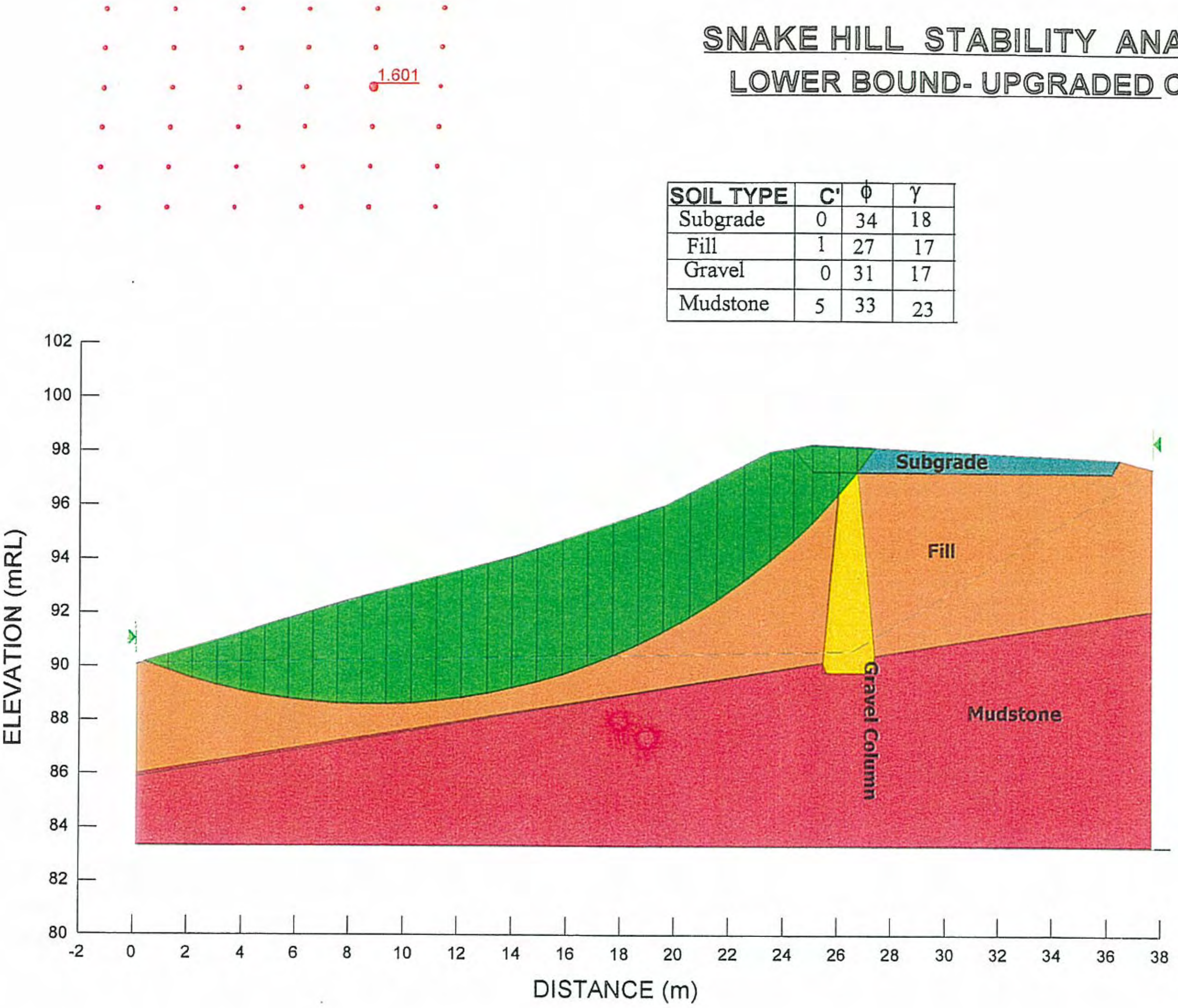
31/10/00-->SH1122
18/04/01-->SH1123

Software by Tonkin & Taylor Ltd

COMMENT:

SH1123-SH1121

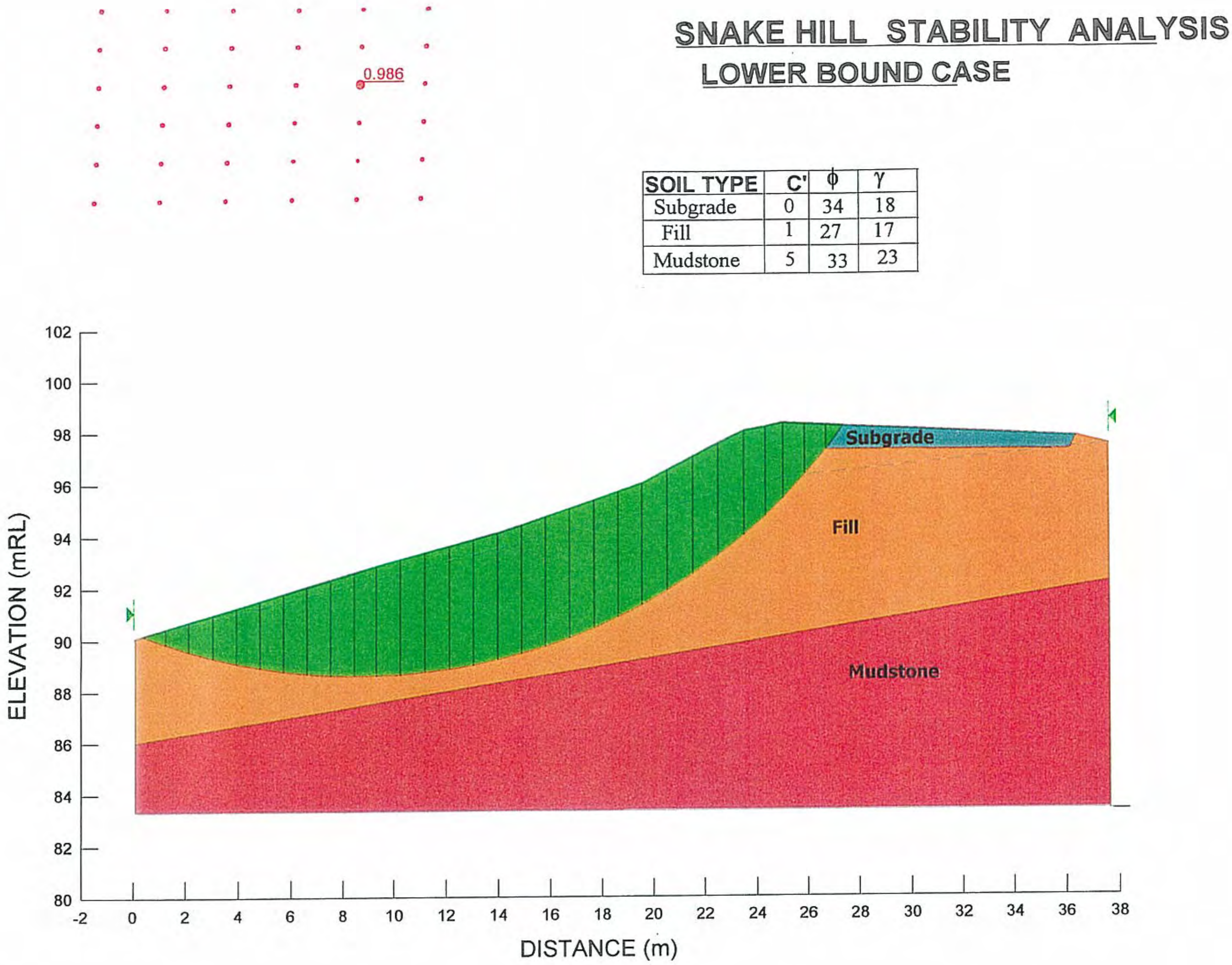
SNAKE HILL STABILITY ANALYSIS
LOWER BOUND- UPGRADED CASE



SOIL TYPE	C'	ϕ	γ
Subgrade	0	34	18
Fill	1	27	17
Gravel	0	31	17
Mudstone	5	33	23

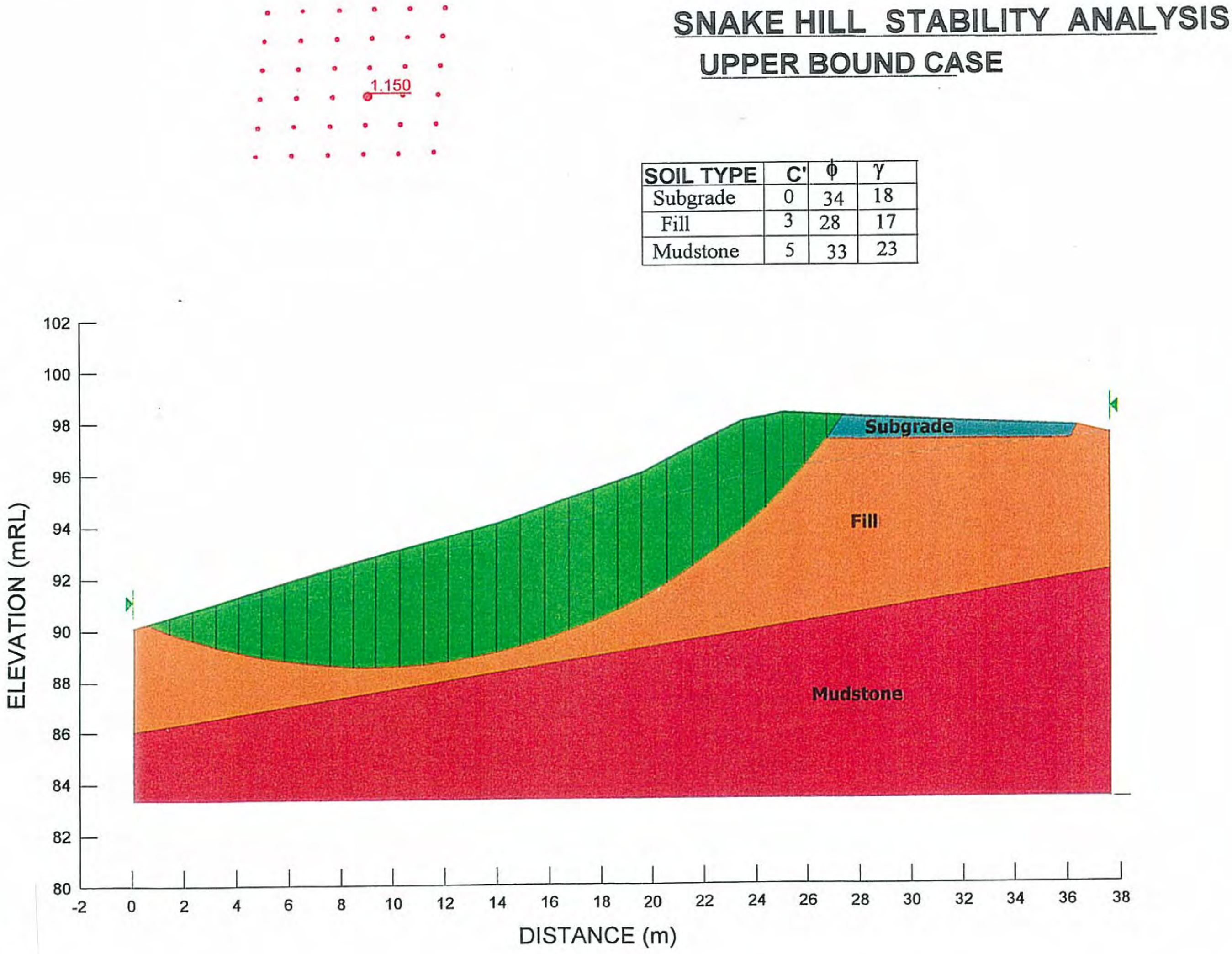
SNAKE HILL STABILITY ANALYSIS
LOWER BOUND CASE

SOIL TYPE	C'	ϕ	γ
Subgrade	0	34	18
Fill	1	27	17
Mudstone	5	33	23



SNAKE HILL STABILITY ANALYSIS
UPPER BOUND CASE

SOIL TYPE	C'	ϕ	γ
Subgrade	0	34	18
Fill	3	28	17
Mudstone	5	33	23



SITE STABILISATION OPTION: Column Drains
COST ANALYSIS

1.1 Cost of works as per attached estimate sheets = **$111,123** (a)

$111,123 (a) x 0.91 = **$101,122** (b)

1.2 Estimated PV of maintenance costs in year 1 = **$1,000** (c)

1.3 Estimated PV of maintenance costs in years 2 to 25 following completion of works

= **$1,000** x 8.57 = **$8,570** (d)

(b) + (c) + (d) = **TOTAL B** **$110,692**

---

2. Describe how the option will improve site stability:

Elevated porewater pressure is the principal driver for the failure at this site. Therefore the provision of positive subsurface drainage improves the long-term stability. Drainage of multilevel failure planes is achieved through the provision of deep vertical graded gravel columns. The grading of the gravel columns controls migration of fine soil particles and thereby ensures long-term, maintenance free site stabilisation.

SITE STABILISATION OPTION: Counterfort Drains
COST ANALYSIS

1.1 Cost of works as per attached estimate sheets = **$243,084** (a)

$243,084 (a) x 0.91 = **$221,206** (b)

1.2 Estimated PV of maintenance costs in year 1 = **$1,000** (c)

1.3 Estimated PV of maintenance costs in years 2 to 25 following completion of works

= **$1,000** x 8.57 = **$8,570** (d)

(b) + (c) + (d) = **TOTAL B** **$230,776**

2. Describe how the option will improve site stability:

Elevated porewater pressure is the principal driver for the failure at this site. Therefore the provision of positive subsurface drainage improves the site stability. However, the construction of Counterfort Drains with trenches greater than 4m deep is difficult. The cost of this option is therefore prohibitive when applied to deep-seated failures.

SITE STABILISATION OPTION: Spider Drains
COST ANALYSIS

1.1 Cost of works as per attached estimate sheets = **$101,910** (a)

$101,910 (a) x 0.91 = **$92,738** (b)

1.2 Estimated PV of maintenance costs in year 1 = **$3,500** (c)

1.3 Estimated PV of maintenance costs in years 2 to 25 following completion of works

= **$3,500** x 8.57 = **$29,995** (d)

(b) + (c) + (d) = **TOTAL B** **$126,233**

2. Describe how the option will improve site stability:

The option consists of drilling and installing sub horizontal pipes to provide drainage to the failure planes. Interception of failure plane is never certain. This is reflected in the lack of effectiveness of Spider Drains at many sites. The consequence of this is the high cost of ongoing maintenance, monitoring, and additional reinstatement at these sites.

SITE STABILISATION OPTION: Pile Retaining Wall
COST ANALYSIS

1.1 Cost of works as per attached estimate sheets = **$250,047** (a)

$250,047 (a) x 0.91 = **$227,543** (b)

1.2 Estimated PV of maintenance costs in year 1 = **$0** (c)

1.3 Estimated PV of maintenance costs in years 2 to 25 following completion of works

= **$0** x 8.57 = **$0** (d)

(b) + (c) + (d) = **TOTAL B** **$227,543**

---

2. Describe how the option will improve site stability:

The option consists of the construction of a bored pile wall to stabilise the site. The retaining wall requires minimal maintenance over a long period of time. Construction is expensive, necessitates disruption of the highway, and the visual impact of the structure on the environment is evident.

Appendix J
External Peer Review

Auckland UniServices Limited

4 June 2001

GHD Limited
PO Box 33 216
Takapuna.

Private Bag 92019
Auckland 1 New Zealand
Visitors' address:
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Phone: + 64-9-37 37 522
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Yours sincerely,

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Senior lecturer in geotechnical engineering.