The paper was published in the proceedings of the 9th Australia New Zealand Conference on Geomechanics and was edited by Geoffrey Farquhar, Philip Kelsey, John Marsh and Debbie Fellows. The conference was held in Auckland, New Zealand, 8 – 11 February 2004.

Design and Construction of Mechanically Stabilised Retaining Walls with Fine Grained Backfill

Nicola Ridgley
BE (Hons)
Associate, Beca Carter Hollings and Ferner Ltd

Grant Newby
BE
Senior Technical Specialist, Beca Carter Hollings and Ferner Ltd

D V Toan
PhD, FIPENZ
Technical Director, Beca Carter Hollings and Ferner Ltd

Summary: Transit NZ's Grafton Gully Project is being constructed under an innovative project delivery method called Project Alliancing. Freeflow is an alliance between the owner, Transit NZ and participants Beca, Fletcher Construction and Higgins Contractors. The project will deliver an improved link between the central motorway system, the lower CBD and the port. The Grafton Gully has undergone many stages of development, which has resulted in fills over 20m deep. The new road alignment results in an excess of cut material. Piled walls to support some of the cuts were not considered economic due to the large embedment depth required and Transit NZ also required usable space to be maximised so cut slopes were not acceptable. Mechanically stabilised retaining walls utilising geogrids were selected to provide both an economic method of retaining that reused selected excavated material e.g. fine-grained soils. Precast full height panelling was selected to provide a facing that could easily match the finish of other wall types such as piled retaining walls. Monitoring of the panels on one of the MSE walls was undertaken to identify the magnitude of movement during and following construction. To date, rotation of panels on walls between 4 and 5m in height have been measured at typically 0.5-0.9° since placement compared to the original tilt back of 1.5-1.7° and 0.45" movement suggested by Elias and Christopher. This is considered consistent with that expected given the fine grained nature of the backfill used and measurements recorded a few months after completion as opposed to immediately after construction.

INTRODUCTION

Transit NZ is upgrading Auckland's motonvay network to improve both strategic links and address Auckland's congestion problems. The Grafton Gully Project is the first project towards improving the motonvay network and aims to improve the strategic link between Auckland's lower Central Business District, the port area and the motorway network.

The Grafton Gully project is being constructed using a contracting method called Alliancing, which is the first time this method of contracting has been used in New Zealand. Alliancing is suited to high risk complex projects and promotes improved performance in a number of areas including best for project decisions, early interaction of design and construction teams allowing flexibility and efficiency, genuine fast tracking and early delivery and collective ownership of all risks and rewards of the project.

Alliancing requires and encourages cost effective design coupled with innovation. The main SH 16 alignment for this upgrade is predominantly in cut, with key requirements to maximise usable space, minimise cut to waste and provide cost effective retaining solutions. The use of fine grained backfill in mechanically stabilised earth (MSE) retaining walls was considered to meet these requirements.

PROJECT DESCRIPTION

The Grafton Gully project is shown on Figure 1 and involves extending SH16A north to pass under Grafton Rd with a new bridge on Grafton Rd (remove the old motorway dog leg exit at Grafton Rd), removing a dog leg from Stanley St into the Strand by extending Stanley St to pass beneath the railway line with a new bridge and providing a new link from Wellesley St to Grafton Rd via a new bridge. Also incorporated is the widening of Stanley St, provision of a free left turn from Stanley St to Beach Rd and an extra right turn from Beach Rd to Stanley St.

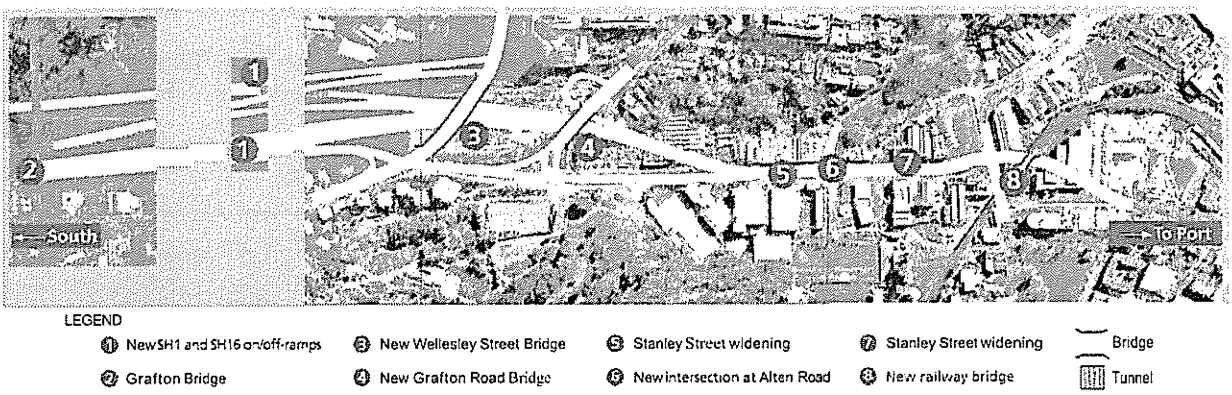


Figure 1: Plan of Project Works and Key Elements

GEOLOGY

Site History

Grafton Gully is an old eroded stream gully where the Grafton Stream flowed in a northerly direction forming an erosion gully later infilled by rise in sea levels. The gully falls relatively steeply from its head near the Southern Motonvay to the Stanley Street – Grafton Road intersection midway down the valley (Upper Grafton Gully). Grafton Gully broadens at the location of the old university carpark and in the early 1800s the lower gully (Lower Grafton Gully) formed a low lying swampy area. At the outlet of the Grafton Stream a tidal influence existed where more recent marine and intertidal sediments were deposited throughout Mechanics Bay and lower Grafton Gully. The tidal zone is expected to have fluctuated with sea level rises and falls associated with the recent glaciation periods. Upper Grafton Gully has been extensively modified since the late nineteenth century primarily due to the construction of Grafton Bridge (~1909), the Blandford Park sports fields south of Grafton Road (unknown age), and the motonvay access ramps (~1965).

Geology

The geology of the study area has been assessed from information obtained from subsurface investigations along with published geological maps (Geology of the Auckland Urban Area Sheet R11, 1:50,000 Geological Map Series; Kermode, 1992). The geological units underlying Grafton Gully through to The Strand comprise fill, alluvium of the Tauranga Group and recent marine sediments over Waitemata Group residual soils and rock of the East Coast Bays formation.

GEOTECHNICAL CONDITIONS

Geotechnical investigations have been undertaken for the Grafton Gully project including more than 50 boreholes, 15 standpipe piezometers, 19 cone penetrometer tests, 12 pavement pits and 7 testpits (Meritec 2001, Freeflow 2001/02). These investigations indicate the following soil profile as described below and in Table 1.

Fill:
Two distinct periods of fill can be identified. The first period of filling probably occurred prior to 1960 to form the Grafton Road sports fields (Blandford Park – early 1900's) in the area the old university carpark. This fill is poorly compacted and contains organic layers, building rubble and refuse. The second period fill is generally clean and well compacted and was placed during the mid 1960's as part of the motonvay access ramp constructions. Fill materials encountered in the Upper Grafton Gully section have been differentiated based on information from various reports and recent investigations. These are described below:

i. Fill and Gravelly Fill : This material includes a mixture of silt-clay, minor sands and gravels, organics and building debris up to 13m thick in places. A more gravelly fill material was encountered up to 21m thick including basalt, scoria, sandstone, siltstone and building debris.

ii. Basalt Fill : Fill materials in boreholes near Wellesley St off ramp encountered basalt boulder fill up to 19m deep. Smaller lenses of boulders and gravels were also encountered within the gravelly fill material or as a base lining directly overlying the Grafton Stream valley.

Tauranga Group Sediments:
These sediments overly the Waitemata Group profile and consist of reworked material, being silt-clay, with some sand and organic silt lenses up to 11m thick.

Waitemata Group:
Waitemata Group rocks (East Coast Bays Formation) underly the site at depths of 3m to 28m. These rocks are very weak to weak interbedded sandstone and siltstone which, have weathered weather to form 1-5m thick of residual soils of soft to very stiff clays, silts and sands.

Table 1: Summary Soil/Rock Profile and Laboratory Test Data

Geological Group	*Vane Shear Strength (kPa)*	*SPT, N (Blows/ 300mm)*	*Atterberg Limits*			*Natural Moisture Content (%)*	*Grading*			
			PL (%)	*LL (%)*	*PI (%)*		*Gravel (%)*	*Sand (%)*	*Silt (%)*	*Clay (%)*
Fill/ Gravelly Fill	38 - 223 Avg = 140	0 - 50 Avg = 16	21 - 32 Avg = 26	49-73 Avg = 62	20-47 Avg = 36	22 - 40 Avg = 29	0-20 Avg = 4	19–40 Avg = 28	31-72 Avg = 40	24-46 Avg = 33
Basalt Fill	N/A	21 - 50+ Avg = 44								
Tauranga Group Alluvium	21 - 168 Avg = 82	0 - 30 Avg = 10	23-26 Avg = 25	48-71 Avg = 58	23-45 Avg = 34	25 - 48 Avg = 35	0	19-60 Avg = 31	22-80 Avg = 44	18-44 Avg = 33
Waitemata Group Residual Soil	37–212 Avg = 130	3 - 33 Avg = 23	18-29 Avg = 25	64-95 Avg = 79	36-77 Avg = 54	17-43 Avg = 32	0	5 - 73 Avg = 37	17-75 Avg = 40	27-63 Avg = 42
Waitemata Group Sandstone/ Siltstone.	UCS = 0.15–2.34 Avg = 1.23	50+	-	-	-	-	-	-	-	-

The standpipe piezometers indicate that the regional groundwater level is located within the Waitemata Group sandstone/siltstone and grades down the valley towards Grafton Rd and Stanley St.

MSE RETAINING WALL DESIGN

Retaining wall types were selected along the project to provide the most suitable wall type for each specific location. This has resulted in an alternating mix of semi-contiguous piled, concrete cantilever or MSE walls. In order to minimise the obvious aesthetic variation in wall type and meet Urban Design requirements all walls (except two) were faced with precast reinforced concrete panels. The MSE wall has full height concrete panels which, allowed for patterning with Urban Design feature on the exposed face of the walls. In order to reduce cut to waste the MSE walls were designed to utilise fine-grained fill. However the risk of increased movement with the use of fine-grained fill was recognised and a monitoring programme was implemented to check the actual wall behaviour. The design team was located in the project office, so design and construction aspects were discussed and developed in conjunction with the construction team, which is one key advantage of Alliancing.

The MSE walls have been designed to meet a number of design requirements and these are summarised below.

Surcharge:
Surcharges to the walls are from vehicular traffic or a slope above the wall. A surcharge of 12.5kPa was applied for traffic loadings to meet the vehicle surcharge loading requirement in the TNZ Bridge Manual 2000 and sloping ground was modelled as either a soil surcharge or by inclined slope earth pressure co-efficients.

Drainage:
A drainage layer was designed at both the rear and along the base of the walls to reduce the likelihood of water building up behind the MSE walls. In addition, a slotted pipe was incorporated in the drainage layer at the base of the wall to provide for positive drainage.

Seismic:
The peak ground acceleration used in design was derived from the Transit NZ Bridge Design Manual 2000. Seismic earth pressures have been derived using Mononobe-Okabe equations and both global, internal and external stability of the wall checked (Bowles, 1988).

Wall Design Standards:
The MSE walls have been designed against several modes of failure. These include global stability, external stability (sliding and overturning) and internal stability (rupture and adherence) (BS 8006:1995), the requirements are summarised in Table 2 below.

Table 2: Wall Design Standards

Item	Design Standard
Global Stability	Minimum factors of safety against instability required are: Static Load Case ≥ 1.5 Seismic Load Case ≥ 1.1
External Stability	Strength reduction factors recommended in B1/VM4 and checked using partial factors recommended by BS 8006.
Internal Stability	Generally in accordance with BS 8006. The grids are sized to allow for the use of both granular fill and a selected excavated fine grained cohesive fill material usina appropriate coefficients of interaction.

Precast Concrete Panels:
The precast wall panels vary between 170 and 220mm thick depending on wall height. This thickness includes an allowance of 20 mm for the urban design patterning depth which, is indented into the wall face. The panels have been designed for a number of load cases including temporary construction lifting loads, soil retaining loads, and grid tension loads. In addition an Ultimate Limit Design case of grids reaching their Long Term Design Strength has also been checked for both panel and connection design. The geogrid was cast directly into the rear of the panels. The panels are founded on a cast insitu reinforced concrete strip footing to spread the panel vertical load. A continuous drainage dish is connected to the top of the panels to act as cap beam to control long term differential outwards movement of the panels.

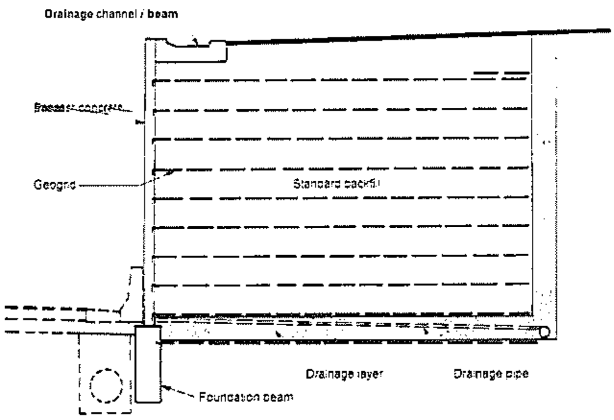


Figure 2: Typical Section MSE Retaining Wall

KEY SPECIFICATION REQUIREMENTS

A number of key Technical Specification requirements have been specified for construction of the MSE walls at Grafton Gully. These include:

Materials:
Reinforcement grid comprising mono-axial high density polyethylene geogrid with a high resistance to damage during construction, ultraviolet degradation, chemical and biological degradation. Drainage material comprising a graded AP20 or coarser drainage aggregate (20-40mm) with the use of geotextile or AP20 graded filter material depending on grid location. A standard backfill comprising a plasticity index less than 40% and a maximum particle size no greater than 125mm.

Excavation:
Following excavation the subgrade was tested using Pilcon Shear vane testing on a 5 x 5m grid to depth of 2m to confirm the shear strength of the underlying soils was specified. Any areas or layers with shear strength less than that specified was undercut and backfill with hardfill.

Compaction:
Geogrids have been connected with standard bodkin joint and lightly tensioned prior to placing fill. The fill was specified to be spread using an excavator bucket or dozer with an opening bucket to cause the fill to cascade over the grids and then compacted with rollers travelling parallel to the wall face. In a zone within 2m of the facing the size of the compaction plant was limited to minimise compaction loadings on the face. The Standard backfill

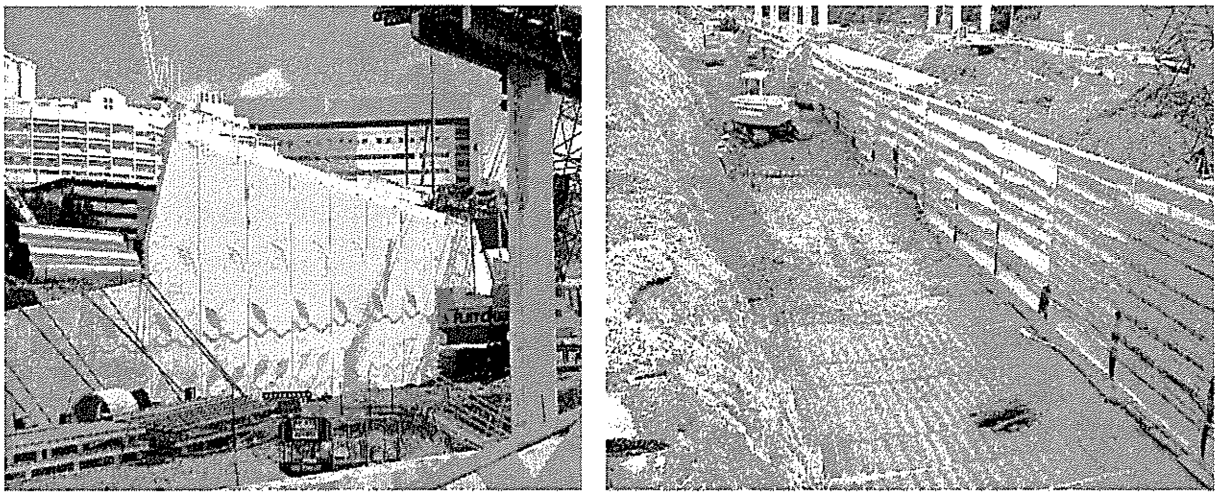
has been placed and compacted to meet specific compaction requirements. These included an insitu density no less than 98% of maximum *dry* density and shear strength no less than 120kPa to 150kPa.

Construction Tolerences:
The MSE walls were required to comply with a verticality of ±5mm/m height, gaps between joints in panels of <20mm, steps in joints no more the 10mm and horizontal alignment along the top of ±15mm from reference alignment

WALL CONSTRUCTION PROCEDURE

The construction of the MSE walls generally followed the construction procedure summarised below:

- The panels were precast on site (on the roof of the sedimentation tank). This innovation resulted in both a time and cost saving and meant that the panels were stored and readily accessible in close proximity to their final location. The panels were precast in widths of 3m.
- The ground was excavated to the foundation level and testing undertaken to determine if undercut was required. Following testing and performing any undercut the concrete footing for the panels was constructed and drainage pipes installed and backfilled in front of the footing as required.
- The panels were erected on the footing, located laterally with steel pins at the base and propped at the top using steel props connecting back to short piles driven into the ground in front of the wall as shown in Figure 3. The props were designed in accordance with recommendations in BS8006 and were removed once the fill reached half the panel height.
- The wall was backfilled with the specified drainage and standard backfill layers. The Standard Backfill material was selected excavated soils from site comprising old fill or excavated Waitemata Group soils and rock. The concrete drainage channel/beam was constructed along the top of the wall following completion of filling to link all the panels together. Testing of the fill was undertaken throughout construction to confirm compliance with the specification.



(a) Front Face with Panel Propping and Urban Design Pattern

(b) Rear Face with Geogrids and Compaction Equipment

Figure 3: Construction Wall 12

CASE STUDY- RETAINING WALL 12

General:
Wall 12 was the first MSE wall to be constructed on the project. The wall is located in cut on the eastern side of the southbound alignment. Wall 12 is around 160m long with a typical retained height of 4-5m but reaching up to 10.5m.

Soil Profile:
Four boreholes were drilled along the length of Wall 12 to determine the soil profile. These boreholes encountered between 0 and 17m fill and gravelly fill. This fill was generally stiff however one pocket of 4-5m thick very soft fill was encountered around 8m below the existing ground surface. Underlying the fill was 1-8m firm to stiff alluvium underlain by Waitemata Group soils and rock. The rock was encountered at depths varying between 5m at Grafton Road and 16m around 40m south of Grafton Rd below ground surface level.

Wall Design:
The design details for Wall 12 are described in Table 3 below.

Table 3: Wall 12 Design Summary

Retained Height	5.0m plus traffic	9 m plus traffic	12m plus traffic
Geogrid Length	6.0m	12-12.5m	14m
Geogrid Type	Tenax TT090 SAMP at 0.5m centres	Varies Tenax TT160 SAMP - Tenax TT090 SAMP at 0.4m centres	Varies Tenax TT160 SAMP - Tenax TT090 SAMP at 0.4m centres
Foundation Strength, (S, min)	85 kPa	110kPa	150kPa

Construction Aspects:
Some undercut was carried out to remove a zone of weak fill that was exposed in the excavation towards the northern end of the wall. The depths of undercut varied from 0.5-1.5m below the base of the retaining wall and were backfilled with *GAP65* hardfill.

The panels were erected and fill compacted that met and exceeded the specified requirements. The Standard fill used in this wall was predominantly highly to completely weathered Waitemata group sandstone/siltstone.

The panels were typically set up to angles of around 1.5-1.7° back from the vertical. At the northern end, where Wall 12 is located adjacent to a vertical piled retaining wall and at the southern end in front of the piles for the Wellesley St bridge abutment panels were set up near vertical to match the adjacent piled wall and to clear the abutment piles. Monitoring of the panels for movement was undertaken during construction and following completion of the wall. The monitoring was carried out using a laser plumb over a 1500mm vertical distance on the face of each panel. Deviations from plumb were measured and recorded to an accuracy of ±0.03°. The panel was measured at initial set up, immediately following removal of the props and at selected times until the southbound alignment was opened some 180-270 days after initial panel and fill placement. Figure 4 below shows panel movement of the panels immediately after prop removal and just prior to southbound opening. The panel movement is variable but as expected shows a slight trend of increased movement after prop removal, with panel height and time. The panels with retained height 4-5m had typically rotated 0-0.3° following removal of the props with a total of 0.5-0.9° by the time of the southbound opening. In addition the rotation of a 4-5m high panel was compared to that suggested by Elias and Christopher (FHWA, 2001). This was calculated to be around 0.45°, which is at the lower end of the panel rotations measured. This is consistent with that expected given the fine grained nature of the backfill used and measurements recorded a few months after completion as opposed to immediately after construction.

Other issues relating to construction of this wall included:

- Some panels have moved differentially compared to adjacent panels. While of little significance structurally, the steps are visible from some angles. Currently the grids are the only connection across the panel joints. In order to limit the potential for these localised displacements we are currently assessing methods such as:
  - Leaving props on longer; or
  - Casting concrete beams mid way up prior to removing props; or
  - Shear key between the panels

- Position of ducts, lighting poles and roadside barriers above the wall require penetration of the grid. Where possible these items have been placed to minimise loss of grid, such as in a single line perpendicular to wall, use of single catch pits wherever possible and only on one side of a width of grid. Options for detailing around these minor structures could be developed into standard methods for future use.

- The location of the piles at the Wellesley St bridge abutment resulted in significant penetration of the grid. Where a joint between panels was located immediately in front of a pile, flexural cracking on the adjacent panels was noted during construction. As a result the fill was removed, and concrete beams were constructed at the rear of the panels to transfer load over the full width of the panels.

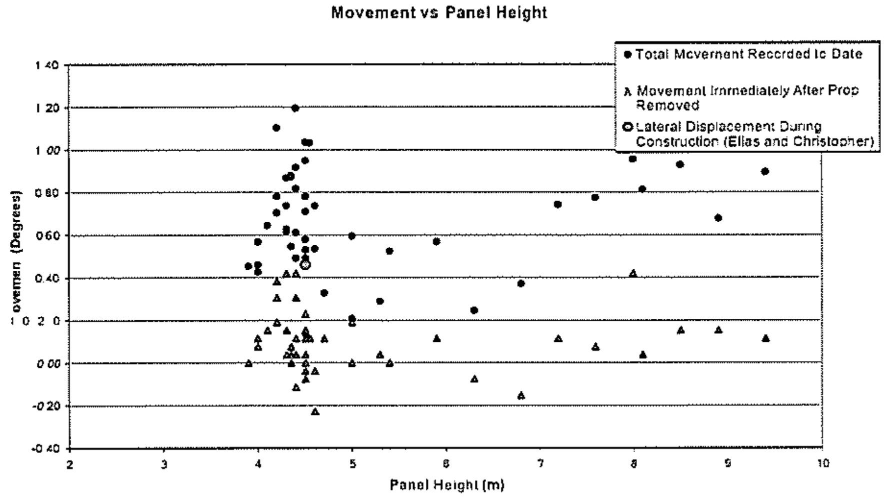


Figure 4: Panel Movement Monitoring

CONCLUSIONS

Grafton Gully project is the first project implemented by Transit NZ to improve Aucklands motorway network. Grafton Gully project is also the first project to be constructed in NZ under the Alliance method of contract delivery and is being designed and constructed by the Freeflow AllianceThe Grafton Gully has undergone many stages of construction including the Grafton Bridge in the early 1900's to sports fields and new motorway connections during the 70s and 80s. As such the Gully soil profile has experienced significant change including fills over 20m deep.

The main SH 16 alignment for this upgrade is predominantly in cut, with key requirements to maximise usable space, minimise cut to waste and provide cost effective retaining solutions. The use of fine-grained backfill in mechanically stabilised earth (MSE) retaining walls was considered to meet these requirements.Wall 12 was designed and successfully constructed utilising selected excavated soils within the site. These comprised predominantly completely to highly weathered sandstone. Monitoring of the panels was undertaken to identify the magnitude of movement during and following construction. To date, rotation of panels on walls between 4 and 5m in height have been measured at typically 0.5-0.9" since placement compared to the original tilt back of 1.5-1.7".

ACKNOWLEDGEMENTS

The authors wish to acknowledge the Project Alliance Board for granting permission to publish this paper.

REFERENCES

Bowles, (1988). *Foundation Analysis and Design,* 4th Edition,Mc Graw Hill Book Company

BS 8006:1995 British Standards Institute: *Code of Practice for Strengthened/ Reinforced Soils and Other Fills*

FHWA (March 2001), *Mechanically Stabilised Earth Walls and Reinforced Soil Slopes, Design and Construction Guidelines.* Publication No FHWA NHI 00 043, US Department of Transportation.

Freeflow Alliance (2001, 2002). *Grafton Gully Stages 1,2 and 3 Additional Geotechnical Investigations.*

Kermode, L. O (1992). Sheet R11, *Geology of the Auckland Urban Area 1:50 000,* Lower Hutt, New Zealand. Institute of Geological and Nuclear Sciences

Meritec Ltd (August 2001). *Contract PA 1734 Grafton Gully to the Strand, Geotechnical Investigation Factual Report*

Transit NZ (2000). *Transit NZ Bridge Manual 2000.*