Geotechnical methods for assessing foundation conditions for flood control structures

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CONTENTS

FIGURES

TABLES

APPENDIX

EXECUTIVE SUMMARY

The West Coast Regional Council has asked GNS Science to provide advice on identifying geotechnical conditions likely to be encountered in areas where river flood protection schemes are proposed. The objective of this work is to develop a methodology for assessing the *in situ* foundation strengths that will be encountered at the sites of proposed stop-banks. The methodology involves using existing information to build a picture of the geological and geotechnical setting of the sites of any proposed stop-banks. This includes published geological and soil maps as well as information that may be held on local authority files (e.g. geotechnical reports for infrastructure development) or in files held by other bodies (e.g. foundation investigation records for wharf infrastructure). Once the desk study phase has been completed the methodology calls for an investigation program to be designed and undertaken to obtain additional geotechnical information in areas where no geotechnical information is available.

The Westport area has been chosen as the location for a case study as sites for stop-banks have been identified by Duncan (2005) and these sites encompass a range of geotechnical and infrastructure settings. Foundation conditions for 12 new stop-banks that will provide flood protection to Westport from the 1% AEP flood have been investigated (AEP = Annual Exceedance Probability and a 1% AEP equates to ~1:100 year flood). The investigations have included a review of published geological and soils mapping and a review of subsurface data including drill-holes and scala penetrometer test results held by the Buller District Council. In addition geotechnical investigations were carried out at the proposed Victoria Road stop-bank because there was no existing geotechnical information for this site.

The proposed stop-banks are all of relatively low height (0.3 -1.6 m). However, in the NIWA report (Duncan, 2005) the height of the stop-banks is simply defined as the height required to successfully keep the modelled 1% AEP flood out of Westport. It is common practice when constructing stop-banks to provide free-board of 0.3-0.5 m. Even with an additional height of 0.3 m added to the stop-banks, the bearing capacity required of the foundations does not exceed 50 kPa.

The soils underlying the proposed stop-banks are all fine-grained but can be divided into two groups, those deeply underlain by gravel dominated sediments adjacent to the Buller River and those underlain by fine grained sediments adjacent to the Orowaiti Estuary. The bearing capacity of gravel soils adjacent to the Buller River will significantly exceed the load added by the construction of the proposed stop-banks. The 2-5 m of mud (silt and clay) overlying the river gravel in the Westport urban area (Nathan, 1978) also has sufficient bearing capacity to support the proposed stop-banks.

The bearing capacity of the fine-grained soils adjacent to the Orowaiti Estuary is lower than for the Buller River soils. Scala penetrometer test results for house foundations indicate that the bearing capacity of these soils is probably greater than 100 kPa and the required bearing capacities are 15-29 kPa. Thus the soils adjacent to the Orowaiti Estuary should have sufficient bearing capacity to support the proposed stop-bank heights.

This study concludes that the foundation conditions are adequate to support all the stop-banks proposed to protect Westport from the 1% AEP flood.

1.0 INTRODUCTION

The West Coast of the South Island of New Zealand has a high annual rainfall due to the orographic effects of the Southern Alps on the moist, predominantly westerly air-flows of the mid-latitudes of the southern hemisphere. This results in a significant flood hazard for rivers on the West Coast. European settlements on the West Coast are relatively old by New Zealand standards and were developed adjacent to the mouths of major rivers to facilitate access by sea. These settlements are commonly at risk from flood hazards.

The West Coast Regional Council has asked GNS Science to provide advice on identifying the geological and geotechnical conditions likely to be encountered in areas where flood protection schemes are proposed. The objective of this work is to develop a cost-effective methodology for assessing the *in situ* foundation strengths (bearing capacity) and permeability of the sub-surface materials at the sites of proposed stop-banks.

Existing information is used to build a picture of the geological setting of the sites for the proposed stop-banks. Existing information can include published geological and soil maps as well as information that may be held on local authority files (e.g. geotechnical reports for infrastructure development) or in files held by other bodies (e.g. foundation investigation records for wharf infrastructure). Once the existing information has been compiled and assessed, areas where there is insufficient geological and geotechnical information can be identified and an investigation program to obtain this information can be designed and undertaken. When all the relevant geological and geotechnical information has been collected and collated, then generic geotechnical parameters can be extracted to design the flood protection structures.

This methodology is demonstrated using the stop-banks proposed by Duncan (2005) for Westport as a case study. NIWA has undertaken several studies of the flood hazard at Westport and these studies have developed and refined the 1% and 2% AEP flood events and are summarised in Duncan (2005), where the sites for stop-banks to protect Westport from the 1% AEP flood were identified (AEP = Annual Exceedance Probability and a 1% AEP equates to ~1:100 year flood). In this case study the geological and geotechnical data for these sites is collected and interpreted.

2.0 METHODOLOGY

A methodology is developed to identify the foundation conditions in areas where stop-banks are proposed. The methodology involves:

1. Collecting existing geological and geotechnical information (desk study);

2. Undertaking sub-surface investigations to collect additional geotechnical information where this is required; and

3. Analyses of the geological and geotechnical data to determine the properties of the foundation materials and make recommendations on foundation treatment to aid the design and construction of the proposed flood protection structures.

2.1 Existing Information

Existing information on foundation conditions can come from a wide variety of sources. For example, this can include:

- Geological maps (both surficial and "basement");
- Soils maps;
- Local authority files;
- Asset Owner files;
- Aerial photos;
- Site visits; and
- Local knowledge.

2.1.1 Geological Maps

Geological maps are available at a variety of scales and have varying degrees of detail. The Q-Map series (1:250,000 scale) is now available for most of New Zealand. Geological maps at other scales (commonly 1:63,360 or 1:50,000) are also available in some areas. Geological maps provide general information on the soil and rock types that will form the foundation material for any proposed stop-banks. The information from geological maps and the accompanying text can often allow an assessment of the materials likely to be encountered in foundations of any proposed structure. For example, geological maps may differentiate between coarse grained sediments (alluvial gravels) and fine grained sediments (swamp deposits or dune and beach sands). The depositional environment can also be assessed and this can provide an early indication of the relative strengths of the materials. For example, river gravels are usually deposited in a high energy environment and this is indicative of soil strengths that are likely to be higher than for silts and sands deposited in a low-energy environment such as a lagoon or estuary.

2.1.2 Soils Maps

Soil maps are also available at a wide variety of scales and levels of detail. Soil maps may provide information on soil origin and thickness. This includes information on the parent material of the soil and from this an indication of the materials underlying the soils can be gained. Soil maps can also provide an indication of the depositional environment, and therefore give an indication of the relative strength of soils at a site.

2.1.3 Local Authority Files

Sub-surface geotechnical information is often available in local authority files. It can be collected as part of the investigation and/or consenting process for new developments (e.g. house sites, commercial and industrial buildings and infrastructure development). This can include information from scala penetrometer tests (usually shallow: 1-2 m), standard penetration tests (SPT), cone penetrometer tests (CPT), test pit and borehole logs and laboratory tests. The geotechnical information is valuable as it provides direct evidence of the strength of the soils at or near a site.

2.1.4 Asset Owner Files

Geotechnical information is also often available in the files of infrastructure owners (for example: commercial buildings, industrial facilities or transit corridors). It is often collected as part of the design process for these facilities. The geotechnical information from these files is of value as it may provide direct evidence of the strength of the foundation soils at or near a site.

2.2 Geotechnical Investigations

Geotechnical investigations collect information on the physical properties of materials upon which structures will be founded. This can include information such as material type (i.e. rock or soil, coarse-grained or fine-grained), strength (relative or measured) and density. Geotechnical investigations can encompass a range of activities which can include the excavation and logging of test pits or natural exposures, probing activities such as scala penetrometer, standard penetrometer and cone penetrometer tests and laboratory tests. The decision as to what is the appropriate geotechnical investigation technique to use at a site will depend on the information that is being sought. The use and limitations of the various investigation techniques are briefly discussed below.

2.2.1 Test Pits and Natural Exposures

The excavation and logging of test pits and the logging of natural exposures can provide information on the material type, strength, permeability and density of near surface materials (2-3 m depth commonly). Test pits and natural exposures can provide an indication of the relative strength and density of materials using diagnostic field evaluations. While these evaluations are interpretive, they can indicate that the available strength is substantially higher than the strength required too support flood protection structures and thus reduce the need for further investigations at a site. Test pits require a reasonable space for the operation of machinery and are therefore best suited to areas where access is available and where the ground disturbance will not significantly affect other activities.

2.2.2 *In situ* testing

2.2.2.1 Scala penetrometer tests

The scala penetrometer test is commonly used in New Zealand to assess the strength of near surface materials (commonly 2-5 m depth). The hand-held test involves measuring the soil resistance to a steel cone of 20 mm end diameter pushed into the ground by dropping a weight of 9 kg a height of 0.51 m and recording the penetration achieved. It is principally designed for use in cohesionless sands and fine gravels where the test gives a conservative estimate of friction angle and safe bearing pressure based on widely-used correlation curves. In natural clays and silts, it can also provide a conservative estimate of safe bearing pressure, provided the material has not been previously exposed to excessive drying.

2.2.2.2 Standard penetrometer tests

The Standard Penetrometer Test (SPT) is a dynamic test similar to the scala penetrometer. A steel tube of 50 mm outside diameter and 35 mm inside diameter is forced into the ground by dropping a weight of 63.5 kg a height of 760 mm with the number of blows required to achieve 300 mm of penetration is recorded. The principal differences from the scala penetrometer are the ability to retrieve soil samples and the much greater depth at which the standard penetration test can be used. The standard penetrometer is truck mounted and is capable of reaching depths of 30 m or more. The truck mounted SPT rigs are limited to areas where access is available and are often undertaken in conjunction with boreholes.

2.2.2.3 Cone penetrometer tests

The Cone Penetrometer Test (CPT) is another common test used to evaluate ground conditions. The CPT test uses a cylindrical rod of 36 mm diameter with a conical tip and a friction sleeve immediately above the conical tip. The forces on the cone tip and friction sleeve are measured as it penetrates through the ground at a constant rate (usually 20 mm/sec ± 5 mm/sec). The results can be used to measure stratification within the soil profile as well as soil type, soil density and *in situ* stress conditions, permeability and shear strength parameters. Of the commonly used soil probing tests, the CPT test provides the most detailed information on soil properties and like the SPT test can reach depths in excess of 30 m in some soil types. Again, truck mounted CPT rigs are limited to areas where access is available and produce the best results when the soils are dominantly fine-grained.

2.2.2.4 Permeability tests

In situ permeability tests can also be undertaken to investigate representative permeabilities for sub-surface materials. Evaluating the permeabilities of subsurface materials is important because it provides information on the probable velocity of groundwater along seepage paths beneath and through stop-banks.

2.2.3 Laboratory tests

Test pits can provide access for shear vane testing, while boreholes can provide soil samples for testing in the laboratory from cores, push-tubes or SPT tests. However, SPT samples are often highly disturbed and can give unreliable results. Standard laboratory tests include moisture content, specific gravity, dry density, Atterburg Limits, unconfined compressive strength and bulk density.

2.3 Geotechnical Parameters

Once all the necessary geological and geotechnical information has been collected it is necessary to collate and assess the range of geotechnical properties. This will ensure that the designers of the stop-banks have sufficient information to enable the works to be designed and constructed to appropriate standards.

2.3.1 Bearing Pressure and Bearing Capacity

The bearing pressure of the stop-banks needs to be calculated along with the bearing capacity of the foundations. The construction of stop-banks will add to the overburden pressure on the natural soils beneath the stop-banks. The additional load or bearing pressure imposed by the construction of a stop-bank of known dimensions can be conservatively calculated as follows (this procedure tends to over-estimate loading under embankments):

$$\text{Additional load on the foundations} = \rho\ g\ h\ \text{(kPa)}$$

Where: ρ = density of a well compacted engineered fill (~2.0 kN/m^3)

g = acceleration due to gravity (~10 m/s^2); and

h = height (in m) of the stop-bank over the natural ground surface.

The bearing capacity of the soil can be determined using a number of different techniques. One technique correlates scala penetrometer penetration rates (mm/blow) to ultimate bearing pressure (NZS 3604). A factor of safety of 3 is usually applied when calculating the safe bearing capacity of foundations (i.e. the ultimate bearing capacity >= 3 x bearing pressure).

2.3.2 Seepage forces and uplift pressures

The geotechnical information also needs to allow seepage forces and uplift pressures on the flood protection structures to be calculated. During a maximum flood the stop-banks create a water-table head differential between the flood flow in the river channel and the area behind the stop-banks. This results in potential seepage paths forming through and/or under stop-banks. This in turn may generate uplift pressures on and in areas behind the stop-banks potentially resulting in failure of the stop-banks.

The size of the seepage force on a mass of soil is determined by the difference in piezometric head on each side of the soil mass, the unit weight of water and the area perpendicular to flow. The seepage forces act in the same direction as flow (i.e. along flow lines).

When seepage occurs beneath a stop-bank in a foundation layer that is more-permeable than the stop-bank the underside of the stop-bank is subject to a force which lifts it upwards. The determination of this pressure is important in analysing the stability of the stop-bank. Summation of the uplift pressures over the bottom area of the stop-banks will give the total uplift force on the structure and this information can be used in stability analyses. The critical geotechnical information for use in calculating seepage forces and uplift pressures is the permeability of the materials forming both the stop-banks and the foundations.

Specific design of stop-banks is beyond the scope of this report and requires specialist engineering advice.

3.0 WESTPORT CASE STUDY

The West Coast Regional Council has nominated Westport for a case study to apply the methodology described above. Westport was selected because detailed flood analysis work by NIWA (Duncan, 2005) identified a number of sites for construction of stop-banks to provide flood inundation protection to Westport at the 1% AEP flood level.

The NIWA report identifies 12 sites (Figure 1) where additional stop-banks are required to protect Westport. These sites fall into three broad areas:

i. Buller River flood plain (Victoria Road)

ii. Orowaiti Estuary border (Hunters Creek and Low 1-5 sites)

iii. Parallel to the Buller River adjacent to port and road infrastructure (Domain 1 & 2, Esplanade 1 & 2 and Wharf sites)

The proposed stop-banks are all relatively low in height (0.3 -1.6 m). However, the NIWA report defines the height of the stop-banks as the height required to successfully keep the modelled 1% AEP flood out of Westport. It is common practice when constructing stop-banks to provide some free-board (usually 0.3-0.5 m). This additional height added to the stop-banks provides a safety margin which allows for settlement and other factors without compromising the level of protection the proposed schemes have been designed to provide. The individual sites are summarised in Table 1.

3.1 Published geological and soil maps

At least five geological maps and two soils maps covering all or part of the areas where the stop banks are located have been sighted (Harris and Harris, 1939; Gibbs et al, 1950; Nathan, 1976; Nathan, 1978; McPherson, 1978; Mew and Ross, 1991; Nathan et al, 2002).

The soils map of Harris and Harris (1939) describes the soils underlying the proposed Victoria Road, Domain 1 & 2 and Esplanade 1 & 2 stop-banks as Buller sandy loam, silt loam, sands &c. (sic). The soils underlying the other stop bank sites are not shown on the map. In the text Harris and Harris (1939) describe the depth of gravels "... below the surface varies from 2" (50 mm) to 36" (900 mm) or more, but in most places they are at 24' (600 mm)".

The Mew and Ross (1991) soils map of the area places all the proposed stop-banks within the same landscape type (Westport landscape) and soil unit which is a mixture of recent soils (Westport series (73%) and Harihari series (22%) with another 5% unnamed inclusions). In the text Mew and Ross (1991) describe all the proposed stop-bank sites as within the parent material province of alluvium deposited by the Buller River. The Buller alluvium is described as "largely silty or fine sandy in upper parts, overlying silts, sands and gravels". The proposed stop-banks adjacent to the Orowaiti River estuary (Hunters Creek and Low 1-5) are mapped as Buller River alluvium although this may inter-finger with Orowaiti River alluvium which is described as coal measures alluvium comprising mainly clays and silts with gravelly bands of sandstone, mudstone and coal".

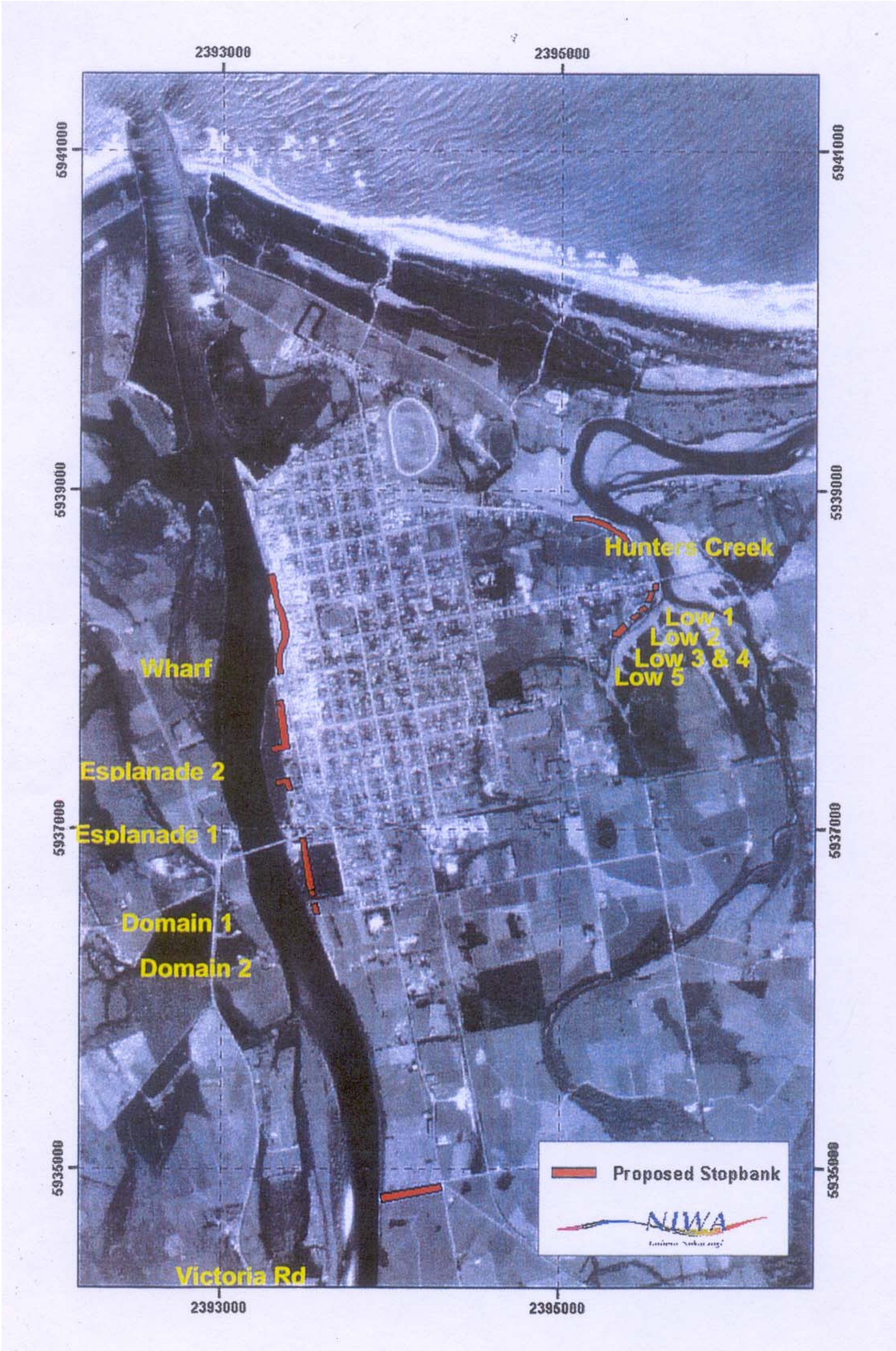

Figure 1 The locations of the twelve stop-banks needed to protect Westport from the 1% AEP flood (from Duncan, 2005). The locations of the stop-banks are shown in red. The widths of the banks have been exaggerated to make them more visible.

Table 1 Stop-bank dimensions and locations required to protect Westport from the 1% AEP flood event (after Duncan, 2005). Elevations are with respect to mean sea level Lyttelton 1937 datum.

Location	Length[1] (m) from Duncan (2005)	Height above mean sea level of top of stop-bank (m)	Height (approx) (m)	Height (m) with additional 0.5 m of freeboard
Domain 1	318	5.3-5.4	0.7	1.2
Domain 2	250	5.6	0.4	0.9
Esplanade 1	73	4.9	0.9	1.4
Esplanade 2	281	4.5	0.5-1.6	1.0 – 2.1
Wharf	584	5.2-5.5	0.4-1.0	0.9-1.5
Hunters Creek	369	2.75	<1	<1.5
Low 1	28	3.3	0.3	0.8
Low 2	63	3.5	0.3	0.8
Low 3 & 4	89	3.5	0.9	1.4
Low 5	89	3.5	0.7	1.2
Victoria Road	378	8.0	1.1	1.6

[1] Stop-bank lengths are taken directly from Duncan (2005) and have not been re-calculated to accommodate the additional 0.5 m of freeboard recommended in this report.

The geological maps of Bowen (1964), Nathan (1976), Nathan (1978) and Nathan et al (2002) show all the proposed stop-banks are underlain by the same geological unit, namely recent alluvium. However, Nathan (1976) in the text accompanying the map describes the Buller River alluvium in greater detail, in part by utilising records from foundation drilling in and around Westport. These drill-holes indicate that the recent Buller River alluvium (Westport Gravel Member of the Nine-Mile Formation) is at least 30 m thick (its base was not penetrated). Most of the alluvium is river gravel and sand, but the top 2-5 m usually consists of mud and peat (Nathan, 1976).

The geological maps of McPherson (1978) include a map of “Terrain features and surface deposits, Westport District” (Figure 10 of McPherson, 1978) that does differentiate between the geology underlying the proposed stop-banks adjacent to the Buller River and those adjacent to the Owowaiti Estuary. The proposed stop-banks adjacent to the Buller River are underlain by recent gravels while the proposed stop-banks adjacent to the Orowaiti are underlain by sediments transitional between gravel alluvium and muddy estuarine sediments.

The existing geological information indicates that the proposed stop-banks adjacent to the Buller River (Victoria Road, Domain 1 & 2, Esplanade 1 & 2, and Wharf) are deeply underlain by gravel dominated sediments deposited by the Buller River which may be overlain by silty and sandy soils between 50-900 mm thick (soil maps) or mud and peat mixture 2-5 m thick (Nathan, 1976). In comparison the proposed stop-banks adjacent to the Orowaiti Estuary are likely to be underlain by a mixture of sediment types ranging from peat through to estuarine derived silts and alluvial gravels. This would indicate that the banks adjacent to the

Orowaiti are likely to have a lower bearing capacity than the banks adjacent to the Buller River at depth.

3.2 Underlying geology

Existing geological data has been collected for a variety of purposes in the Westport area. This includes:

1. Geological and geotechnical data collected by MWH (Andrews and Davis, 2006) for the Westport and Orowaiti Sewerage Projects including bore-hole, test-pit and laboratory data;
2. Scala penetrometer data collected by the Buller District Council to determine foundations depths for house sites adjacent to the Orowaiti Estuary (Buller District Council Files – summarised in Appendix 1); and
3. Drill-hole data for investigations for port works.

Additional geotechnical data was collected specifically for this study for the Victoria Road site as no existing data was available. This involved 11 scala penetrometer tests along the proposed alignment of the stop-banks (Appendix 1).

The geotechnical data for each of the proposed sites for stop-banks is summarised below and in Table 2.

3.2.1 Victoria Road

The site of the proposed Victoria Road stop-banks is located between the intersection of Victoria Road and Nine Mile Roads and the Buller River approximately 2 km south of the Buller Bridge on the true right bank. The proposed Victoria Road stop-bank is perpendicular to the alignment of the Buller River and has a length of 378 metres and an approximate height of 1.6 m (this includes 0.5 m freeboard). No existing geotechnical information was available for the Victoria Road site so eleven scala penetrometer tests were carried out along the alignment specifically for this study (Appendix 1).

The scala penetrometer test results show 0.7 m to >1.5 m of soft mud (silts and clays) with occasional lenses of sands and gravels. Although gravels were probably only encountered at test site 2 (Appendix 1) the stratigraphy at this site is probably consistent with that elsewhere along the Buller River (see below) with 1-2 metres soft silt and sandy silt, and very loose sand overlying dense to very dense gravel.

3.2.2 Domain 1 and 2

The Domain 1 and 2 sites are adjacent to the Buller River immediately south of the Buller Bridge on the true right bank (eastern side of the Buller River). The proposed Domain 1 and Domain 2 stop-banks have a combined length of 568 metres and an approximate height of 0.9-1.2 m (this includes 0.5 m freeboard). Existing geotechnical information sighted for this study is limited to BH6 data from Andrews and Davis (2006). BH6 is located at the northern end of the two proposed stop-banks.

The log of BH6 shows 2.4 m of very loose silty sand overlying 1.8 m sandy gravel and 1.5 m gravel/cobbles that are dense to very dense. This stratigraphy is broadly similar to other boreholes (BH7; BH9; BH11; BH13; BH14; BH15; & BH16) located to the north of BH6 and to the scala penetrometer results for the Victoria Road site (see 3.2.1 above). On this basis the foundation conditions for the stop-bank at this location are assessed as 1-3 m of soft mud and very loose silty sand overlying dense to very dense gravel.

3.2.3 Esplanade 1 and 2

The Esplanade 1 and 2 sites are adjacent to the Buller River to the north of the Buller Bridge and on the true right bank. The proposed Esplanade 1 and 2 stop-banks have a combined length of 354 metres (73 m and 281 m respectively) and an approximate height range of 1.4-2.1 m (this includes 0.5 m freeboard). Existing geotechnical information sighted for this study comprises TP4 (~100 m to the south of Esplanade 1), BH9 (~100 m to the north of Esplanade 1 ~100 m to the south of Esplanade 2) and TP5 and BH11 near the northern end of Esplanade 2. All the geotechnical data is from Andrews and Davis (2006).

The geological data near Esplanade 1 (TP4 and BH9) show 0.1-0.6 m topsoil (0.1 m firm organic clayey silt in TP4 and 0.6 m soft silty clay in BH9) overlying 0.4-0.7 m of very loose to dense, silty sand or sand. In TP4 these fine-grained materials are 0.5 m thick and overlie >1.5 m of dense gravelly sand. In BH9 the fine-grained materials are 1.3 m thick and overlie >4.8 m of dense to very dense sandy gravels or gravelly sands.

The geotechnical data near Esplanade 2 (TP4, TP5 and BH11) varies with TP4 at the southern end showing 0.1 m firm organic clayey silt (mud) overlying 0.4 of dense to hard silty sand. These fine-grained materials are 0.5 m thick and overlie >1.5 m of dense gravelly sand in TP4. At the northern end of Esplanade 2 the logs of TP5 and BH11 show 0.2 m fill (TP5) or 0.5 m sandy silt (BH11) overlain by 2.3-2.7 m of very loose to firm sand and silty sand. Both logs show medium dense to dense sandy gravels below depths of 2.8-2.9 m.

3.2.4 Wharf

The Wharf site is adjacent to the Buller River to the north of the Esplanade 2 stop-bank site on the true right bank of the Buller River. The proposed Wharf stop-bank has a length of 584 metres and an approximate height range of 0.9-1.5 m (this includes 0.5 m freeboard). The geological data from Andrews and Davis (2006) sighted for this study comprises TP6 (near the middle of the proposed stop-bank), TP7 (at the northern end of the proposed stop-bank) and four boreholes (BH12-15) spaced evenly along the length of the stop-bank. In addition a driller's log (Alton Drilling) for an investigation borehole for the Crane Wharf development drilled in 1995 was supplied by the Buller Port Company. However, this borehole log is of limited value as the log starts 8.0 m below deck level. Assuming deck level is at or close to the ground level for calculating the stop-bank heights this indicates the materials described in this log are at least 8.0 m below the ground surface and located to the west of the proposed stop-bank location and in the river bed itself.

The geological data near the proposed Wharf stop-bank 1 (TP6-7 and BH12-15) all show varying amounts of fill ranging from 0.3 m (TP6) to 2.5 m (BH15) but mostly in the range 0.8-0.9 m (TP7, BH12-14). Below the fill the logs show soft to firm or very loose fine grained materials (sandy silt, silty sand, silt, sand and gravelly sand) to depths of 2-3 metres. Below the fine-grained materials, dense to very dense coarse-grained materials were shown on the logs to depths of 6.0-8.5 m.

3.2.5 Hunters Creek

The Hunters Creek site is adjacent to the Orowaiti River estuary north of the SH67 bridge over the Orowaiti Lagoon. The proposed Hunters Creek stop-bank is 369 m long with a maximum height of 1.5 m (this includes 0.5 m of freeboard). Existing geotechnical information for this site comprises data from Andrews and Davis (2006) with a test pit (TP9) located ~200 m from the western end of the stop-bank and a borehole (BH18) located ~200 metres from the southern end of the proposed stop-bank.

The geological data near the western end of the proposed Hunters Creek stop-bank (TP9) shows 1.1 m of loose to medium dense fill overlying at least 1.4 m of medium dense sand. Near the southern end of the proposed stop-bank the log of BH18 shows 1.4 m of soft sandy clay/silt, silt and loose silty gravel. Below this is at least 5.0 m of dense gravelly sand.

3.2.6 Low 1, 2, 3, 4 and 5

The proposed Low 1, 2, 3, 4 and 5 stop-bank sites are all located to the south of the SH67 bridge over the Orowaiti Lagoon on the true left bank of the Orowaiti River. The proposed Low 1 stop-bank is 28 m long and has an approximate height of 0.8 m (this includes 0.5 m of freeboard). The proposed Low 2 stop-bank is 63 m long and again has an approximate height of 0.8 m (this includes 0.5 m of freeboard). The proposed Low 3 and 4 stop-banks have a combined length of 89 m and an approximate height of 1.4 m (this includes 0.5 m of freeboard). The proposed Low 5 stop-bank is 89 m long and has an approximate height of 1.2 m (this includes 0.5 m of freeboard). Existing information for this site comprises data from Andrews and Davis (2006) and two sets of scala penetrometer test results for house sites held in Buller District Council files. Data from Andrews and Davis (2006) includes a test pit (TP12) located ~400 m from the western end of the stop-banks and a borehole (BH18) located ~100 metres from the northern end of the proposed stop-banks.

The geological data near the western end of the proposed Low stop-banks (TP12) shows 0.6 m of dense silty sand overlying at least 2.1 m of dense sandy silt. Near the northern end of the proposed stop-banks the log of BH18 shows 1.4 m of soft sandy clay/silt, silt and loose silty gravel overlying at least 5.0 m of dense gravelly sand. The scala penetrometer test results for the two house sites (Appendix 1) show up to 1.5 m of loose to very loose sands or very soft to stiff silts and clays.

3.3 Geotechnical Parameters

3.3.1 Bearing pressure / Bearing Capacity

The extra load (or the required bearing capacity) added to the foundation soils can be calculated using the formulas described previously in Section 2.3.1. Using this method the required bearing capacity for each of the proposed stop-banks has been calculated and the results are given in Table 2.

The scala penetrometer test results have been used with the ultimate bearing pressure values (Table 2) taken from a chart correlating the penetration rate of a scala penetrometer with ultimate bearing pressure. (The ultimate bearing pressure is calculated for stop-bank foundation materials 1.0 m below current ground surface.) At sites where scala penetrometer tests were not carried out the ultimate bearing capacity values used are considered conservative (c.f. scala penetrometer results) and correspond to those in Andrews and Davis (2006) who gave an ultimate bearing capacity of 100 kPa for very loose to loose silty sands or soft silts.

Most texts recommend using a factor of safety (FOS) of 3 when comparing the required bearing capacity with the ultimate bearing capacity. The only site that potentially has problems with insufficient bearing capacity when the FOS = 3 is the Esplanade 2 stop-bank (i.e. required bearing capacity is 42 kPa and a conservative ultimate bearing capacity is 100 kPa). If the materials in the foundations are compacted (as they all should be) prior to stop-bank construction then sufficient bearing capacity should be achieved to provide a factor of safety of at least 3 between the required bearing capacity and the ultimate bearing capacity (i.e. the compaction process should improve the ultimate bearing capacity of the foundations).

For Westport the 1% AEP flood occurs when a peak river discharge coincides with high tide. In this case with a tidal range of approximately 2 m, the peak flood level is relatively short lasting only a few hours during high tide. This short duration flood peak combined with the low height of the stop-banks (maximum height 1.6 m in Table 1) means that with a short term low-differential head across the stop-banks, significant seepage and uplift pressures are unlikely to develop in the low permeability clays and silts beneath the stop-banks at Westport.

3.3.2 Seepage forces and uplift pressures

The key information required for understanding the effects of seepage forces and uplift pressures on the performance of stop-banks is knowing the permeability of the flood protection structures (if relevant) as well as the permeability of the foundation materials. In Andrews and Davis (2006) it is stated that a number of *in situ* permeability tests were carried out in selected boreholes. However, they note that the permeability values determined from the *in situ* testing were about two orders of magnitude lower than what would be considered typical for material found on site. Andrews and Davis (2006) used empirical correlations of permeability with grain-size distribution test results to indicate that the sand / gravelly sand / sandy gravel deposits have permeabilities ranging from 5.6 x 10^{-3} to 1.4 m/s and noted that this range was in agreement with the typical permeability values for these materials.

It is expected that the permeability of well compacted materials used to construct stop-banks will be less than this and in the range 10^{-5} to 10^{-4} m/s.

Table 2 Stop-bank dimensions and locations required to protect Westport from the 1% AEP flood event (after Duncan, 2005). Elevations are with respect to mean sea level Lyttelton 1937 datum. The available bearing capacity has been estimated using soil descriptions and visual observations at the sites of the proposed stop-banks. The required bearing capacity has been calculated taking into account the height of the stop-bank and an engineered fill density of 2,000 kg/m^3.

Location	Height (m)[1]	Probable subsurface geology after foundation excavation	Assessed ultimate bearing capacity (kPa)[2]	Required bearing capacity (kPa)[1]
Domain 1	1.2	0.0-2.0 m soft silts and very loose silty sand 0.0-6.0+ m dense to very dense gravel	100	24
Domain 2	0.9		100	18
Esplanade 1	1.4	0.0-0.3 m very loose silty sand or sand 0.0-6.0+ m dense to very dense sandy gravels and gravely sand	100	28
Esplanade 2	1.0 – 2.1	0.0-1.9 m very loose to firm sand and silty sand 0.0-6.3+ m medium dense to dense sandy gravel and gravelly sand	100	20 – 42
Wharf	0.9-1.5	0.0-1.5 m loose gravelly sand (FILL) 0.0-2.3 m soft to firm silt and sandy silt and very loose silty sand, sand and gravelly sand 0.0-6.5+ m dense to very dense gravelly sand and sandy gravel	100	18 -30
Hunters Creek	<1.5	0.0-0.4 m soft sandy silt, silt and loose silty gravel 0.1-4.6+ m medium dense sand and dense gravelly sand	100	30
Low 1	0.8	0.0-0.5 m soft sandy silt, silt and loose silty gravel 0.0-5.4+ m dense sandy silt and dense gravelly sand	250	16
Low 2	0.8		250	16
Low 3 & 4	1.4		250	28
Low 5	1.2		250	24
Victoria Road	1.6	0.0-2.0 m soft silt and sandy silt and very loose silty sand and sand 0.0-3.0+ m dense to very dense gravelly sand and sandy gravel	200	32

[1] Values are stop-bank heights with an additional 0.5 of freeboard added to height and calculated bearing capacity with additional height used in the calculations.

[2] The ultimate bearing pressure values of natural ground are taken from chart correlating penetration rate of scala penetrometer with ultimate bearing pressure and calculated for stop-bank foundation materials 1.0 m below current ground surface.

3.4 Design and Construction Recommendations

Our recommendation for the proposed stop-banks in the Westport area is for a basic stop-bank design comprising a foundation excavation 1.0 m deep by 8.0 m wide excavated in the soft or very loose layer found throughout Westport. The 1.0 m deep excavation is required to ensure that all top-soil and the weakest subsurface materials are removed prior to construction of the embankment. Once the excavation has been completed a vibrating roller should be used to compact the remaining soft silts or very loose sands below this foundation level. This will reduce both the potential for post-construction settlement, and the permeability of these materials while increasing the ultimate bearing capacity of the layer.

The stop-bank can then be constructed using the excavated material mixed with imported gravel - preferably a low permeability gravel (e.g. similar properties to road sub-base) - and compacted into the foundation to build a stop-bank foundation 8 m wide by the required height. If the required height is 1.0 m these dimensions will produce a stop-bank with a 2.0 wide top and 1V:3H side slopes. If the height required is greater than 1.0 m then the toes of the stop-bank can be extended further provided the topsoil is stripped off on either side of the foundation trench to the required width (a maximum of 14 m for the Esplanade 2 stop-bank).

The proposed Wharf stop-bank is located in an area that has developed infrastructure already in place and there are space (and infrastructure – e.g. railway lines) constraints on building a stop-bank of similar dimensions to that suggested for the other sites. If space constraints are not critical then the recommended stop-bank design can be used.

If space constraints are important then alternative designs for flood protection will need to be developed. One possibility is for a mix of stop-bank types including earth embankment where space allows, cut-off walls and sealable gates (where railway lines are required to cross the stop-bank). Any sheet-piling used to build a stop-bank may need to be founded in the dense to very dense sandy gravels (at least 3m deep). Using sheet-piles or reinforced earth embankments to construct narrow stop-banks would greatly reduce the space requirements to ~1.0 m wide.

The proposed “Low” stop-banks are close to a bank defining the edge of the Orowaiti Lagoon and the bank may need additional protection from erosion during flood events to help protect the stop-banks. Rip-rap placed along this bank may help. Again space constraints may be an issue at this site and alternative stop-bank designs may need to be considered. This is not such an issue for Low 1 & 2 as their height is small (0.8 m) and the foundation widths can be reduced accordingly (vehicular access may not be needed for these stop-banks either which means the total width of the foundation excavations may be able to be reduced to 5.0 m or less and provide a 1.0 m wide walking track along the top of the stop-bank.

The dimensions recommended in this section are minimum dimensions and final engineering design will depend on things such as the need for continued access for machinery (e.g. excavators and trucks) along the stop-banks for maintenance and repair requirements.

4.0 SUMMARY AND CONCLUSIONS

The West Coast Regional Council has asked GNS Science to provide advice on identifying geotechnical conditions likely to be encountered in areas where river flood protection schemes are proposed. The objective of this work is to develop a methodology for assessing the *in situ* foundation strengths that will be encountered at the sites of proposed stop-banks. The methodology involves using existing information to build a picture of the geological and geotechnical setting of the sites of any proposed stop-banks. This includes published geological and soil maps as well as information that may be held on local authority files (e.g. geotechnical reports for infrastructure development) or in files held by other bodies (e.g. foundation investigation records for wharf infrastructure). Once the desk study phase has been completed the methodology calls for an investigation program to be designed and undertaken to obtain additional geotechnical information in areas where no geotechnical information is available.

The foundation conditions for 12 new stop-banks that will provide flood protection to Westport from the 1% AEP flood have been investigated using this methodology. The investigations have included a review of published geological and soils mapping, review of sub-surface data including drill-holes, test pits, standard penetrometer test and scala penetrometer test results held by the Buller District Council. In addition geotechnical investigations were carried out at the proposed Victoria Road stop-bank because there was no existing geotechnical information for this site.

The proposed stop-banks are all of relatively low height (0.3 -1.6 m). However, in the NIWA report (Duncan, 2005) the height of the stop-banks is simply defined as the height required to successfully keep the modelled 1% AEP flood out of Westport. It is common practice when constructing stop-banks to provide free-board of 0.3-0.5 m. Even with an additional height of 0.3 m added to the stop-banks, the bearing capacity required of the foundations does not exceed 50 kPa.

The soils underlying the proposed stop-banks are all fine-grained but can be divided into two groups, those deeply underlain by gravel dominated sediments adjacent to the Buller River and those underlain by fine grained sediments adjacent to the Orowaiti Estuary. The bearing capacity of gravel soils adjacent to the Buller River will significantly exceed the load added by the construction of the proposed stop-banks. The 2-5 m of mud overlying the river gravel in the Westport urban area (Nathan, 1978) also has sufficient bearing capacity to support the proposed stop-banks.

The bearing capacity of the fine-grained soils adjacent to the Orowaiti Estuary is lower than for the Buller River soils. Scala penetrometer test results for house foundations indicate that the bearing capacity of these soils is probably greater than 100 kPa and the required bearing capacities are 15-29 kPa. Thus the soils adjacent to the Orowaiti Estuary should have sufficient Bearing capacity to support the proposed stop-bank heights.

This study concludes that the foundation conditions are adequate to support all the stop-banks proposed to protect Westport from the 1% AEP flood.

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APPENDIX 1 SCALA PENETROMETER INVESTIGATION RESULTS

1. Between Buller River and intersection of Harney and Nine Mile Roads (undertaken by R.D. Beetham of GNS Science on 19/12/2007)

Scala Penetrometer sub-surface investigation carried out for a stopbank extending towards the Buller River from the intersection of Harney and Nine Mile Roads (see Figure 1). 11 Scala tests were carried out in hot sunshine by Dick Beetham using a Scala kit borrowed from Buller District Council (Trish Casey) on Wednesday 19 December 2007.

Probe No.	1	2	3	4	5	6	7	8	9	10	11
Location Distance from road in m	10	40	65	90	120	150	185	220	260	300	350
Probe penetration (cm)											
10											
20		1	1								
30	2	1	1						3	4	
40	2	2	1						4	4	3
50	3	3	2			2		3	2	3	2
60	2	2	1	2		3	3	3	3	2	
70	2	2	2	2	1	2	6	3		2	2
80	3	12	2	2	2	2		3	4	2	1
90	6	13	3	2	2	3		4	3	2	2
100	5		5	2	2	3			2	2	2
110				2	2	4			2		2
120				2	2						
130				2	2						
140				2	3						4
150				4							6

Notes:

Generally the probe could be pushed in by hand to start each test. Often the ground was soft mud with low blow counts. However, in some places it became sandy and gravely. In my interpretation the ground generally consists of poorly consolidated, soft, overbank silty mud flood deposits with occasional lenses of sands and gravels.

Probe No 4 was in the invert of a ~2m deep, ~40m wide channel which now acts as a drain for the surrounding area.

Summary by Dick Beetham
GNS Science, Lower Hutt

Figure 1 Site on the right bank of the Buller River arrowed.

Figure 2 Detail of the site where the Scala tests were carried out – along the red line.

2. 138a Brougham Street (Officers of the Buller District Council; 23/2/95)

Location	**138a Brougham St**			
Probe penetration (cm)	**Probe Number**			
	1	**2**	**3**	**4**
10				
20				
30				
45	3	3	4	4
60	4	13	4	4
75	9	18	13	14
90	10			

3. 29a Eastons Road (Officers of the Buller District Council; 31/3/95)

Location	**29a Eastons Road**			
Probe penetration (cm)	**Probe Number**			
	1	**2**	**3**	**4**
10				
20				
30				
45	3	3	4	2
60	3	3	4	2
75	5	3	4	3
90	4	4	6	4
105	4	4	5	5
120	5	5	5	6
135	5	5	5	5
150	10	8	8	5

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