Stopbank Design and Construction Guidelines

Bay of Plenty Regional Council
Guideline 2014/01

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NEW ZEALAND

ISSN: 1179-9595 (Print)
ISSN: 1179-9609 (Online)

BAY OF PLENTY REGIONAL COUNCIL

Document control

Document information

Document name:	Stopbank Design and Construction Guidelines
Contact person:	David Boothway – Engineering Manager
Status:	For circulation and public use

Document review

Review timeframe:	Every two years – starting 2016
Reviewers:	Engineering Manager to assign

Document history

Author	Description of change	Date	Version
Britton Consultants	Issued for review by BOPRC staff (Engineering Section and Rivers and Drainage Section)	June 2014	1
Britton Consultants	Update across document using review comments	November 2014	1.1

Distribution control

Person	Role	Date of issue	Version
David Boothway	Engineering Manager	25 November 2014	1.1

Authorised by: David Boothway .... Date: 25/11/2014

Reviewed by: Debbie Fransen............................ Date: 25/11/14

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Cover Photo: Rangitāiki Floodway stopbank reconstruction 2014, Arch Delahunty.

Foreword

Stopbanks are the main structural measure used by the Bay of Plenty Regional Council (BOPRC) to protect people and property from floodwaters. The Regional Council has built and maintains some 346 km of stopbanks which line the banks of rivers and streams on five major and minor flood protection schemes.

Over time the Regional Council has amassed a great deal of experience in the design, construction and ongoing maintenance of stopbanks. Whilst much of the operational and maintenance is summarised in Regional Council's Asset Management Plan very little Council documentation exists to describe the process of designing and building stopbanks.

The aim of this document is to provide guidance to existing and potential owners of stopbanks on how to build, own and maintain stopbanks that are reliable especially when working under design loading conditions. The document provides guidance on vital points to consider from the planning stage right through to describing flood emergency barrier options.

This guideline documents Regional Council's in-house experience and compliments it with other best practices adopted by other national and international agencies responsible for stopbanks. In particular, acknowledgment is given to the UK-based Construction, Industry Research and Information Association (CIRIA) for publishing the International Levee Handbook in 2013. The handbook outlines best current international practice on every aspect of stopbanks. The CIRIA handbook became available at the same time this Council guideline was being prepared so the content of this guideline document has benefited immensely. Acknowledgment is also made to contributors comprising Bay of Plenty Regional Council, Manawatu Horizons, Environment Waikato, Environment Canterbury, Greater Wellington and Northland Regional. Special thanks also to Peter Blackwood and Marianne O'Halloran who were peer reviewers.

Stopbanks should be the last resort when considering flood risk mitigation. Stopbanks create an ongoing financial burden as they need to be maintained, rebuilt or strengthened over time. Before considering structural measures such as stopbanks, stakeholders are encouraged to seek non-structural measures such as zoning land use areas, relocating people and assets outside of potential floodplain areas. In addition stakeholders need to be aware that better catchment management that reduces discharges to waterways, such as reforestation, may also reduce need for stopbanks. Examples of good catchment management include reducing hardstand surfaces and/or constructing offline flood mitigation ponds both of which reduce the need to discharge to the main waterway that has or is being considered for stopbank protection.

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Part 1: Introduction

1.1 Objective

The objective of this document is to provide guidance to owners of stopbanks who wish to ensure their stopbanks are and remain reliable at keeping floodwaters away from people and property.

This document is for use by anyone who owns and/or is responsible for constructing and maintaining stopbanks and their appurtenant structures. It is a guideline in that it describes general principles to be applied with reference to existing textbooks and design guidelines for detailed information. For example this guideline draws on the detailed information provided in the recent 2013 release of CIRIA's International Levee Handbook and readers are encouraged to refer to that textbook for further information.

The document covers the general fundamentals of stopbanks including planning, design, construction, maintenance and emergency works. However there will be situations where specialist input is required and readers should consult technical experts such as geotechnical engineers for assistance where appropriate. Similarly, in some situations other solutions and procedures to those presented may be more appropriate. The guideline does **not** cover the specialist areas of:

- Coastal protection works design. Council has published a separate guideline for this purpose which identifies criteria and standards for the design of coastal erosion protection works in the Tauranga Harbour (2002).
- Stormwater quality and stormwater quantity design. Council has published a separate guideline for permanent stormwater management for land development areas (2012).
- Erosion and sediment control for land disturbing activities. Council has published a separate guideline for erosion and sediment control related to earthworks operations (including quarries and in and around watercourses) (2010).
- Erosion and sediment control for forestry operations. Council has published a separate guideline for erosion and sediment control related to planning and implementation of forestry operations (2000).

Instead these stopbank guidelines add to the list of guidelines listed above and are to be used in conjunction with the Regional Councils 2012 Hydrological and Hydraulic Guidelines (HHG). The HHG outlines recommended methods for undertaking waterway design, including calculation of rainfall run-off, flow, tidal levels and erosion protection with and without climate change effects.

1.2 Challenges

These guidelines were developed primarily for the Bay of Plenty Regional Council (BOPRC) who have built and are responsible for maintaining some 346 km of stopbanks that line the banks of rivers and streams on five major and minor flood protection schemes. The document formally outlines practices Council generally follow when managing their own stopbanks. The document can also be used by others or their advisers, who intend to plan, design, build and maintain their stopbanks.

Whilst preparing this document Council has documented some of the challenges it has faced and methods of overcoming these as managers of the stopbank asset. Examples of challenges faced include:

- Selection of design standards and deciding how best to address increases in waterway flow due to oncoming climate change or other causes.
- Stopbank stability issues such as how to mitigate against ongoing settlement and potential piping failure.
- Preparing for emergencies and identifying other methods for protecting people and property against flood inundation.

1.3 About this document

The layout of this guideline follows a simple process that might typically be employed by someone who wishes to build a new stopbank. However owners of existing stopbanks who need to say, check flow capacity or carry out maintenance, may also find specific chapters useful. The process is:

Planning → Design → Construction → Maintenance → Emergency Works

Chapter 2 describes the planning considerations such as purpose, function and location of stopbanks and what geotechnical investigations and resource consents are likely to be required.

Chapter 3 outlines the various design standards applied to stopbanks, including different loading cases. It focuses on stopbank stability including review of potential failure modes and means of checking and mitigating against such scenarios arising.

Chapter 4 shifts focus to the type of construction that may be necessary to build new or upgrade existing stopbanks. It looks at contract type and conditions of contract and provides a sample specification for earth fill stopbanks.

Chapter 5 provides advice on maintenance aspects of stopbanks. It points out aspects that need to be considered as part of ongoing condition monitoring.

Chapter 6 discusses emergency preparedness and options available to Council and/or landowners to protect themselves against floodwaters that may arise from a breach of an existing stopbank or inundation of other unprotected floodplain areas.

The appendices provide greater detail on matters raised in the main body of the text.

1.4 Role of the Bay of Plenty Regional Council

The purpose of the Resource Management Act 1991 (RMA) is to promote sustainable management of natural and physical resources. Under the Act regional councils have the functions of managing the use of land, air, water and coastal resources to give effect to the purpose of the Act within their regions. The Bay of Plenty Regional Council provides a limited advisory service to applicants undertaking activities, whether these require consents or not; however for detailed calculations applicants should employ their own consultant.

Another of the Council's functions is to manage their river and drainage schemes under the Soil Conservation and Rivers Control Act 1941.Over the years, the Bay of Plenty Regional Council has gained knowledge of its stopbanks during the design, construction and maintenance of their assets. This knowledge is reflected in these guidelines and is made available for the use of other existing or potential stopbank owners to ensure a consistent approach for management of these assets.

1.5 Relationship to other Council plans and guidelines

This guideline must meet the environmental standards contained in the RMA and Regional Water and Land Plan (RWLP) (2008). These guidelines are also subject to the requirements of the Building Act, RMA and other Council guidelines, as indicated in the Figure 1.1 flow chart below.

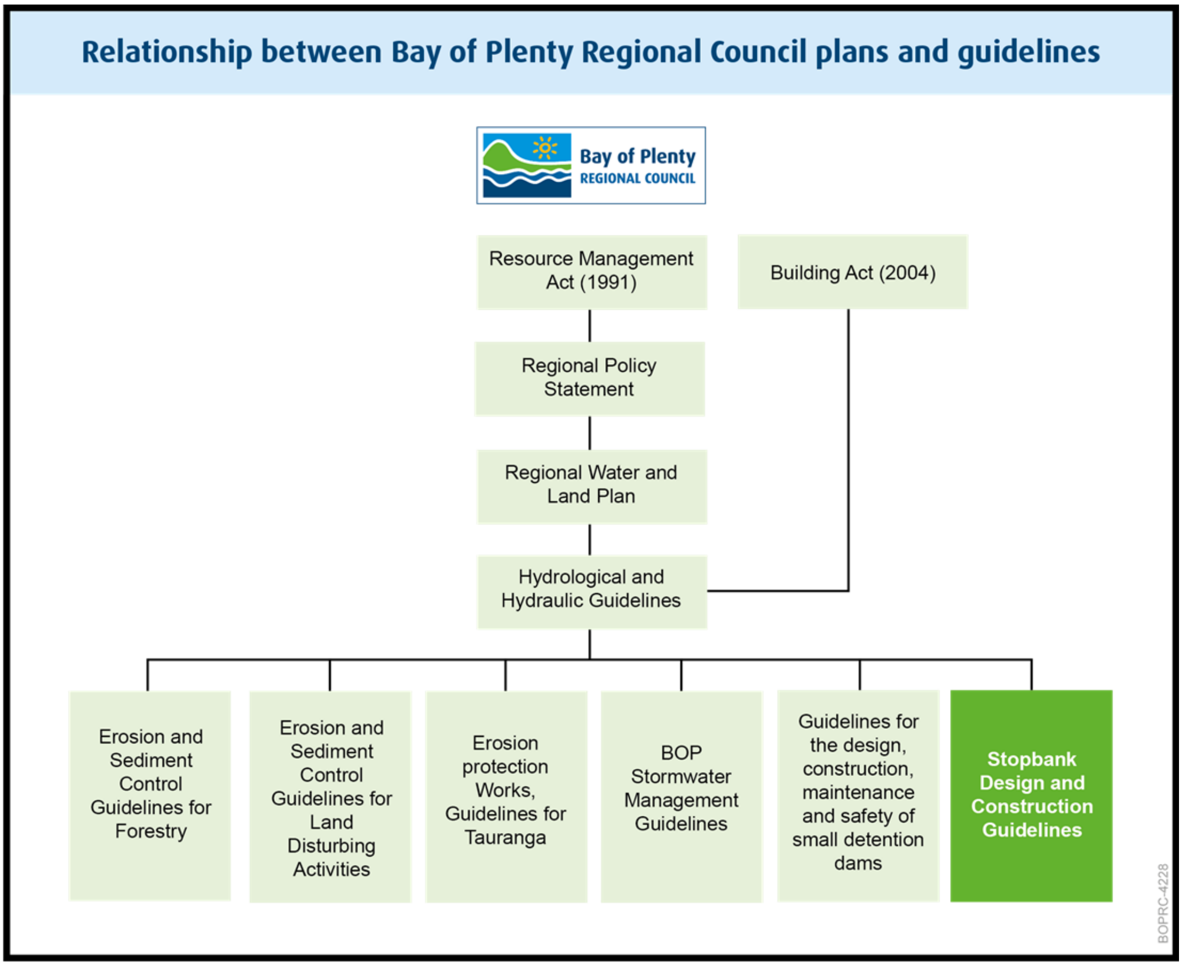


Figure 1.1 Relationship between New Zealand statutes, BOPRC policy, plans and guidelines.

Part 2: Planning

2.1 Purpose and function of stopbanks

Stopbanks are generally raised earth embankments that provide protection against flood events from rivers and artificial waterways. Floodwalls are used instead of earth embankments where there are site restrictions. Stopbanks form part of a wider flood protection scheme that may also include pump stations and drainage gates.

Stopbanks are designed to remain structurally stable and capable of controlling seepage under hydraulic loads. Stopbanks with a suitable geometry for the resistance of hydraulic loads generally can also withstand seismic loads except where there is an increase in pore water pressure or complete liquefaction in the foundation soils. The importance level of the structures and facilities being protected by the stopbank and life risk need to be considered when assessing this risk of stopbank failure. Refer s3.3.4 and Appendix B for further discussion on approach to combined flood and seismic risks.

Stopbanks comprise components that fulfil different functions. Their presence (or otherwise) depends on location constraints, design requirements, available construction materials and foundation conditions. *Thus commonly stopbanks may not require all of these features, but it is important to consider whether they are important to maintain structural integrity.* Components are shown in Figure 2.1 with brief description of function described below.

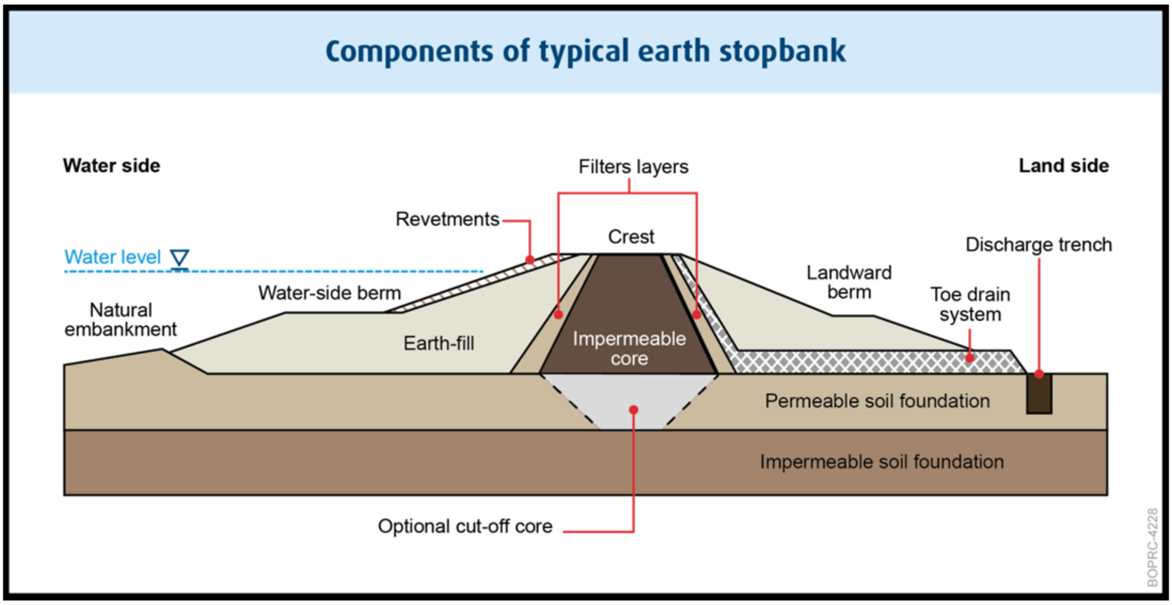


Figure 2.1 Components of typical earth stopbank (Source CIRIA, 2013).

It is understood that few (if any) zoned stopbanks belong to the Regional Council. This is due to Regional Council stopbanks being relatively low and the limited variety of soils available for construction.

Foundation soils: Foundation soils bear the weight of the stopbank. Foundation seepage must be capable of being controlled.

Earth fill: Constitutes the bulk of the stopbank. Earth fill usually comprises granular or cohesive soil (clay, silt, sand and/or gravel). Earth fill provides mass for structural stability and controls seepage through the embankment.

Core: Reduces seepage through the embankment significantly when the rest of the earth fill is unable to by itself. It is constructed of low permeability materials (clay).

Cut-off core: An optional structural feature, which reduces the risk of potential foundation piping failure due to high permeability of the foundation. Refer to more information on cut-off cores in section 3.5.2 Earth Stopbanks.

Crest: The relatively flat, top surface level of the stopbank provides access and freeboard. If the crest is paved or constructed of cohesive soil then it may also provide protection against erosion due to rainfall runoff or overtopping.

Revetment: Also known as armouring. On waterside – provides protection against external erosion due to wave action, currents. On landside – provides protection against surface erosion due to rainfall runoff and limited protection against overtopping. Armouring would only be used on the landside where topsoil and grass or other protection measures are unsuitable.

Berms: Constructed as an extension of the stopbank on the landside and/or waterside. They help to control sub-surface seepage by lengthening the seepage path. On the waterside they reduce the wave run-up on the stopbank and provides a buffer against erosion of the stopbank should the riverbank or revetment erode. The added weight of a berm on the landward side of a stopbank can reduce the risk of heave where there are high sub-surface water pressures due to a highly permeable layer.

Filters: Prevent fines in the core migrating into the downstream shoulder causing internal erosion. This is normally achieved using a soil that is specifically selected, graded and placed for this purpose.

Drainage system: Comprises toe drains and/or a seepage discharge trench to reduce the seepage pressures in the stopbank and discharge the seepage water in a safe controlled manner.

2.2 Stopbank location

The location of stopbanks is generally determined by existing development and land use, particularly in urban areas. Future developments such as new subdivisions and infrastructure including roads, infrastructural networks and other services also affect stopbank location.

When assessing a stopbank's potential location the designers should ensure:

- The stopbank location enables adequate water way cross-sectional flow area to convey the design flood.
- Any new stopbank constructed does not have any adverse impact on other properties particularly during floods. For example a new stopbank can potentially throttle flow raising flood levels upstream and/or blocking off existing floodplain drainage routes, thus creating a new flood hazard on the landward side of the stopbank.
- The stopbank footprint area is large enough to enable construction of a wide crest width and gentle slopes thus allowing for potential future stopbank rising.

If other infrastructural assets exist in the area, such as roads, the possibility exists to incorporate those assets into the design, where appropriate.

2.3 Stopbank investigations

Geotechnical investigation is recommended after potential stopbank locations have been identified. Investigation confirms whether:

- Foundation material has low risk of internal erosion caused by seepage passing through a permeable layer and day lighting on the landward side of the stopbank.
- Foundation has low risk of excessive settlement caused by compressible layers such as peat that result in an unacceptable loss of freeboard.
- There are any potential borrow sites nearby that can be used to construct a stable stopbank.

2.4 Consent requirements

The purpose of a resource consent is to control and minimise the impacts of activities on people and the environment where activities have been identified in the regional plans as requiring management.

Landowners are advised to contact the Regional Council early in the planning process, to discuss the proposed activity and seek advice on consent requirements and the consent process. In some instances the water course may actually be managed by the Regional Council who already has resource consents for the stopbanks and appurtenances. In this case adjacent landowners should contact the Council with enquiries relating to service levels, future upgrade works or maintenance issues.

There are four types of resource consents that the Bay of Plenty Regional Council can issue:

1. Land use consents.
2. Discharge consents.
3. Water consents.
4. Coastal consents.

Landowners, who wish to build new, modify or remove existing stopbanks and appurtenant structures must apply to the Regional Council for resource consents before construction commences.

2.4.1 Land use consents

Different land uses can have environmental effects such as decreased water quality or sedimentation. Landowners may need a land use consent for any combination of the following activities:

- Build or alter a bridge.
- Construct or alter a well or bore.
- Construct or alter a culvert.
- Disturb or alter a wetland area.
- Disturb the bed of a river or lake (such as excavate, drill, erect a structure).
- Carry out earthworks, roading or tracking.
- Erect an erosion control structure in a watercourse.
- Construct or alter a ford across a waterway.

- Carry out mining or quarrying activities.
- Reclaim or dredge the bed of a watercourse.
- Remove sand or gravel from the bed of a watercourse.
- Carry out soil cultivation.
- Construct or alter a stopbank.
- Plant or clear vegetation.
- Carry out a nutrient discharging activity e.g. increase stocking rates within the Rotorua Lakes Catchment area.
- Disturb contaminated or potentially contaminated land.
- Disturb or alter a geothermal surface feature in the Rotorua area.

2.4.2 Discharge consents

Discharge consents cover activities which discharge to water, land or air. Landowners may need a discharge consent if their activity discharges:

- Water into water (this includes clean or contaminated water).
- Contaminated water onto, or into land.
- Effluent or waste products into water, or onto or into land.
- Landfill or clean fill leachate.
- Water and/or contaminants into water, or onto or into land, in association with a geothermal take.
- Dust, steam, smoke or other contaminants into the air and/or those that create offensive odour.

2.4.3 Water consents

Landowners may need a water consent if they want to divert a water course, construct a dam or stopbank, or take or use:

- Water from a river, stream, dam, lake, spring or the coast (surface water).
- Water from an underground source (groundwater).
- Geothermal water, heat or energy.

2.4.4 Coastal consents

Coastal consents relate to resources in the coastal marine area (CMA). This is a defined area of foreshore, seabed, coastal water, and air space above the sea from the line of mean high water springs out to the territorial limit (12 nautical miles). The mean high water springs line is the average line of the spring high tides. The CMA can extend further inland if the mean high water springs line crosses a river. For a full definition of the CMA, refer to the Regional Council's Regional Coastal Environment Plan.

The Regional Council owns and maintains stopbanks and appurtenant structures within the CMA and has consents for ongoing management of these assets.

Landowners (including the Regional Council) may need a coastal consent if they wish to construct stopbanks, appurtenant structures and/or carry out other activities. Activities include (but are not limited to) installing/modifying culverts, bridges, jetties, erosion protection, marinas etc. Landowners should contact the Regional Council if they are in any doubt as to whether a coastal consent is required within the CMA.

2.5 Compliance with Floodway and Drainage Bylaw

Bylaws are necessary for the security and efficient operation of Regional Council Flood Protection and Drainage Schemes.

The Bay of Plenty Regional Council Floodway and Drainage Bylaw 2008 was published to advise stakeholders what they can and cannot do when working near or on existing Council flood scheme assets including stopbanks. In effect the bylaw aims to protect the scheme assets that have been constructed to prevent damage, danger and distress to the community from river flooding and problems associated with a lack of drainage. It is crucial that these assets are functioning properly when needed and that stakeholders comply with requirements written therein.

For more information on stopbank penetrations including pipe thrusting, overhead lines and fences refer to section 3.12 Penetrations.

Part 3: Design

3.1 The design process

Regardless of the extent or nature of the works, the typical design process for stopbanks will be the same. The three broad phases are:

1. Identify the need (reconnaissance); the site and its environment are characterised and hydraulic conditions established.
2. Conceptual design stage (feasibility study): Evaluate options based on simple calculations, judgement and experience.
   (a) For new stopbanks consider:
      - Range of potential alignments.
      - Use of appurtenant structures at strategic locations e.g. spillways.
      - Range of potential cross-section shapes.

   (b) For existing stopbanks consider:
      - Local raising or repairing stopbank for short length to restore service levels.
      - Local widening of stopbanks which are too narrow (and may have short seepage paths to the landward side face) and/or reducing batter slopes that are too steep.
      - General stopbank raising or strengthening, to address perceived increase of flood risk.
      - Repairs following damage and/or breach which occurred during flood event.

   Study outcomes will be captured in Resource Consent application(s).
3. Detailed design stage including:
   (a) Finalising design criteria, site investigations, soils testing and modelling to establish hydraulic conditions for design.
   (b) Use of judgement, calculations and engineering experience to finalise design.
   (c) Production of drawings and specifications to allow works to be constructed.

Two further stages complete the stopbank project namely:

4. Construction stage: where works are carried out in compliance with drawings and specifications.
5. Operations and maintenance: Designers prepare the document and pass this on to the stopbank owner.

A flow chart showing the stopbank design and construction stages are presented as Figure 3.1.

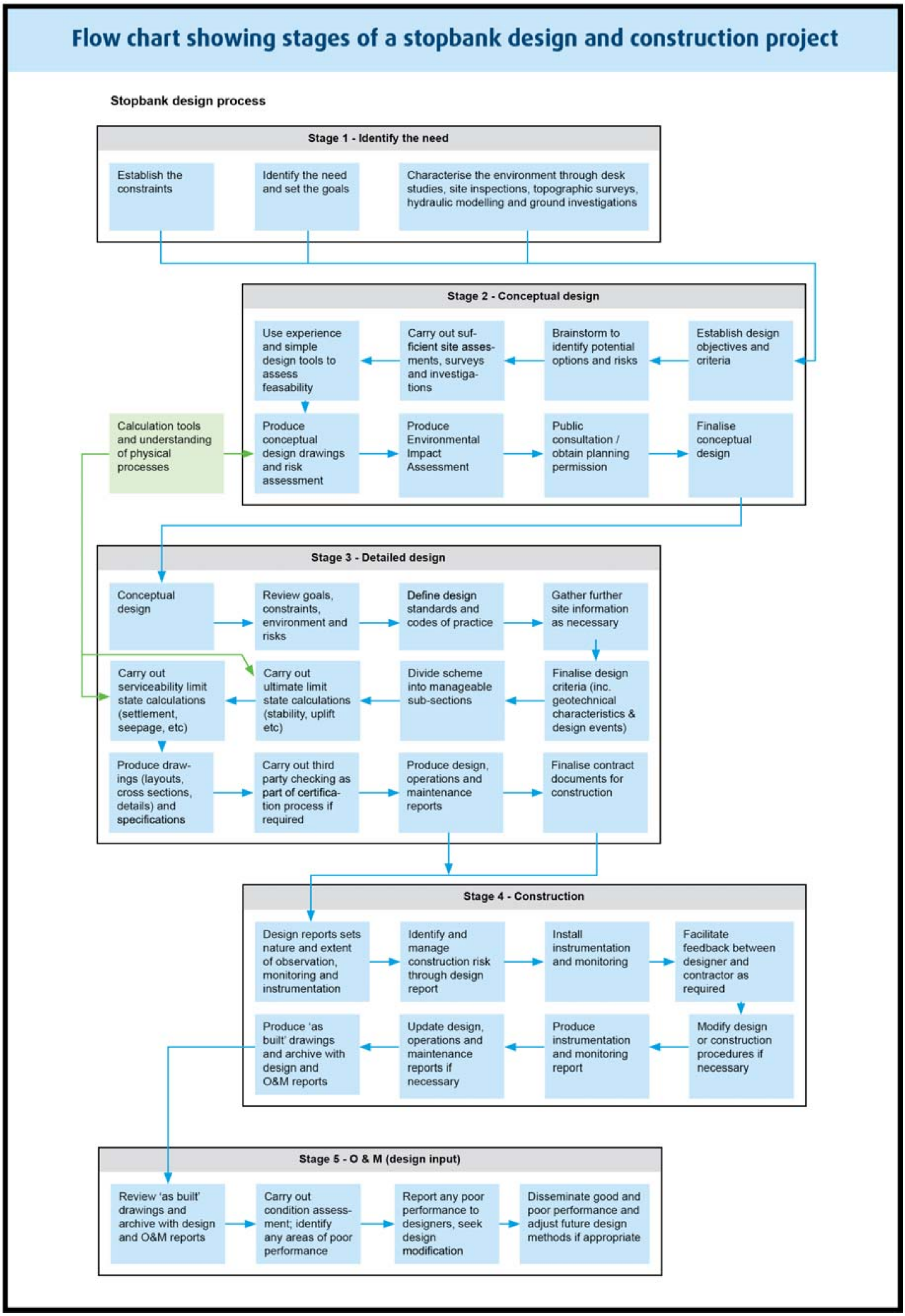


Figure 3.1 Flow chart showing stages of a Stopbank Design and Construction Project (CIRIA, 2013).

3.2 Design levels

3.2.1 Design standards

The Regional Council's Rivers and Drainage Asset Management Plan (2012) strategic aim is to '*provide flood protection in River and Drainage Scheme areas to agreed design levels*'. Design levels vary from one geographical area to another however fundamental aspects include:

- Level of service. What area is to be protected by the stopbanks; will they be protecting urban or rural area and assets?
- Cost of achieving level of service. Ultimately the cost of stopbank construction and ongoing maintenance will be borne by the landowner so type, quality and location of stopbank needs to be thought through carefully before committing to protection of assets located on landward side of the proposed stopbank.
- Effects of climate change. Are predicted changes to frequency and intensity of floods and sea level included in the proposed level of service?
- Topographical changes. Is actual and forecast land settlement being taken into account? For example floodplains often comprise compressible organic material such as peat and are known to settle significantly. Tectonic forces may also be causing floodplains to rise or fall. Changes expected in local topography need to be considered in stopbank design and construction.
- Geomorphological aspects. Has the watercourse alignment and cross-section changed over time and will it continue to do so in the future potentially impacting the integrity of the proposed stopbank? Gravel and sediment transfer can cause aggradation and degradation of the bed which can lead to changes in alignment and reduction in freeboard.

The design levels for stopbanks are higher in urban areas than in rural areas. The higher standard reflects the need to protect a larger population from flood inundation.

Stopbank design standards are listed in Council's Rivers and Drainage Asset Management Plan for each river scheme it owns and maintains. The stopbank design standard in scheme managed urban areas is based on providing protection against a 1% AEP (100-year) flood. Protection for rural areas tends to vary but generally the level of protection provided ranges between 5% AEP (20-year) to 50% AEP (2-year) flood.

The height of the stopbank, whether concrete wall or earth embankment should be constructed to the required design level, with an additional height allowance to provide freeboard. Where a level of protection less than 1% AEP (inclusive of climate change) is chosen, careful consideration should be given to the setting of minimum subdivision platform and/or building floor levels in areas subject to flooding.

Owners of existing or proposed stopbanks should consult the Regional Council as to what the recommended design standard is at the particular site of interest.

3.2.2 Freeboard

Freeboard is an additional height allowance used in the design of stopbanks to cover variables inherent in that design. Freeboard is the standard engineering provision for estimate imprecision/uncertainty (even the most sophisticated design techniques are unlikely to exactly predict complex hydraulic scenarios) plus phenomenon not explicitly included in the hydraulic calculations e.g. geotechnical settlement such as consolidation effects, waves, aggradations, bend effects, debris blockage and passage.

Freeboard allowances in the Bay of Plenty vary from location to location. In urban areas the Regional Council generally nominate freeboard in its Asset Management Plan ranging between 500 mm and 800 mm whereas in rural areas it ranges between zero and 450 mm. Through urban areas a differential freeboard is frequently applied by the Regional Council, with lower freeboard specified for areas on the opposite bank to that of protected areas. This is to provide for 'overdesign' floods.

Landowners should consult Regional Council before confirming their proposed stopbank freeboard requirements. A minimum of 500 mm and 300 mm freeboard is recommended for new stopbanks that are to be designed to protect urban and rural areas respectively. These minimum provisions are provided to give a good degree of certainty for normal situations. However they should be reviewed against any site specific design factors to see whether they warrant altering. For example, in steeper, high energy streams a higher freeboard provision may well be wise – to provide for both waves and inherent decreases in the accuracy of modelling these turbulent reaches.

3.3 Other loads

3.3.1 Intermittent flood loading

Stopbanks are normally designed and constructed to retain intermittent water loading up to the design flood level. Design for intermittent loading is less than frequent loading.

3.3.2 Frequent flood loading

The United States Army Corps of Engineers (USACE, 2000) guidance, is that a frequently loaded stopbank is defined as one that experiences a water surface elevation of 300 mm or higher above the elevation of the toe on the landward side of the stopbank at least once a day for more than 36 days per year on average. Refer Figure 3.2.

Stopbanks may be frequently loaded due to natural or man-made causes. Natural causes may include increases in water flow due to climate change effects and tidal changes.

Man-made causes may result from changes in catchment rainfall-runoff characteristics. For example changing discharge patterns of hydraulic structures such as an upstream hydropower station that opts to change from single to multi-peaking generation.

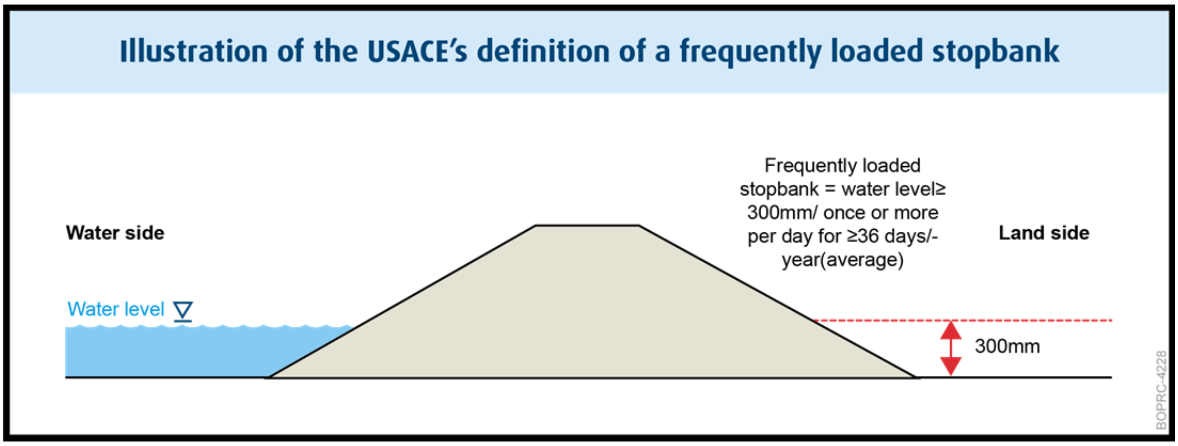


Figure 3.2 Illustration of the USACE's definition of a frequently loaded stopbank.

Frequently loaded stopbanks should include seepage control features, like those commonly included in earth dams of similar height (e.g. with impervious cores), if the stopbank geometry allows seepage to exit the landward side shoulder of the stopbank or if the consequences of failure are more serious than average, for example if the stopbank protects an urban area.

3.3.3 Prolonged water loading

Prolonged water loading can be more demanding on a stopbank than frequent loading.

The USACE (2000) also offers the following additional guidance when designing stopbanks subject to prolonged periods of hydraulic loading on the water side of stopbanks:

> *Embankments that are subject to water loading for prolonged periods (longer than normal flood protection requirements) or permanently should be designed in accordance with earth dam criteria rather than the stopbank criteria.*

Regional Council stopbanks exposed to prolonged water loading include those located close to coastal reaches where water levels are elevated longer due to tidal range and protected ground is below sea level e.g. stopbanks in lower reach of Reid's Canal near the river mouth outlets.

3.3.4 Impacts of water loading on stopbank design

It is important that designers of stopbanks assess stability for all relevant water load cases for all stopbanks and a comprehensive checklist is provided in Table A1.1 of Appendix A.

Some observations of stopbank behaviour under various flow regimes have shown that it is not necessarily large floods that cause damage to stopbanks. Drawdown failure of waterside slopes along stopbanks can occur under any flow regime with size of the failure dependent on the height and duration of flood peak. Table 3.1 outlines some examples of how intermittent, frequent and prolonged water loading can affect stopbank design.

Table 3.1 Impacts of water loading on stopbank design.

Water load case	Definition	Effects on stopbank design
Intermittent	Waterside slope subjected to water loading occasionally.	Few known adverse effects.
Frequent	Water loading on waterside slope ≥300 mm above landward toe level/ once or more per day for ≥36 days/year (average).	Frequent loading is often the worst case for small drawdown failures appearing as erosion within the range of frequent water level changes. Impact on design may be the requirement to reduce waterside slope and/or increase erosion protection.
Prolonged	Waterside slope subject to water loading longer than normal or permanently.	Prolonged loading can lead to greater seepage through a stopbank and potential instability of the stopbank's landward slope. If the stopbank is constructed primarily of granular sandy material then saturation and potential instability of the stopbank can occur within 12 hours. Impact on design may be the requirement to design embankment as a dam capable of remaining stable under steady state seepage conditions including provision of filter and drainage zones.

3.3.5 **Seismic loading**

The horizontal ground accelerations resulting from earthquakes can cause slope failures in a stopbank. The cyclic nature of earthquake accelerations can also cause significant loss of strength of the soil within and beneath the stopbank, resulting in deformation and settlement. Alluvial foundation soils may suffer complete loss of strength due to liquefaction, leading to collapse of the stopbank and/or lateral spreading of the stopbank and river bank towards the river. Refer Figure 3.3.

Figure 3.3 Stopbanks along Rangitāiki Plains showing lateral spreading damage to waterside shoulder resulting from 1987 Edgecumbe earthquake.

The consequences of stopbank failure should be assessed so that the importance level of the stopbank can be determined in terms of NZS 1170 Part 0:2002 Structural Design Actions, General Principles. It is considered that most stopbanks protecting farmland or urban housing would be of Importance Level 2. If the stopbank is protecting a hospital, school or major electrical substation, a higher importance level could be assigned. The seismic action considered in the stopbank design should be obtained from NZS 1170 Part 5:2004 Earthquake Actions – New Zealand or a site specific hazard analysis.

Stopbanks considered to be Importance Level 2 structures should be designed so that there is no damage in the serviceability level earthquake, a 1-in-25 year event. If analysis of the stopbank stability, including the liquefaction potential of the foundations, shows that there could be considerable damage to the stopbank in the ultimate design level earthquake, a 1-in-500 year event, a sensitivity analysis should be carried out to estimate the return period earthquake at which failure is initiated. In most areas of New Zealand significant strength loss in the foundation soils is not likely to occur in earthquakes with return periods less than 100 years.

A risk assessment should then be carried out on new and existing stopbanks to consider the risk of an earthquake big enough to cause stopbank failure occurring at the same time as the stopbank is holding back water. An example of a seismic risk assessment carried out on a stopbank is provided in Appendix B. Several stability analyses may be required with different combinations of earthquake and hydraulic loading. Load combinations may comprise:

- Stopbank subject to ultimate level earthquake loading only i.e. no water against upstream shoulder.
- Stopbank subject to average annual flood level plus serviceability level earthquake loading.

- Stopbank subject to design flood level, D plus serviceability level earthquake loading.

As most stopbanks are built to protect alluvial plains from flooding they are very prone to damage due to the liquefaction of the alluvial soils in their foundations in major earthquakes and lateral spreading towards the river. An assessment of the risk of liquefaction should be carried out as part of the seismic risk analysis discussed above. An example of a liquefaction assessment is provided in Appendix B.

Strengthening of existing stopbank foundations to prevent liquefaction damage is very expensive and as the risk of liquefaction leading to flooding is typically low it is not often carried out. If the predicted damage is mainly due to lateral spreading it may be possible to move the stopbank further away from the river to an area of acceptable damage. An alternative approach for owners is to make provision for rapid inspection and repair following an earthquake. This provision should include identifying the type, amount and location of any labour, plant and materials required to make repairs at short notice.

Further discussion and detail regarding stopbank stability and seismic analysis is provided in section 3.7 and Appendix B respectively.

3.4 Site restraints

Designers of stopbanks should take account of the following issues which could affect future flood protection requirements:

- Land ownership.
- River, coastal and estuarine morphology.
- Hydrological, hydraulic and climate changes.

3.4.1 Land ownership

Ideally the stopbank owner should own sufficient land for immediate and future stopbank construction including provision for inspection and maintenance purposes. The stopbank area should include allowance for:

- Seepage/stability berms and/or drainage systems.
- Future stopbank top-ups.
- Restricting land modifications that might jeopardise stopbank stability e.g. restricting excavations on the landward side of the stopbank that might open up an uncontrolled foundation seepage path.

If landownership is not possible then the stopbank owner should seek permission from the landowner to access and use the entire footprint area including the stopbank and berms. A formal agreement for the desired footprint area through an easement is preferred.

3.4.2 River, coastal and estuarine morphology

Rivers, coastlines and estuaries can change over time, the effects of which can be both positive and negative for the safety of the adjacent stopbanks. The main morphological processes that can affect the stopbank include lateral and vertical movements:

- Lateral movements: a shift in position of the channel, the development of meanders, movement of sandbanks, avulsion[1] and stream patterns.
- Vertical movements: degradation and/or aggregation of the floodplain, foreshore, tidal flat, or river channel bed by scour and bed form migration.

The effect of these processes on stopbanks can be either positive (increasing the strength/reducing the hydraulic load) or negative (decreasing the strength/increasing the load). Table 3.2 provides an overview of effects that morphological processes have on a stopbank.

Table 3.2 An overview of effects of morphological processes on a stopbank (CIRIA, 2013).

Phenomenon	Strength of the stopbank	Hydraulic load characteristics on the stopbank
Erosion Scour of channel and erosion of the foreshore, beach or floodplain.	Decrease in stability of the waterside slope of the stopbank and (submersed) slopes of the foreshore, due to the reduced elevation of the surface and/or steepening of the slope. Impermeable layers (that control seepage) may lose their hydraulic resistance and (eventually) disappear.	Water level: • For river stopbanks the river water level may decrease during floods as channel flow capacity increases. • An increased water depth on the front of the stopbank may decrease wave set-up. Waves[2]: • An increased water depth in front of the stopbank may increase wave height.
Sedimentation Sedimentation	Increase of the stability of the waterside slope of the stopbank and (submersed) slopes of the foreshore, due to reducing the height and/or steepness of the slopes. Reduction of pore pressures and seepage pressure, in the case of an increase of hydraulic resistance of the zone in front of the stopbank (foreshore/floodplain). Reduction in sediment transport downstream can reduce sediment supply that helps to protect river banks and stopbanks against erosion. Reduction in sediment supply can result from waterway restrictions such as dams.	Water level: • For river stopbanks the river water level may increase during floods as channel flow capacity decreased. • A reduced water depth on the front of the stopbank may increase wave set-up. Waves[3]: • A reduced water depth in front of the stopbank may reduce wave height.

[1] In fluvial geomorphology, **avulsion** is the rapid abandonment of a river channel and the formation of a new river channel.
[2] If the water is shallow enough to restrict wave height.
[3] If the water is shallow enough to restrict wave height.

Designers of stopbanks need to consider these morphological effects and may need to develop mitigation measures where these effects are anticipated.

Information that can be used to anticipate any adverse morphological trends include:

- River cross-section surveys. These show where and at what rate erosion is occurring along the river, berm and stopbank. They also show where sedimentation is occurring.
- Gravel and sediment balance analyses. These show at which reaches and cross-sections gravel is being taken from and where it is being deposited. These analyses may lead to specific gravel extraction strategies to either minimise erosion threats to the stopbanks (undermining caused by over-extraction) or maintain stopbank flood flow capacity (through targeted extraction).

Earthquakes can bring about changes in the river channel due to:

- Movement across faults traversing across the river,
- Liquefaction causing lateral spreading and a narrowing of the river channel,
- Liquefaction causing soil to be ejected into the river bed, and
- Post-earthquake ground subsidence changing the gradient of the river bed and tributaries.
- Settlement in stopbank reducing height of crest.

3.4.3 Hydrologic, hydraulic and climate changes

The correct AEP flood flow and associated water level are required for designing stopbanks. Sometimes the local or regional councils have this information for water courses they are responsible for managing.

Stopbank designers need to be aware of the age of the hydrological data being supplied to them by the Council and should confirm with Council that the data can still be used for current design purposes. Councils usually update the hydrology of specific catchments on a regular basis. The Regional Council does this for each of its river schemes for flood protection planning purposes. District plans usually also identify areas that are prone to flooding. Development can then be controlled in those areas and minimum levels set for buildings and subdivisions located in the floodplain. Council personnel responsible for managing flood protection assets update catchment hydrology and watercourse flood levels to check that stopbank freeboard hasn’t reduced due to say stopbank settlement. If freeboard reduction has occurred the Council will often restore design levels by topping up low points along the length of the stopbank.

If Council has not updated the hydrology of a particular watercourse of interest the stopbank owner may need to update the record themselves. This involves updating the flood frequency analysis by adding new rainfall data to the historical data set and then re-calculating the design flood for the selected AEP. Numerous methods can then be used for converting rainfall depths into equivalent flows. TM61 and Rational method are two methods commonly used in the Bay of Plenty for this purpose. Other methods include application of Regional Analysis and transposition of flood frequency estimates determined from flow records at neighbouring hydrologically similar catchments.

Reasons for changes in the flood frequency analysis results may include:

- Updated and improved methods of hydrological analysis.
- Changes in catchment land-use.
- Climate change effects.

Stopbank designers need to check with the Regional Council to confirm which rainfall frequency and intensity data they should be using to calculate design flows. The Regional Council has been closely involved in verifying the appropriateness of rainfall data generated for hydraulic design purposes. Currently the Regional Council endorses the use of NIWA's (National Institute of Water and Atmosphere) HIRDS Version 3 software which produces rainfall values for catchments in the Bay of Plenty.

Changes in the catchment land use often lead to changes in rainfall run-off and subsequent design flows. For example conversion of land currently in forestry to dairy farming can result in significant increases in run-off that contributes to flows discharging into downstream watercourses. Another example is an increase in development where earthen surfaces are converted into hardstand areas which increase run-off and flow into downstream watercourses. Stopbank designers should therefore consider what features can be integrated into current stopbank design that will allow it to be upgraded in future to cope with expected increases in flow e.g. a widened stopbank crest to provide for future raising.

The Regional Council has adopted the Intergovernmental Panel on Climate Change (IPCC) estimates for climate change in the region's rivers, drainage schemes and stormwater systems. Climate change and in particular global warming has the potential to increase the magnitude, level and frequency of flooding. Hence the capacity of existing and future stopbanks and appurtenant structures must be reviewed periodically to check that service levels can still be satisfied. Ideally new stopbanks should be designed and constructed taking into account the effect of climate change that includes rising sea level and increased frequency and magnitude of floods. The impact of climate change and guidance on how this can be taken into account is provided in the Council's Hydrological and Hydraulic Guidelines (2012).

3.5 Stopbank type

3.5.1 General

The most common stopbank type built in the Bay of Plenty is a homogeneous earth embankment. There are limited soil types available in the area for stopbank construction and the stopbanks are generally less than 4 m high, therefore zoned stopbanks are uncommon. Some newer stopbanks have been built with cut offs through shallow permeable foundation layers. Refer Figure 3.4. Where the location is restrictive, such as around urban areas, there may be need to use another option such as a concrete wall.

The seepage and stability requirements dictate the minimum general dimensions of stopbanks. These can then be varied to suit the site conditions, for example the crest width can be varied to cater for access requirements, batters can be flattened and lengthened to allow for mowing and sections of crib or concrete walls can be used where there are space restrictions due to roads, trees or other physical features.

3.5.2 Earth stopbanks

Under normal conditions, the maximum stopbank batter slopes would be 2.5H: 1V for the waterside slope and 2H: 1V for the landward slope. These may have to be flattened for stability or other reasons, such as mowing.

Where there is a limited availability of good quality low permeability soil to construct the whole stopbank it may be necessary to construct a core, or zoned cross-section, in which the material in the central zone comprises selected low permeability soil. The material in the outer zone shoulders can then be *"run of the mill"* earth fill material won from a local borrow pit. Refer Figure 3.5. Zoned stopbanks normally incorporate a drain layer placed in the downstream shoulder e.g. No 5 Ford embankment located in the Kaituna River Scheme. This discharges seepage passing through the central zone safely to the downstream toe area.

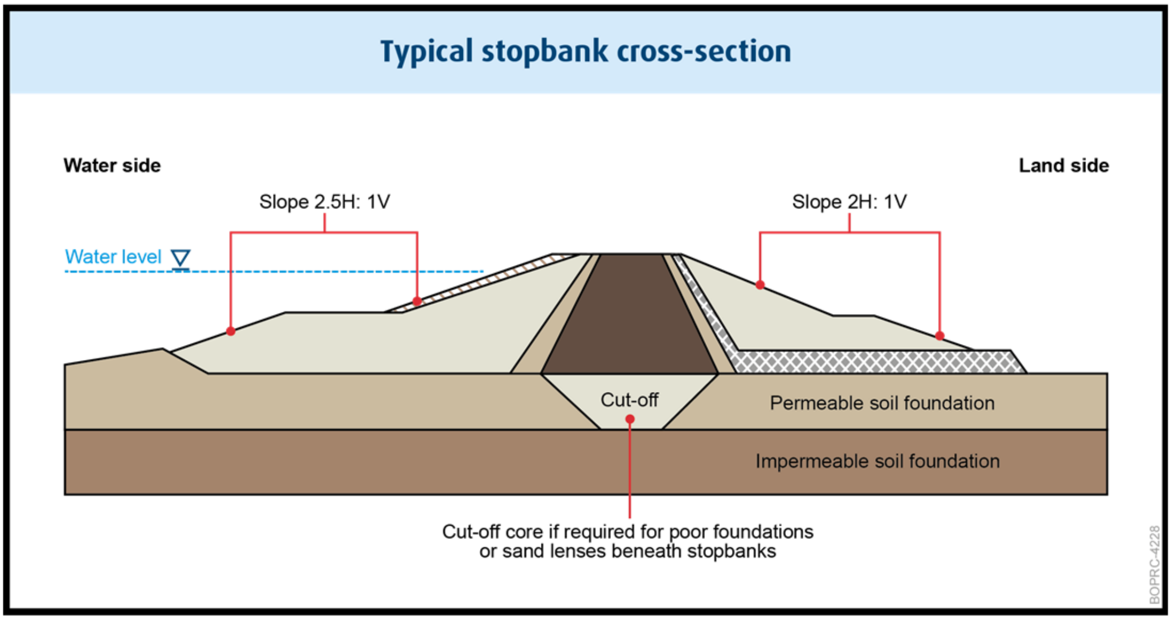


Figure 3.4 Typical stopbank cross-section.

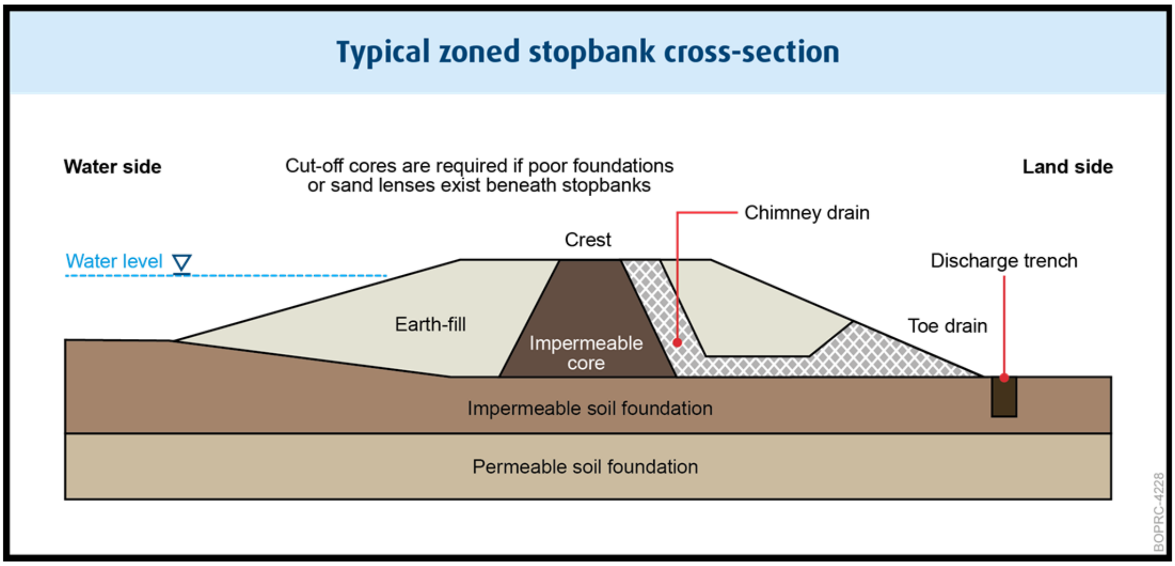


Figure 3.5 Typical zoned stopbank cross-section.

3.5.3 **Concrete flood walls**

Concrete floodwalls provide a useful alternative stopbank, particularly in and around urban areas where there are site restrictions. Figure 3.6 shows an example of a concrete floodwall with pedestrian access ramp.

Figure 3.6 Concrete floodwall with access ramp, Muriwai Drive, Whakatāne.

In situations where the wall is mainly required to provide freeboard and not withstand a significant depth of water, a concrete block wall may be adequate. Depending on the height required the wall may be free standing or backed up by earth fill.

The main disadvantage of a floodwall is that, unlike an earth stopbank, it is not easy to temporarily raise it if necessary. Earth stopbanks can be raised using sandbags or earth, but this is not possible with most narrow concrete walls. However concrete retaining walls do provide a consistent crest height and if it is not on top of an earth embankment it is not as subject to settlement which would reduce available freeboard. Sometimes Regional Council increases floodwall freeboard beyond standard freeboard allowances (refer section 3.3.3) to reduce risk of overtopping due to gradual loss of freeboard. Freeboard reduction may result from settlement and/or increasing flood levels. Flood levels can increase over time due to climate change effects which include increased flood frequency and intensity.

Figure 3.7 shows various types of concrete floodwall.

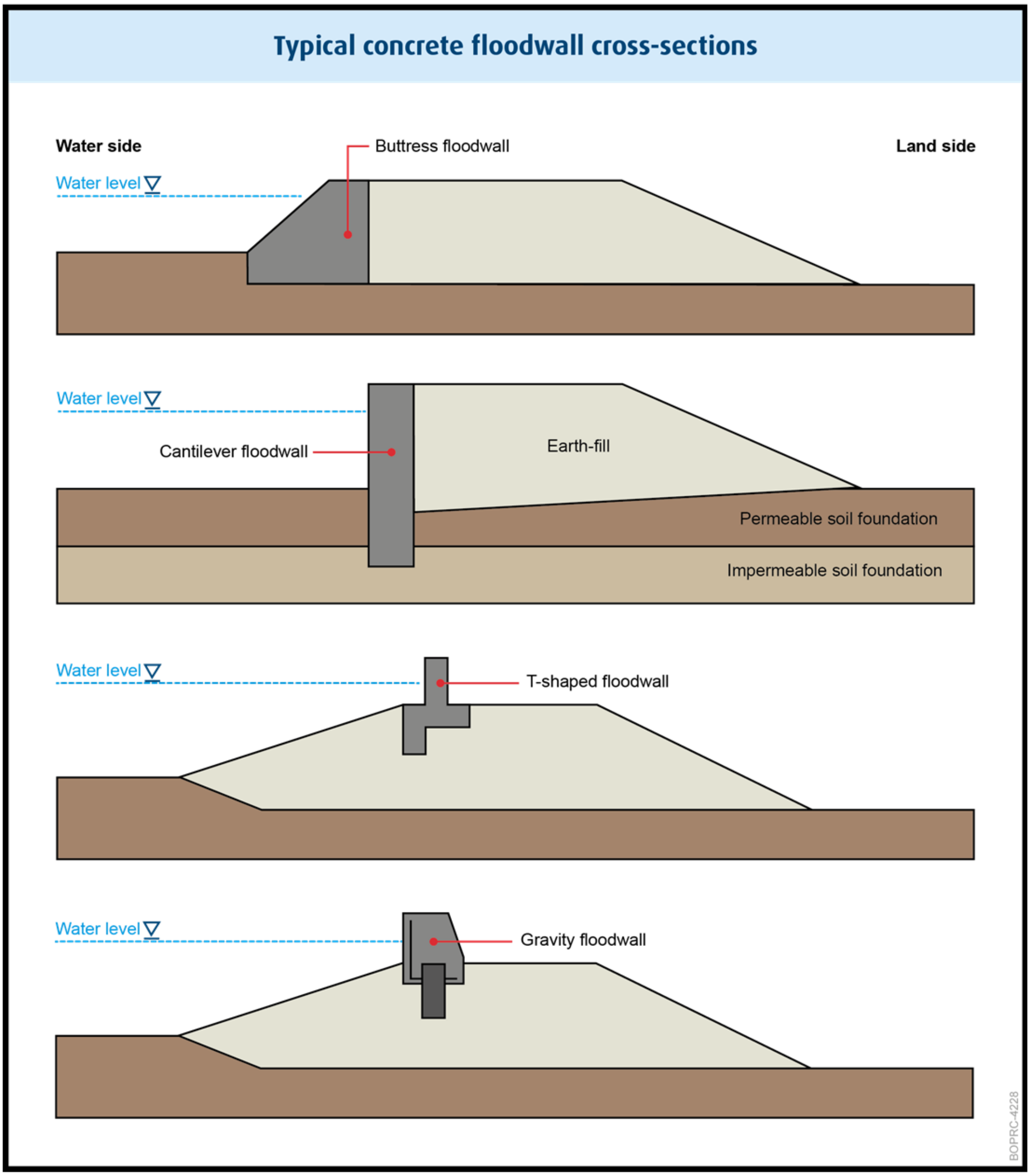


Figure 3.7 Typical concrete floodwall cross-sections.

Concrete walls also have the disadvantage that a failure can be more unexpected than a stopbank failure with a sudden flow of water at considerable velocity. In contrast to some stopbanks all flood walls require a rigorous design to ensure their stability. It is most important that flood walls are designed by qualified civil or environmental engineers that are familiar with all the forces applied to the wall including hydrostatic uplift and can assess the seepage characteristics of the soils beneath the wall. Refer to Section 3.7 and Appendix A3.2 for further detail on flood wall stability requirements.

3.5.4 **Timber retaining flood walls**

Full or partial timber flood retaining walls are a useful alternative where there is limited room to construct an earth stopbank. A full timber flood retaining wall comprises two vertical walls with a compacted soil core. Refer Figure 3.8.

Figure 3.8 Full timber flood retaining wall showing pump pipework penetrating and tie back supports, Eastern Drain.

A partial timber flood retaining wall is constructed with a conventional batter on one side, a crest and a timber retaining wall on the other side, which may adjoin a road or other asset. Refer Figure 3.9.

These alternatives also provide the opportunity, as with conventional stopbanks, to incorporate a walking or bike track into a proposal. It is not common to use timber flood retaining walls on the water side of a stopbank, however if this is required it is recommended that a geofabric be laid behind the retaining timber flood wall to reduce risk of loss of soil particles through the wall due to wave action or draw down. If seepage is expected at the landward timber wall due to elevated river levels or rainfall, geotextile should also be placed behind this wall.

3.5.5 **Crib walls**

The use of a full or part crib wall is an option where there is limited space to construct a stopbank. A full crib wall comprises two slightly sloping walls with a compacted clay core whereas as a part crib wall is constructed with a conventional batter on one side, a crest on the other side, which may adjoin a road. These alternatives also provide the opportunity to incorporate a walking or bike track. It is not common to use crib walls on the water side of the stopbank, however if necessary then a geofabric should be laid behind the crib to reduce risk of scouring. Refer Figure 3.10.

Figure 3.9 Partial timber flood retaining wall, Rangitāiki River.

Figure 3.10 Part crib wall, flood wall and stopbank combination, Edgecumbe.

3.5.6 Sealed roadways

Existing roadways can provide a stopbank option worth considering if no alternative option is apparent. Raising the roadway can provide an excellent stopbank with no access problems and the "crest" can be maintained as part of normal road maintenance arrangements. A sealed road has the advantage that access is not weather dependant and consequently is accessible during flood events. Refer Figure 3.11.

Figure 3.11 Sealed roadway/stopbank crest, Eastern Drain, Rangitāiki Plains.

3.6 Foundation conditions

The correct stripping of topsoil from the stopbank site is critical to ensuring the necessary bonding of the stopbank with the underlying material. Stripping should be carried out to the depth required by the designer. Where topsoil is shallow a minimum stripping depth of 300 mm should be adopted to ensure all surface roots and vegetation are removed.

If a cut-off core/key trench is not being incorporated in the stopbank, then the foundation clay must be ripped and re-compacted to remove any further roots from the bank and ensure a good bond.

3.7 Stability

3.7.1 Earth fill stopbanks

The stability of stopbanks needs to be assessed to ensure they retain floodwaters on the waterside for the duration of the flood without failing. In addition the stability of stopbanks during and after earthquakes should be assessed so that the post-earthquake repairs are minimised, or at least prepared for, as discussed above. Potential failure modes for stopbanks include those given in Table 3.3.

Table 3.3 Potential stopbank failure modes.

Hydrostatic	**Seismic**
Overtopping	Slope stability with lateral accelerations.
Slope instability • high river level • low river level • rapid draw down	Slope stability with liquefaction in the embankment and/or foundations.
Piping/internal erosion	Lateral spreading induced cracking.
Undermining scour erosion	Post-earthquake settlement.

The analysis of these hydrostatic and seismic load cases is covered in Appendix A and B respectively.

Overtopping

Overtopping is normally assessed by calculating the design flood water level at critical stopbank cross-sections. Freeboard is then added to the design flood level to obtain the final crest level. It is prudent to calculate the design flood level taking climate change effects into account. In the Bay of Plenty climate change is likely to cause increased rainfall intensity and frequency thus causing flood levels to rise over time. If final crest levels do not take account of climate change effects some thought should be given as to how the current stopbank height could be raised in the future.

Figure 3.12 Collapse of the water side slope of a stopbank due to scouring, Kōkōhinau Bend, 2004.

Slope In-stability

Low stopbanks and stopbanks that are built of good material and are resting on proven foundations may not require extensive stability analysis. For these cases, practical considerations such as type and ease of construction, maintenance, seepage and slope protection criteria, control the selection of stopbank slopes. This is demonstrated as follows:

- Type of construction. Fully compacted stopbanks generally enable the use of steeper slopes than those of stopbanks constructed by semi-compacted or hydraulic means. Space limitations in urban areas often dictate that stopbank sections be kept to a minimum requiring select material and proper compaction to obtain a stable section.
- Ease of construction. A stopbank with 2H: 1V slope is generally accepted as the steepest slope that can easily be constructed and ensures stability of any riprap layers.
- Maintenance. A stopbank with 3H: 1V slope is the steepest slope that can be conveniently traversed with conventional mowing equipment and walked on during inspections. Where mowing is not a requirement, batter slopes of 2.5H to 1V on the water side, and 2H to 1V on the protected side, are previously suggested minimums, depending on the soil type and other criteria.
- Slope protection. Riverside slopes flatter than those required for stability may have to be specified to allow the placement of protection from damage by wave action.

Embankment design requires detailed stability analysis for stopbanks of significant height or when there is concern about the adequacy of available embankment materials or foundation conditions. Further slope stability considerations such as load cases, factors of safety, analysis and remedial measures are detailed in Appendix A.

Piping

Piping is a form of internal erosion which initiates by backward erosion from the point where a seepage path exits the ground surface or crosses from a fine soil to a coarser soil. It results in the formation of a continuous tunnel called a 'pipe' between the landward and watersides of an embankment or its foundation. Earth fill material migrates towards the landward side of the stopbank under pressure, creating a conduit and ultimately a collapse of the landward slope or the whole stopbank section into the foundation. In July 2004 a section of the Rangitāiki River stopbank at Sullivan's Bend collapsed causing widespread flooding as a result of foundation piping. Refer Figure 3.13.

Figure 3.13 Stopbank failure at Sullivan's Bend caused by piping failure, Rangitāiki River.

Piping seepage is generally the result of:

- Permeable layers within the fill or foundation soils, or the presence of cracks or fine fissures.
- Animal burrows in the fill or foundation.
- The rotting of vegetation roots in the fill allowing uncontrolled seepage.
- The presence of pipes or other structures that pass through the stopbank.

The risk of piping failure in stopbanks can be reduced by reducing water pressures, lengthening potential seepage paths and managing the interface between soils to reduce the risk of material migrating towards the landward slope. In general coarser graded material placed landward of the centre of the stopbank helps to trap finer graded particles that may migrate landward under water pressure and allow seepage to discharge from the landward slope in a safer controlled manner. Further detail on internal erosion/piping such as failure modes, basic mechanisms, stages of erosion, analysis and remedial options are outlined in Appendix A.

Liquefaction

Liquefaction occurs when water prevents granular soil particles from moving into a denser state when subject to vibrations due to earthquakes or machinery. A rise in water pressure results and the soil loses its frictional strength. As a result, the soil behaves like a liquid, has an inability to support weight and can flow down very gentle slopes. This condition is usually temporary and is most often caused by an earthquake vibrating water-saturated fill or unconsolidated foundation soil.

Liquefaction most often occurs when three conditions are met:

- The fill or foundation soil comprises loose, granular sediment,
- The fill or foundation is saturated by ground water, and
- Strong shaking occurs, such as during an earthquake.

As most stopbanks are founded on alluvial soils with relatively high ground water level they are highly susceptible to liquefaction during earthquakes. However it is unlikely to be cost effective for foundations to be treated to reduce the risk of liquefaction over the length of the stopbank system. In this case the risks of liquefaction need to either be accepted or the stopbank needs to be relocated. Particularly important structures could be ring fenced by a stopbank with improved foundations or floor levels could be lifted above the flood level expected after stopbank failure. Additional details on liquefaction are provided in Appendix B.

Undermining

Undermining scour erosion occurs at the water-side toe of the stopbank when channel flow velocity exceeds the earth fill and/or natural riverbed material's ability to resist erosion. As a result the toe area becomes undercut and earth material is swept away with the current. If undercutting continues the water side slope and/or berm can collapse which can lead to breach of the stopbank. Refer Figure 3.14.

Increases in scour velocity can result from:

- Overdesign flood events;
- Meandering of the river bed with deeper sections migrating towards a stopbank toe; and
- Restriction of the channel flow area (due to say gravel and/or debris accumulation).

Undermining is enhanced if the riverbed degrades (lowers). This can be due to several causes including normal river processes in steep of confined channels, upstream sediment restrictions (dams) or excessive gravel extraction (Refer Section 3.15.7).

Figure 3.14 Undermining scour erosion, Pryor's stopbank, July 2004.

3.7.2 Concrete floodwalls

Floodwalls are an integral part of the Flood Protection System. They are often embedded into the stopbank section. In the Bay of Plenty they are typically constructed on top of existing stopbanks where it is difficult to top-up the stopbank or where space is restricted. They are usually short in length and height. Safety factors against sliding, overturning or bearing failures should be at least 1.5 for the whole flood hydrograph, taking into account water pressures. Stability assessment aspects of floodwalls are discussed further in Appendix A3.2.

3.8 Seepage control

Stopbanks are primarily designed to reduce and control seepage discharges resulting from flood waters loading the waterside of the embankment. If there is no seepage control then:

- Seepage through stopbanks can result in internal erosion/piping failures;
- Seepage in stopbank foundations can result in piping failure and/or excessive hydrostatic pressures building beneath an impervious layer causing heave; and/or
- Excessive seepage volumes can cause surface flooding.

Foundation seepage risks are greatest where:

- A pervious layer underlies a stopbank;
- A pervious layer extends from the landward to the waterside of the stopbank; and
- It is overlain by a relatively thin lower permeability layer on the landward side of the stopbank.

A pervious layer provides an ideal path for seepage to travel from the watercourse to the floodplain on the landward side of the stopbank particularly after river bed scouring has removed any lower permeability sediment which was sealing the river end of the layer.

Principal seepage control measures through and below stopbanks comprise:

- Constructing new or widening existing stabilising berms to lengthen the seepage path beneath the stopbank and reduce hydraulic gradients.
- Construction of impervious layers on the upstream stopbank face to reduce the volume of seepage through the stopbank.
- Seepage cut-off walls through permeable layers to stop water flow.
- Internal drains to relieve seepage pressures and provide a controlled water outlet.
- Insertion of toe drains in shallow permeable layers to relieve seepage pressures.
- Relief wells to reduce the seepage pressures in deeper permeable layers.

These measures along with analysis methods are discussed further in Appendix C.

3.9 Material selection

Almost any soil can be used for constructing stopbanks, except very wet, fine-grained non-cohesive soils or highly organic soils. In some cases, though, even these soils may be considered for portions of stopbanks. Accessibility and proximity are often controlling factors in selecting borrow areas. Sometimes it may be better to haul good quality borrow from further afield than to use local poorer quality borrow.

Where compacted stopbanks are planned, it is necessary to obtain borrow material with water content low enough to allow placement and adequate compaction without excessive drying time. Borrow soils undergo seasonal water content variations; hence water content data should be derived from samples obtained from borrow areas in that season of the year when stopbank construction is planned. Possible variations of water content during the construction season should also be considered.

Generally, the most economical borrow scheme is to establish borrow areas parallel and adjacent to the stopbank. Where possible, borrow area locations on the waterside of a stopbank are preferable provided the removal of soil from the river berm does not compromise the stability of the stopbank and shorten seepage paths in high permeability foundation layers. Borrow area locations within the protected area are less desirable environmentally, as well as generally being more expensive. The removal of soil from the landside of the stopbank may increase the risk of heave. Waterside borrow locations in some areas will be filled eventually by silt, thus reducing the man-made changes in the landscape. For the above reasons the stopbank designer should assess any proposed borrow areas near stopbanks.

A berm should be left in place between the stopbank toe and the near edge of the borrow area. The berm width depends primarily on foundation conditions, stopbank height, and amount of land available. The berms width should be established by:

- Seepage analyses where pervious foundation material is exposed in the sides or is close to the base of the borrow area; and
- Stability analyses where the excavation slope is near the stopbank.

It is generally preferable to have waterside borrow areas “wide and shallow” as opposed to “narrow and deep.” While this may require extra right-of-way and a longer haul distance, the benefits derived from improved under seepage, hydraulic and environmental conditions usually outweigh the extra cost.

In computing required fill quantities, a compaction factor of at least 25% should be applied (i.e. borrow area volumes should be at least 125% of the stopbank cross-section volume). This will allow for material shrinkage and hauling, and other losses. The stopbank designer should advise a suitable compaction factor as some soils, such as volcanic ashes, could have compaction factors of 40 to 50%.

3.10 Stopbank geometry

The stopbank cross-section shape depends on the location of the stopbank, soil type, access arrangements, construction methods, maintenance arrangements and other considerations.

Access requirements for a stopbank system must be given serious consideration at the initial planning phase of a project. This should include access along each side of the stopbank, along the crest and over the stopbank. Access along the base of the stopbank should generally be at least 3 m wide.

The method adopted to provide access will affect the construction process as well as maintenance procedures, hence capital and ongoing maintenance costs. Points to be considered are:

3.10.1 Public access

Public access can be incorporated into the design, but the requirement for public access should be established during the planning stages.

Care should be exercised when adding features for the public such as picnic tables or trees as these can restrict access for maintenance works. Permission to modify the environment immediately adjacent Council stopbanks should be obtained prior to carrying out the works.

3.10.2 Vehicular access

Vehicular access requires that the crest be wide enough to safely accommodate a vehicle. It must have appropriate signage, clearly indicating traffic direction, and must have suitable on/off ramps to give safe access. The minimum width of a stopbank crest, necessary to safely accommodate a vehicle is 3 m.

Vehicle crossings are a necessary feature of stopbanks and provide access to the waterway side from the landward side of stopbanks other than in periods of flooding.

For public roads and access track crossings, designers must consider the safety aspects of the vertical alignment and sight distance. Where this is a problem, the approaches may need to be raised to provide adequate sight distances.

Vehicle crossings require frequent maintenance, however, this can be significantly reduced if the crest and batters are gravelled, sealed or concreted, to prevent the wearing down of the trafficked area.

Where the vertical crossing alignment is critical for access by heavy, long or low clearance vehicles, it may be necessary to have a lowered section of the stopbank that can be closed, if needed, by suitable stoplogs.

The additional crest treatment required to adequately carry regular traffic will result in a higher level of maintenance, including pothole repairs, grading and the occasional topping to maintain crest level. Care must be taken to prevent water ponding on the stopbank crest in vehicle ruts.

Generally, **it would be preferable to deny access to the stopbank area by public vehicles.** If vehicular access is permitted, then access at the base of the stopbank should be considered. This does not affect the integrity of the stopbank and also allows access in emergency situations, when the crest may not be available due to sandbagging or other activities. Access behind stopbanks also has lower maintenance requirements, than crest access, and its suitability and safety are not governed by the width of the crest, but by the needs of vehicles.

3.10.3 Pedestrian and bicycle access

Pedestrian access generally does not require major treatment, or create maintenance demands on the crest. However if bicycle access is envisaged, additional maintenance will be necessary and if the stopbank site is located close to an urban area or school and is likely to attract significant use, then consideration should be given to sealing the track to prevent rutting. Refer Figure 3.15.

Figure 3.15 Sealed pedestrian access way on stopbank crest, near mouth of Whakatāne River, viewing downstream.

3.10.4 Maintenance access

Access for heavy earthmoving vehicles moving across the stopbank crest should be specified prior to construction. The main consideration for maintenance access is where to provide access and egress points from the formal road network, and at what frequency these points should be provided to minimise use of the stopbank by maintenance vehicles.

Irregular use of the crest for access by maintenance vehicles is unlikely to create any problems, even if the crest has only a sown topsoil surface.

3.10.5 Access for inspections or during flood events

Access requirements for inspection or during flood events, are similar to maintenance requirements and should be considered in a similar way. One of the main considerations is the proximity of the road network and where to provide the most efficient access points.

Consideration should be given to providing access on the landward side of the stopbank where this is a viable option. This would keep the stopbank free from all but maintenance traffic, reduce deterioration and allow access to all parts of the bank in an emergency, without using the crest that could be in use for sandbagging operations.

The decisions relating to access will have a significant impact on the final stopbank design. They will affect such aspects as the size and appearance of stopbank, public access to the area and future maintenance requirements and costs.

For example, if the public is not to be permitted access to the stopbank, the stopbank can be built to a minimum width, top-soiled and grassed. This would be sufficient to carry maintenance traffic as required. In these circumstances removable barriers or gates would have to be installed to prevent public access. Another example is where vehicular access is required across stopbanks during floods. In this case prior placement of rock across the crest, allowing grass to grow through will reduce risk of crest rutting and damage and allow vehicle passage during wet conditions.

3.11 Transitions

In some areas, a flood protection system may be composed of stopbanks, floodwalls, and drainage control structures (gated structures, pumping plants, etc.). In such a system there are interfaces between the stopbank and concrete structures which require careful design. At the interfaces between a stopbank and a concrete floodwall the wall itself is usually embedded into the stopbank embankment. When the stopbank ties into a drainage control structure by abutting directly against the structure, as shown in Figure 3.16 the abutting end walls of the concrete structure should be battered at 1H to 10V to ensure a firm contact with the fill.

When joining a stopbank embankment with a concrete structure, items that should be considered in the design of the interface are:

- Differential settlement.
- Compaction.
- Seepage.
- Embankment slope protection.

Differential settlement caused by unequal consolidation of the foundation soil at the interface between a relatively heavy stopbank embankment and a relatively light concrete closure structure can be serious if foundation conditions are poor and the interface is improperly designed. Preloading has been used successfully to minimize differential settlements at these locations.

Thorough compaction of the stopbank embankment at the interface between the concrete structure and stopbank is essential. Good compaction decreases the permeability of the embankment material and ensures a firm contact with the structure. Heavy compaction equipment such as pneumatic or sheepsfoot rollers should be used where possible. Heavy equipment should not be allowed near the concrete structure until concrete has reached 75% of its design 28-day compressive strength. Designers should note that the concrete structure should be capable of withstanding compaction loads which can be very high. Hand operated compactors or walk behind rollers should be used to compact fill placed in thin loose lifts adjacent concrete structures. This includes in confined areas such as those within 1 m immediately adjacent to concrete walls. Fill placed against concrete structures should be at the moisture content specified in contract documents and be compacted in layers no greater than 150 mm thick to achieve 95% maximum dry density. Compaction testing should be carried out at no greater than 10 m intervals along the structure for every 300 mm lift.

Seepage needs to be analysed to determine the embedment length of the structure-stopbank interface required to prevent piping. Zoning of the embankment materials needs to be maintained across the interface unless analysis indicates different zoning is required.

Slope protection should be considered for the stopbank embankment at all interfaces with concrete closure structures. Turbulence may result at the junction due to changes in the geometry between the stopbank and the structure. This turbulence will cause scouring of the stopbank embankment if slope protection is not provided.

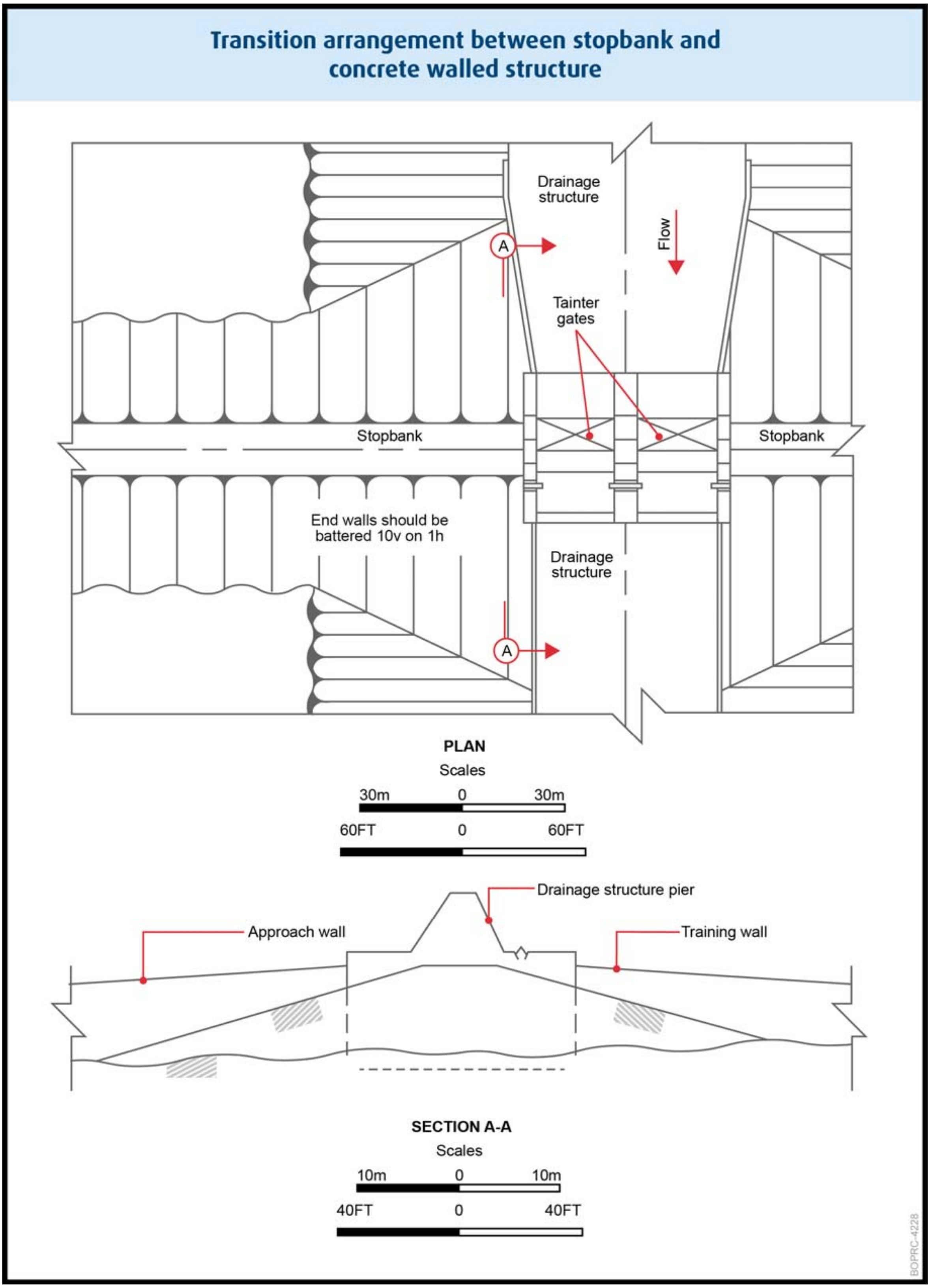


Figure 3.16 Transition arrangements between stopbank and concrete walled structure (USACE, 2000).

3.12 Penetrations

The crossing of a stopbank by another service must be managed carefully to ensure that the works do not lead to the creation of a weakness in the stopbank and a potential failure point.

The main services stopbank managers will encounter are pipelines, which need to cross the stopbank by either open cut or drilling. Aerial lines also need to be given some consideration.

Any works carried must not create a weakness in the stopbank and it is important to ensure that works are covered by an appropriate maintenance period, with an appropriate financial guarantee to ensure any defects can be repaired promptly.

Authorities or persons wishing to construct works, through or under a stopbank, must obtain prior approval from the stopbank owner. For example according to Council's Floodway and Drainage Bylaw (2008), prior permission from Council is required if people wish to:

- Plant any vegetation on a stopbank or within 12 m of the landward side of any stopbank or between the watercourse and stopbank.
- Construct any structure in a stopbank or within 12 m of the landward side of any stopbank or between the watercourse and stopbank.
- Carry out any excavation between the watercourse and stopbank.
- Carry out any excavation including for building foundation, within 20 m of any stopbank.

The owner must ensure appropriate specifications for the works are supplied and that the works are carried out according to the specifications by having a suitably qualified supervisor to oversee the works.

Most crossings will be by a pipeline, installed by open cut or directional drilling methods. Drilling is commonly used for installation of cables and smaller pipes, where the pipe or cable is either laid in a sleeve pipe or pulled through an oversized hole. For stopbanks close to water courses the pipeline must be established adequately below the forecast scour level at the watercourse crossing. This is to avoid exacerbating scour and any potential threats from this to stopbank undermining.

Overhead lines, although not affecting the integrity of the stopbanks, have the potential to create hazards and interfere with maintenance and future works. Posts and poles can penetrate to high permeability layers, creating a shortened seepage path and possibly enabling the development of piping. It may be necessary to install a filter around poles to prevent the loss of soil particles due to seepage up the side of the pole.

Treatments of penetrations are discussed below. They include:

- Fences;
- Pipelines (open cut trench); and
- Aerial crossings.

3.12.1 **Fences**

Fences may be required around stopbanks to protect stopbank surfaces from erosion due to stock. Refer Figure 3.17. Cattle stock may eat or trample grass cover which in turn exposes the stopbank surface to rainfall runoff or waterway flow, increasing the risk of erosion. Stopbank owners should satisfy themselves that installation of fence posts will not create an internal erosion issue such as piping. Internal erosion could occur if the posts penetrate the phreatic surface within the stopbank. Piping could also occur if fence posts penetrate the seepage path beneath the stopbank on the landward side toe area as discussed above.

Figure 3.17 Fences around stopbank to protect grass cover from too much stock traffic, Kaituna River.

3.12.2 **Open cut trench pipelines**

Excavating a trench in a stopbank to install a pipeline is not desirable due to the increased risk of internal erosion/piping. However this risk can be mitigated if care is taken in the detailed design and installation.

Often it is difficult to ensure good compaction of fill material around the pipeline so preferential seepage can occur between the external surface of the pipe and the stopbank. Poor compaction can result in areas of low soil pressure, particularly under pipe haunches. If connection is made between floodwaters and a seepage path in a low soil pressure area hydraulic fracture of the fill can occur increasing the seepage and ultimately leading to the collapse of the stopbank. Refer Figure 3.18.

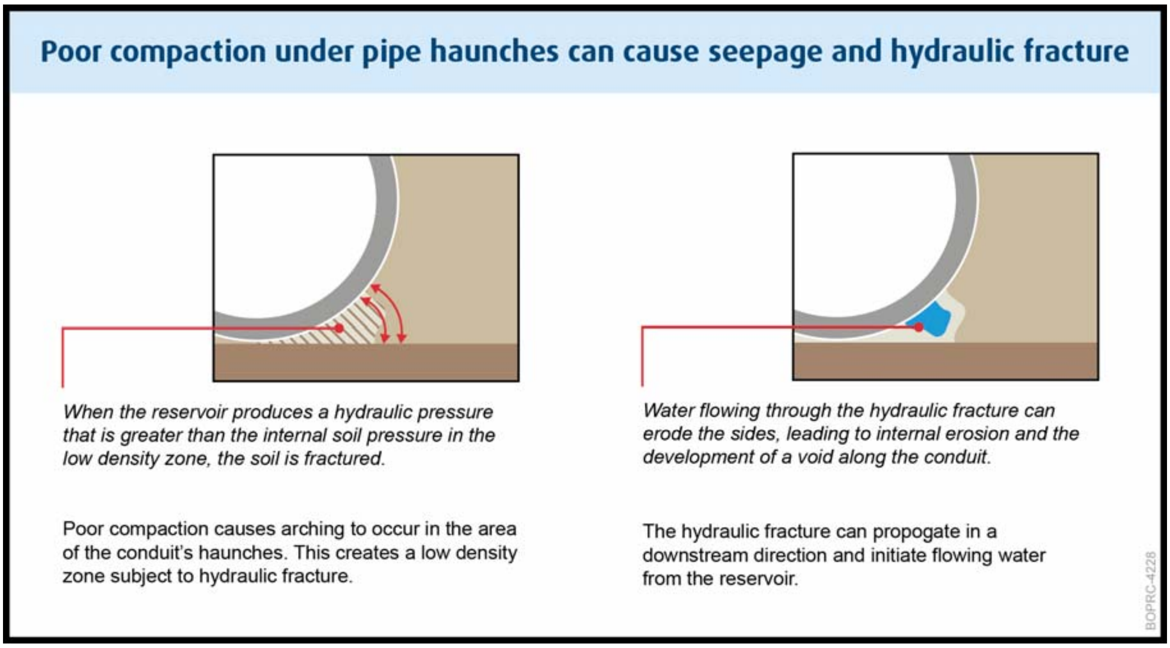


Figure 3.18 Poor compaction under pipe haunches can cause seepage and hydraulic fracture.

In the past, seepage problems around pipes in water retaining embankments were solved by installing anti-seepage collars around the pipe. However this is no longer considered good practice as collars are unable to overcome the issue of poor compaction around the pipe.

For pipes or culverts passing through or under stopbanks USACE (2000) recommends the installation of the drainage filter around the inlet one-third of the pipe length on the landward side of the stopbank. Refer Figures 3.19 and 3.20.

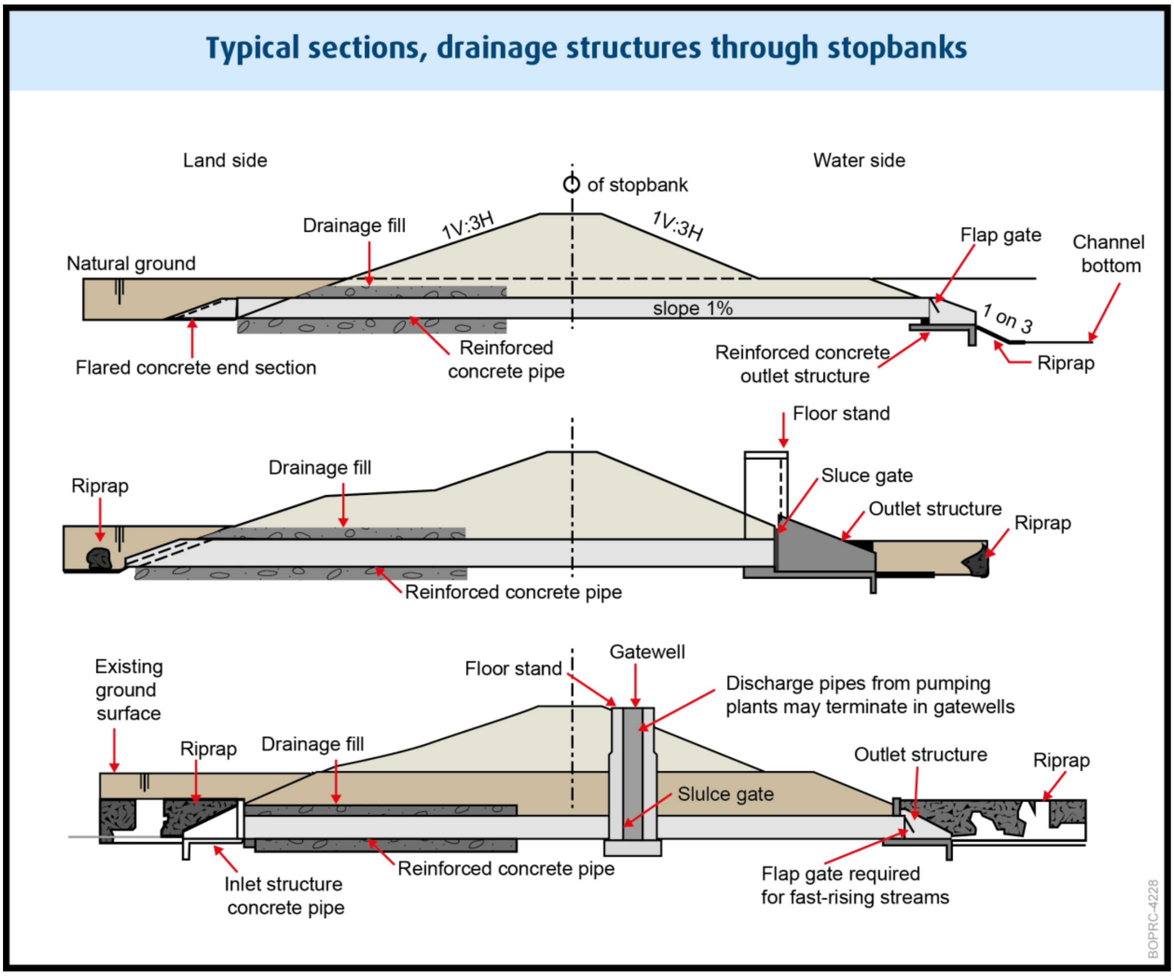


Figure 3.19 Drainage filter placed around pipes passing through stopbanks (USACE, 2000).

The current best practice for bedding pipes beneath stopbanks entails:

- For rigid pipes (e.g. concrete): The construction of a concrete cradle beneath and around the pipe. Joints in the cradle coincide with joints in the pipe to allow for potential differential settlement along the pipe length. To facilitate compaction sharp edges are removed from the cradle and side slopes are 1H: 10V of flatter. The weight of the pipe and concrete cradle should be compared to the weight of the displaced soil to determine if differential settlement between the pipe and the adjacent stopbank could occur. If this is the case the stopbank fill around the pipe should be designed to prevent cracking or other measures considered, such as supporting the pipe on piles.

- For flexible pipes (e.g. HDPE): Pipe bedding, haunching and backfill should be prepared and well compacted in accordance with the pipe manufactures instructions. Ensure the pipe is encased in a porous filter collar. This will allow seepage to track along the external surface of the HDPE pipe and discharge safely in a controlled manner to the toe of the landward slope.

Figure 3.20 Example of well compacted drainage fill being placed around a culvert embedded within a stopbank.

3.12.3 **Drilled pipelines**

In the case of a directionally drilled hole, under a stopbank, the principal concern is to avoid drilling the stopbank or the key of the stopbank. Refer Figure 3.21. It is also necessary to prevent water getting into the small annular space left around the pipe, after it is pulled through the drilled hole.

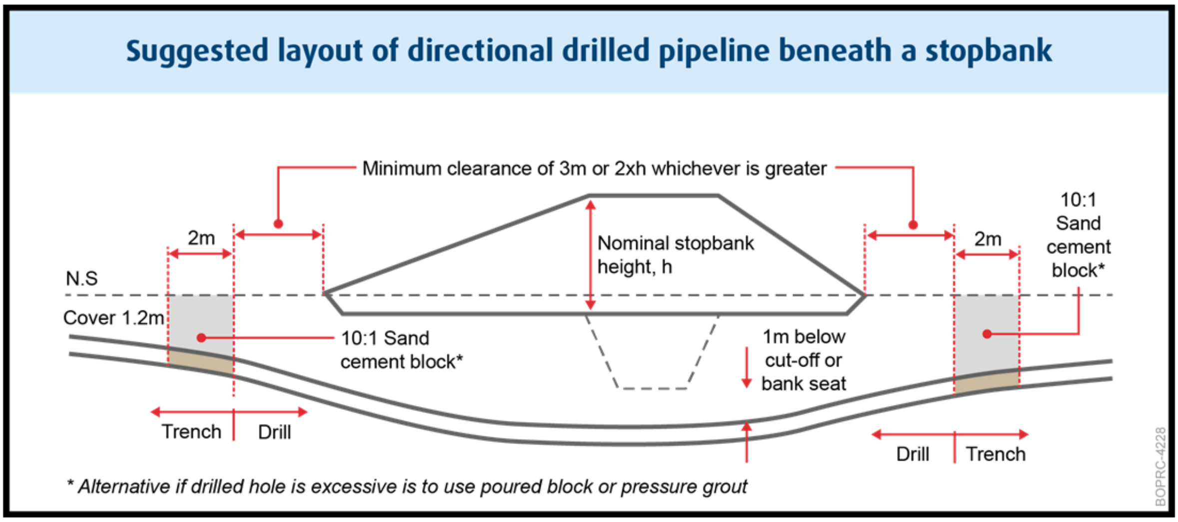


Figure 3.21 Suggested layout of directional drilled pipeline beneath a stopbank (NRE, 2002).

To achieve this, the following suggested procedures should be considered and adopted where appropriate:

- Trenching should not be undertaken within a distance of twice the height of the stopbank, h or 3 m either side of toe on both sides, whichever is the greater.
- The depth of the pipe should be based on 1.2 m of cover, below natural surface, at the start of the drilling. If the stopbank is keyed into the foundation material, the top of pipe should be at least 1 m below the invert level of the key, to avoid interfering with the integrity of the key.
- The diameter of the drilled hole should be kept to the minimum that will allow the service pipe to be pulled through.
- Should an annular space be left around a pipe, the space should be filled by pressure grouting, using a 9:1 sand cement grout mix. An alternative grout could be a cement bentonite water mix – without sand provided the annular space is not too large.
- For stopbanks of up to 1 m high, the ends of the pipe outside of the drill hole should be supported 150 mm above the bed of trench. The first 2 m of trench, on either side of the stopbank, should then be filled, to within 150 mm of natural surface, with a poured block of compacted 10:1 sand cement mixture.
- Final backfilling of the trench is to be completed using 150 mm topsoil.

3.12.4 Power cables under stopbanks

Additional requirements that must be included in the granting of permission to install power cables under stopbanks are:

- Cables must in all cases be enclosed in a heavy-duty rigid PVC conduit to AS/NZS2053. The conduit must have a minimum cover of 1 m, within 10 m of each toe of the stopbank.
- Concrete slabs constructed to AS/NZS 3000, must be used to protect cables. These slabs are to be laid 150 mm above the cable. Caution should be exercised to ensure the weight of the concrete slabs do not cause differential settlement and new seepage paths that could lead to potential piping failure.
- Plastic warning tape must be laid 300 mm above the cable, along the entire underground length of the cable.
- Warning signs must be located on either side of the stopbank indicating the presence of a cable.

3.12.5 Aerial crossing

These crossings are generally required by power or telephone authorities or private works associated with these services. They are usually not a major issue, however, consideration must be given to any negative impacts that these works may have on the management of the stopbank.

Matters that should be considered are:

- Clearance above the stopbank crest must be sufficient to allow the safe passage of plant and vehicles required for maintenance or emergency works on the stopbank.
- Supporting poles must be set back sufficiently, say at least 10 m, so as not to interfere with future access or other works requirements outside either toe of the stopbank.
- Necessary warning signs should be displayed at each aerial crossing advising of the danger, as well as the contact authority, for further information on the crossing.

3.13 Appurtenant structures

Facilities incorporating pumps, gates, stop logs, fish passage facilities or valves, located in pipelines that pass through stopbanks, can be used to prevent drainage waters backing up on the landward side of a stopbank during flood events. The choice of structure will depend on the conditions under which it is to operate.

Screw operated doors or gated valves have the advantage of being able to be securely closed or used partly closed if needed. The Regional Council practice is to also have a hydraulic power pack on hand to raise and lower screw operated gates that are difficult to operate under load. Refer Figure 3.22.

Figure 3.22 Hydraulic pack used to operate screw operated gates under hydraulic load.

Flap gate valves are self-operating and convenient. They are located on the waterside of a stopbank but are prone to blockage and may stick open during flooding. Flap gate valves need to be checked regularly to ensure they operate properly. Refer Figure 3.23.

Figure 3.23 Kope Orini flap gates, Whakatane River.

Stop logs are usually used in larger structures where manual operation is possible and access is available during times of flood. Refer Figure 3.24.

Figure 3.24 Installation of stoplogs within a stopbank system on the Whakatāne River.

3.14 Erosion

Erosion threats to stopbanks are either external or internal. External erosion is due to either rainfall or waterway flow impacting the stopbank exterior resulting in embankment material washing away and eventual collapse of the stopbank. Internal erosion is due to embankment seepage creating a conduit resulting in the washing out of fines and potential collapse of the stopbank. Conduits can be created due to embankment material properties or around penetrations such as culverts, tree roots, animal burrows, etc.

Measures to protect the stopbank against internal erosion are described in Section 5 and in Appendix A under internal erosion. This section addresses measures to protect against external surface erosion.

3.14.1 External surface erosion protection measures

The design of successful stopbank surface protection involves:

- Calculating current velocities and/or wave action on the waterside slope and toe of the stopbank.
- Comparing these values with the allowable limits of the revetment materials; movement (erosion) will occur if velocities exceed material limits.

Flow velocities can be calculated using a variety of methods ranging from basic open channel flow formulae such as Manning's equation, right through to unsteady non-uniform flow methods made available with one-dimensional MIKE11 software.

Various revetment cover types are used above normal water levels. Grass is the simplest and most common revetment cover used in the Bay of Plenty. Refer Figure 3.25. Provided grass is well maintained it will bind the topsoil together to resist surface erosion under laminar flow conditions.

Other alternatives are:

- Rock gabions or mattresses, including geotextiles.
- Placed concrete blocks including tiered block mattresses.
- Continuous concrete or asphaltic paving.

Figure 3.25 View of grassed slope of stopbank at Langdons Bend, Rangitāiki River (view upstream).

Grass surface

Figure 3.26 can be used as a rough initial estimate of the ability of grass to withstand a range of flow velocities and duration. Knowledge of local grasses uses for erosion cover purposes is invaluable in final selection.

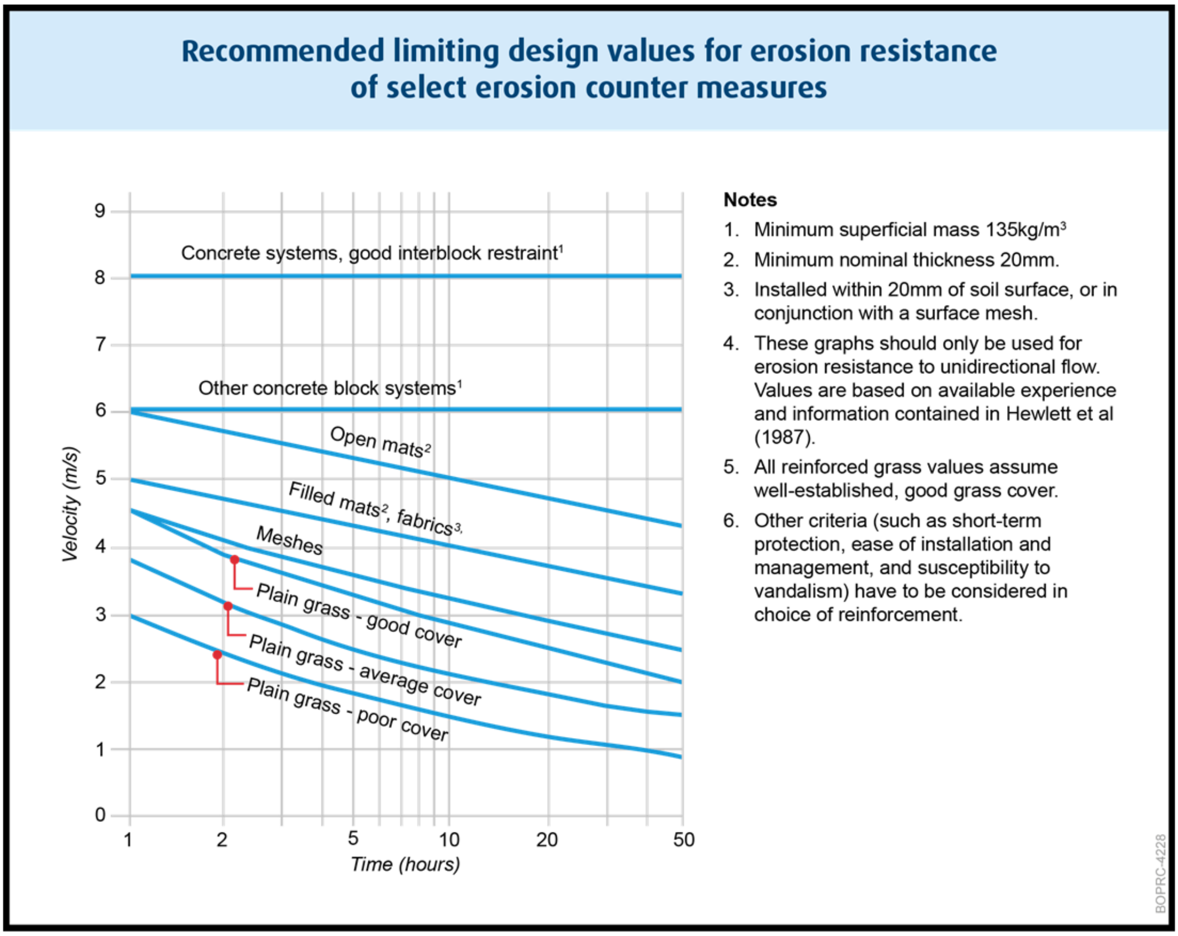


Figure 3.26 Recommended limiting design values for erosion resistance of erosion counter measures.

When grassed surfaces alone are not sufficient to resist the erosive forces turf reinforcement such as geotextiles mesh or turf reinforcement mattresses could be considered. Higher performance turf reinforcement mattresses exhibit greater ultimate tensile strengths and higher resistance to ultraviolet light. An example is Enkamat, a high strength polyamide geomesh produced by Maccaferri. Refer Figure 3.27.

Figure 3.27 Maccaferri Enkamat, a geomesh, used to line banks of the School Stream, Havelock North, Hawkes Bay.

Rock gabions and reno-mattresses

Rock gabions and reno-mattresses are formed baskets that are filled with rock, typically between 100 mm and 150 mm diameter. They form flexible gravity structures, which can resist scour and overturning. The most common disadvantages are that tie wires can corrode resulting in the basket contents unravelling. Gabion baskets are particularly vulnerable to corrosion in salty coastal environments and therefore may not be suitable for this environment. Gabion and mattress design life can also reduce due to abrasion when constructed in gravel river beds. It is essential that gabions and reno-mattresses be placed on a graded aggregate base or on a geotextile to prevent loss of fines from the foundation soils through the rock filled baskets.

Gabions can be supplied with specialised surface protections that can significantly extend their design life. If this is required then specification for gabions and mattresses should be that baskets are constructed of zinc aluminium mischmetal alloy with plastic (polymer) coating or equivalent. Refer Figure 3.28.

Figure 3.28 Maccaferri gabion baskets used to line and protect water side slope of stopbanks along the Awatararariki Stream, Matatā.

Concrete

Placed concrete blocks are positioned close together on a bedding layer. There is sufficient gap to allow drainage of pore pressure. Their interlocked mass provides sufficient resistance against uplift. For applications where more turbulent flow exists block mattresses are often thicker and tied together. Tied concrete blocks remain stable whilst the slope settles.

The advantage of concrete or asphaltic paving is that the surface can withstand turbulent hydraulic loading provided the leading edge is well designed and does not lift and peel back during the flood. However the lack of permeability means high pore pressures can build up in the stopbank increasing the risk of slope instability. The weight of continuous concrete or asphaltic paving needs to be sufficient to balance uplift pressures developed during drawdown of the water level. Surfaces can crack, causing loss of fines beneath the surface and differential settlement. Inaccessibility to the underlying stopbank earth slope could cause voids to go unnoticed that might lead to erosion.

Maintenance of surface protection measures

Once surface protection measures have been constructed it is important that they are maintained to ensure the stopbank continues to be protected from erosion, caving and scouring. Further recommendations on how to reduce risk of surface erosion are provided in Appendix D.

3.15 Stopbank raising and prevention of toe scour

There are a large number of stopbank types and design manuals available for instructing engineers in the design of these structures. This particular section describes details recommended for two common construction activities:

- Raising stopbank height;
- Prevention of scour at the toe of the waterside stopbank slope.

3.15.1 Raising stopbank heights

Raising stopbank heights typically involves placing fill on the top of the crest and across the landward slope of the stopbank for stability purposes. In order to achieve a good connection between the new and existing fill it is necessary to ensure that:

- The new fill does not slide down the existing landward slope; and
- The new interface does not create a new seepage path.

To achieve these two goals it is necessary to remove the crest and slope topsoil and then create a series of steps as shown in Figure 3.29.

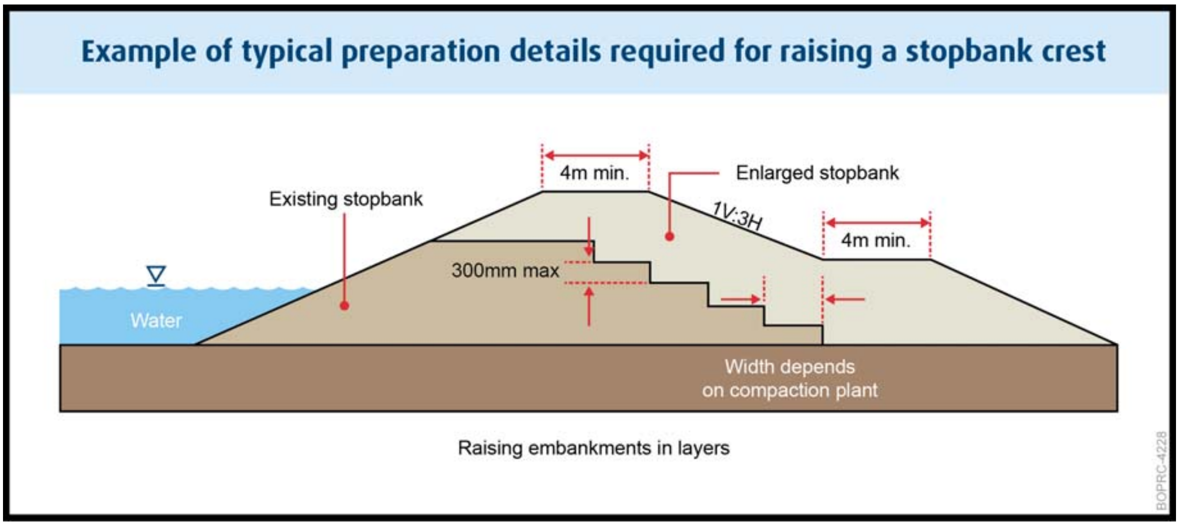


Figure 3.29 Showing an example of typical preparation details required for raising the stopbank crest height.

If an existing stopbank comprises mostly pervious materials (such as rural stopbanks constructed of topsoil) then it may be necessary to construct a cut-off through the existing crest to reduce the amount of seepage. Refer Figure 3.30. If the height of the existing pervious stopbank is too great for an earth fill cut-off then a cut-off wall may be more appropriate. Refer Figure 3.31.

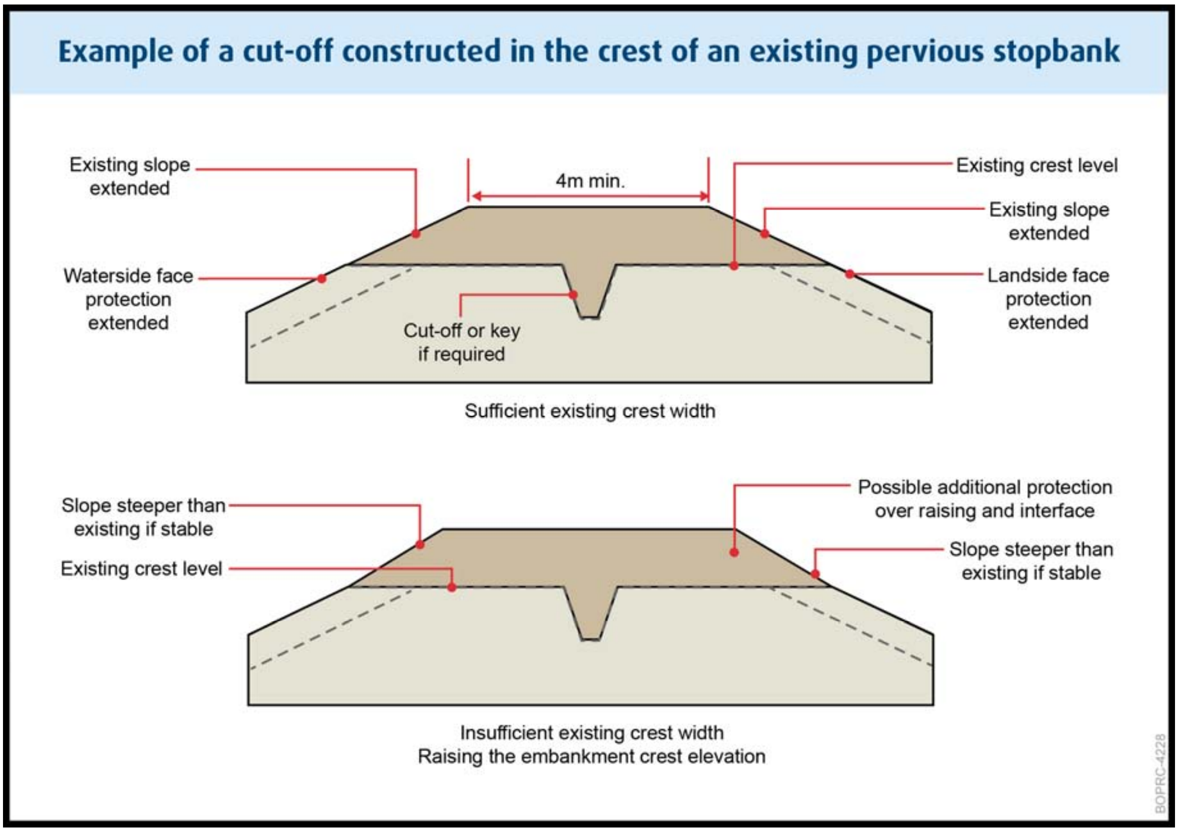


Figure 3.30 Showing an example of a cut-off constructed in the crest of an existing pervious stopbank.

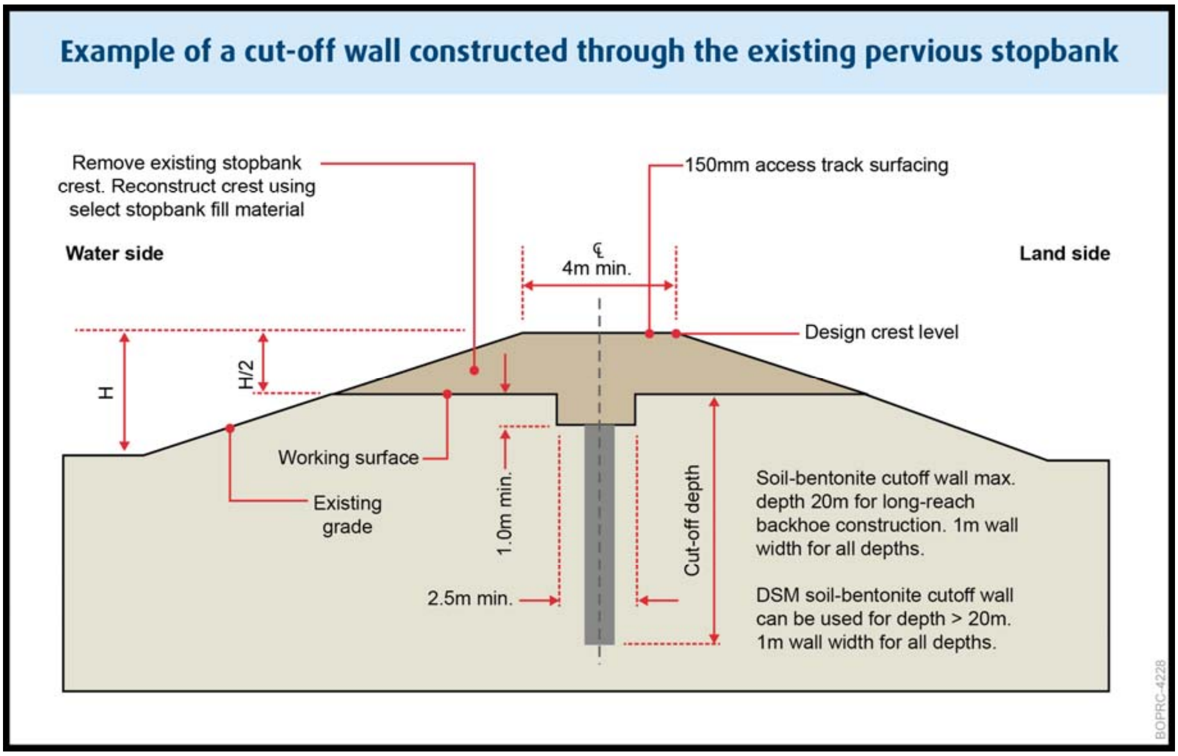


Figure 3.31 Showing an example of a cut-off wall constructed through the existing pervious stopbank.

3.15.2 **Prevention of toe scour**

Many stopbank failure mechanisms result from reduced strength at the base/toe of the waterside slope of the stopbank. For example a shift in the river thalweg can alter local riverbed elevations and change the attack of flow. This can lead to increased scour at the bank which may in turn threaten the stopbank.

There are two main ways of ensuring the toe is protected against undermining scour erosion:

- By providing sufficient material at sufficient depth to account for the maximum scour depth predicted.
- By providing a flexible revetment that will continue to protect the toe as the scour hole develops.

The principal issue for toe protection is that a sufficient quantity of armour material must be placed such that stone can settle into the scoured area as it develops without jeopardising the stability of the remaining bank or slope protection.

Riprap provides an ideal material for protecting the waterside toe against undermining scour erosion. Riprap comprises natural rock laid over a granular or sometimes a geotextile filter layer. The rock acts as a natural energy dissipator and the filter layer allows pore pressure to dissipate from the waterside slope of the stopbank without causing erosion. Refer Figure 3.32.

Figure 3.32 Riprap lined stopbank slope at Reid's Central Canal (viewing downstream).

Figure 3.33 shows some example details for how to secure the toe of rock armouring given in riverine situations.

3.15.3 **Scour at stopbank toe**

Consideration should be given to all the possible modes of scour including general scour (inclusive of scour around bends), any local scour, constriction scour and short term variations in riverbed levels or long term degradation trends. The calculation of scour can be a specialist task and should be undertaken by those experienced in the field. There is an array of formulae available and ones which are recommended are presented in following sections – although this does not discount the use of other proven formulae.

The design scour assessment should be for at least the same frequency flood as the stopbank design. For example, where a stopbank is designed to contain the 1% AEP flood, then the estimate of scour depths (and commensurate protection works design) must be to at least the 1% AEP standard. The Regional Council's advice for protection works outlined in its Hydrological and Hydraulic Guidelines (2012) that design should allow the passage of the 20-year flow without damage **is not** applicable for the protection of stopbanks.

Where cross-section records are available for periods closely following major floods, then they should be carefully inspected to determine the remnant scour depths. Remember these are probably not the maximum depth attained during the flood and the provision will likely need to be increased, but they will give some indication of the scale of scour. The assessment should look at all cross-sections in the vicinity of the proposed stopbank works – this may require assessment of cross-section information over a distance of several hundred metres either side. Cross-section information should also be examined to determine regular variations in riverbed levels.

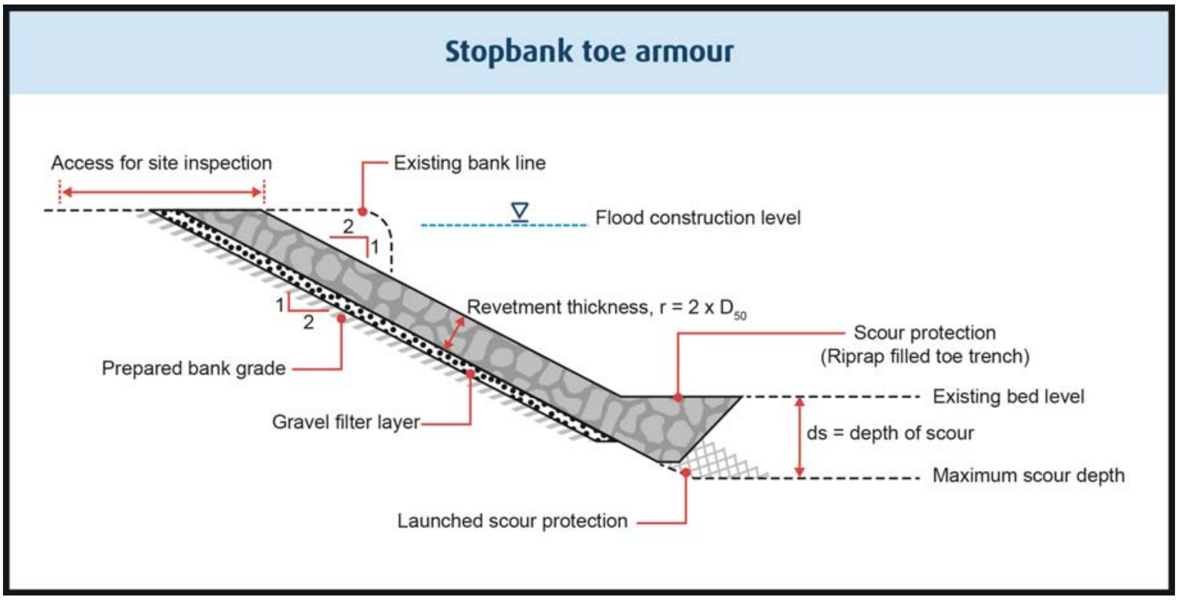


Figure 3.33 Toe armour details (BC, 2000).

With respect to Figure 3.33, a flexible 'launching apron' is laid horizontally on the bed at the foot of the revetment with a height of about 1.5 times the predicted revetment thickness. The intention is that when scour occurs, the apron will settle and cover the side of the scour hole on a natural slope. Alternatively a rock-filled toe trench or toe berm can be constructed at the foot of the slope. This is a variant of the 'launching apron' since the rock in the trench launches as scour develops. This option requires encroachment into the river channel; however a toe trench can be re-buried beneath native stream bed materials.

3.15.4 General scour

Estimates of design general scour depths are necessary for protecting stopbank toes. Two methods are recommended for calculating general scour depths, both of which have proven reliability for New Zealand conditions. They are the NZ Railways method and Maza and Echavarria's method. Formulas and detail on these two methods are provided in the Ministry of Works publication titled 'Code of Practice for the Design of Bridge Waterways' (MWD, 1979). Formulas have been re-produced in Appendix E for the reader's convenience.

The potential for scour can increase as water accelerates around a bend in the river channel. Scour depth around bends may be calculated using the methods described above. However the mean channel velocity should be adjusted as follows:

- Normal bends – increase velocity by factor of 4/3.
- Very sharp bends and groyne heads – increase velocity by factor of 1.5.
- Culvert exits – increase velocity by a factor of at least 1.1 unless hydraulic calculations indicate a greater increase (this might apply at submerged outlets).

3.15.5 Local scour

Local scour is that due to an obstruction, for example a bridge pier. It is rarely possible that there could be a component of local scour from a badly misaligned watercourse hitting a stopbank at close to a right angle. However, in most cases the river and stopbanks will have trained flow to avoid local scour and this component is rarely if ever included.

3.15.6 Constriction scour

Constriction scour occurs where a channel and/or the associated river berm suddenly narrows. If the change in waterway area is more than 10% and velocities markedly increase, then available formulae should be applied. Alternative application of the general scour formulae provided in Appendix E may be possible.

3.15.7 Long-term scour

Consideration is needed of long-term degradation (or aggradation) due to possible factors including:

- Natural degradation or aggradation trends such as in a gorge, or steep reaches;
- Excessive gravel extraction, that may not have worked through to the site yet;
- Upstream dam impoundments, capturing sediment.

In some cases the scour depth in say the 1% AEP flood may be too deep to be fully protected by rock riprap or other means and protection may be installed to a lesser depth, but with provision to top up the protection should settlement occur.

Calculation of rock riprap sizing for stopbank toe protection is provided in Chapter 7 of Council's Hydrological and Hydraulic Guidelines (2012). To protect the stopbank the rock riprap lining should be well compacted and have a layer thickness of at least two times the median rock size (D_{50}).

Maintaining a layer thickness of at least two times the median rock size usually enables the rock to remain in a structurally cohesive mass. Extreme care is required in this approach and it should rarely be used when protecting urban stopbanks, but has uses in the rural setting in deep rivers.

The design of scour protection is covered in Austroads (1994) Section 6.3. Particular attention is required to the depth of embedment of the toe of the rock riprap and the interfaces between the riprap and any adjoining surfaces.

3.16 Settlement

Stopbanks can compress the underlying soils over a zone of influence greater than the stopbank's actual footprint. This compression process is called settlement and is important to designers if it causes loss of freeboard and/or damages the stopbank. Settlement can occur within the stopbank and in foundation soils. Refer Figure 3.34.

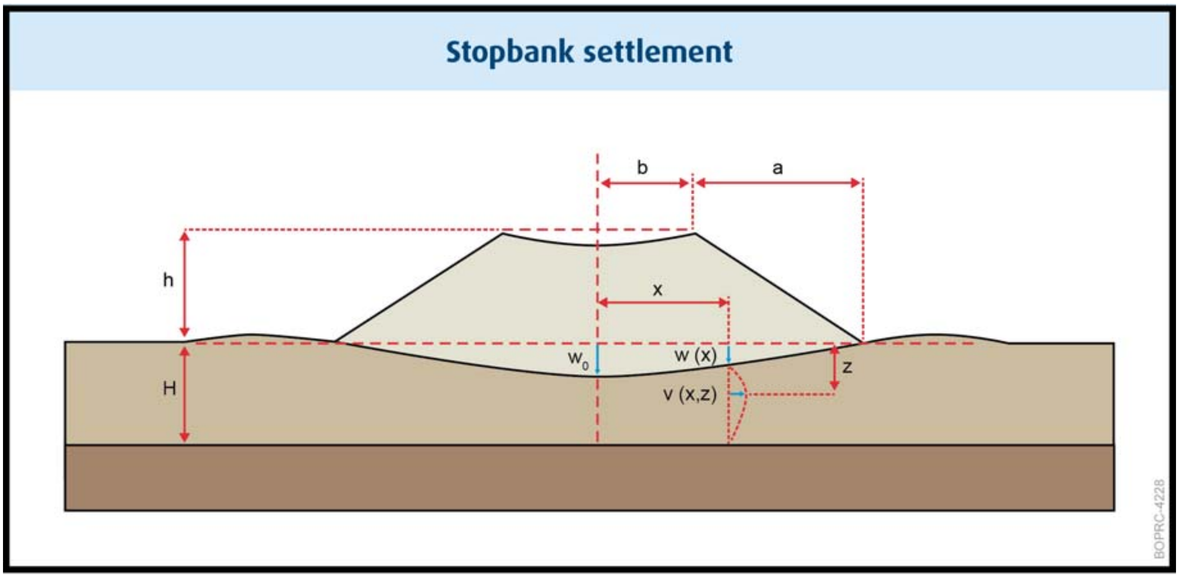


Figure 3.34 Stopbank settlement.

Total settlement (w_t) comprises different stages as demonstrated in Figure 3.35. The stages are described as follows:

- Instantaneous settlement (w_i) which occurs during initial loading under un-drained conditions.
- Primary or consolidation settlement (w_c), that is a function of the different soil layer types and is due to the squeezing out of water from within the soil mass.
- Secondary or creep settlement (w_s), which corresponds to soil grain re-organisation. For soft soils and peat, the secondary phase can have significant impact over the life of the stopbank and should be taken into account early in the project.
- Settlement due to irreversible lateral movement (w_l), vertical settlement can also cause horizontal soil displacement.

Where the foundation soils have high permeability or the drainage paths to a high permeability layer are short most of the settlement will occur during construction. For low permeability soils it is usually conservatively assumed that all the calculated settlement of a stopbank built by a normal sequence of construction operations will occur after construction. Where analyses indicate that more foundation settlement would occur than can be tolerated, partial or complete removal of compressible foundation material may be necessary for both stability and settlement purposes. When the depth of excavation required accomplishing this is too great for economical construction, other methods to ensure stability and promote consolidation, such as staged construction or vertical sand drains may have to be employed.

There should be little post construction settlement within an embankment built of fill well compacted at close to its optimum water content.

Settlement estimates can be made by theoretical analysis as described in most geotechnical texts. One such useful text is 'Principles of Engineering Geology and Geotechnics: Geology, Soil and Rock Mechanics, and other science as used in civil engineering' by D.P Krynine (1957) by McGraw-Hill.

Detailed settlement analyses should be made when significant consolidation is expected for example when there are high embankment loads, embankments built of highly compressible soil, embankments built on highly compressible foundations and beneath steel and concrete structures in stopbank systems founded on compressible soils. Numerical methods such as the Finite Element Method (FEM) are available for more detailed settlement predictions however some models require complex input data which are not easily obtained from laboratory tests.

Many stopbank owners simply overbuild a stopbank by a given percent of its height to take into account anticipated settlement both of the foundation and within the stopbank fill itself. Overbuilding does however increase the severity of stability problems and may be impracticable or undesirable for some foundations.

Common allowances for settlement within the fill are:

- 0% to 5% for compacted fill;
- 5% to 10% for semi-compacted fill;
- 15% for un-compacted fill; and
- 5% to 10% for hydraulic fill.

Compacted fill stopbanks are built when foundations have adequate strength and are of low compressibility. They are found where space is limited in urban areas both with respect to quantity of borrow and stopbank geometry. The natural water content of the borrow material is reasonably close to specified ranges required in the stopbank.

Semi-compacted fill stopbanks are built where there are no space or stopbank slope limitations. Relatively weak foundations exist and under seepage conditions are such that a wide stopbank footprint is required. The Bay of Plenty has few (if any) semi-compacted fill stopbanks and this option would not be selected today.

Un-compacted fill stopbanks are constructed infrequently today. They may be constructed in times of emergency where fill is simply dumped in place in thick layers with little or no spreading or compaction. Borrow material is often very wet and frequently has high organic content.

Hydraulic fill consists mostly of pervious sands built with one or two end-discharge or bottom discharging pipes. Hydraulic fill is pervious and will erode quickly if overtopped. Hydraulic fill is used to construct stopbanks that protect rural areas whose failure will not endanger human life and in zoned stopbanks that include impervious seepage barriers.

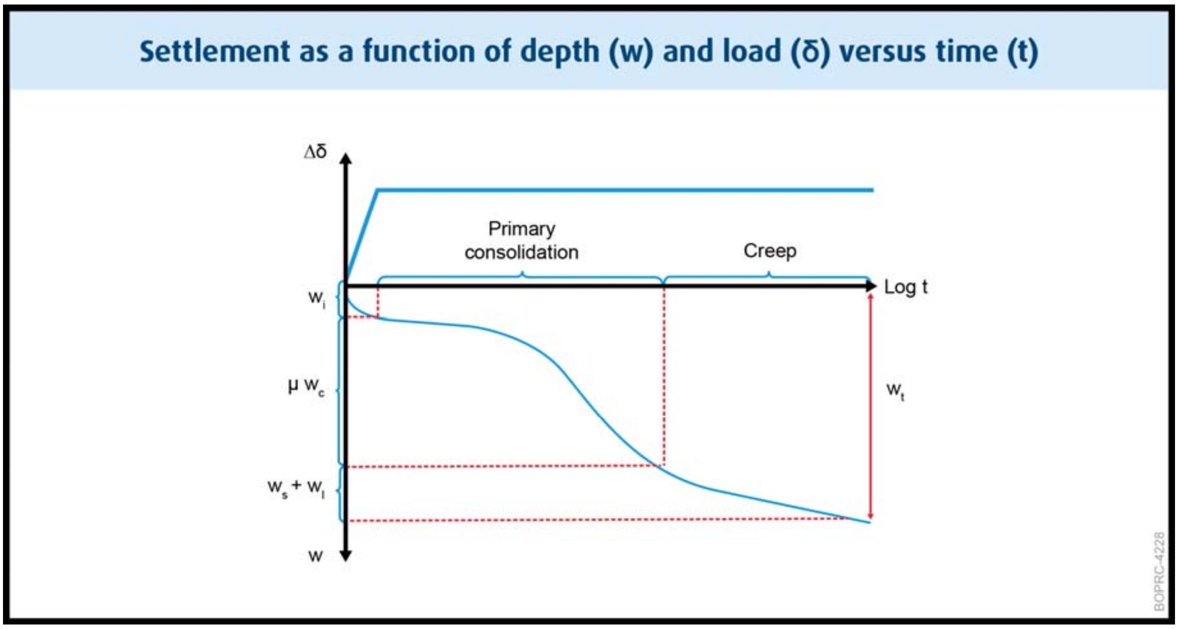


Figure 3.35 Settlement (w) and load (σ) versus time (t). Note: 'Creep' detailed in this figure is also referred to as 'secondary settlement'.

Part 4: Construction

4.1 Pre-construction planning

The success of a stopbank construction project can depend, in many ways on how well planning was done before hand. Planning the stopbank project should involve people with experience in design and construction of stopbanks to reduce potential risks. Prior to carrying out construction it is assumed the owner will already have:

- Confirmed a flood risk exists and identified the service level requirements for proposed stopbank.
- Confirmed land ownership of the proposed construction site.
- Consulted with relevant stopbank designers, planners and contractors.
- Identified potential stopbank construction risks.
- Undertaken investigations to confirm the best structural measure to provide flood protection.
- Acquired relevant resource consents including identification of risks, adverse effects, proposed mitigation and subsequent confirmation of approval from stakeholders to construct the stopbank. Stakeholders include neighbour landowners, relevant local and regional authorities.
- Carried out detailed design of the stopbanks, penetrations (such as culverts) and appurtenant structures (such as flood gate and pump structures).

4.2 Contract type

Authorities responsible for the construction and/or maintenance of stopbanks should formulate procedures for managing different types of stopbank construction including the type of contract to be used for the works (large and small). Table 4.1 describes some contract type options available to stopbank owners, including their advantages and disadvantages.

Table 4.1 Typical contract types suitable for stopbank construction, upgrades and repairs.

Contract type	Advantages	Disadvantages
Design – tender – construct Suitable for risky new stopbank or upgrades. Undertaken by qualified designers. Used where construction timing not critical but budget is a priority.	Separate design and construction specialists. Increased opportunity for screening qualifications and competitive bidding between specialists.	Potential delays between design and construction stages. Requires owner to co-ordinate between designer and constructor (supervised by designer). No constructor involvement during design stage.
Early constructor involvement Suitable for risky or complex new stopbanks or upgrades. Used where construction timing is critical and budget is not a priority.	Separate design and construction specialists. Constructor involvement during design phase. Shorter construction time due to concurrent awards.	Requires owner to co-ordinate between designer and constructor.

Contract type	Advantages	Disadvantages
Design – build Suitable for simple new stopbanks, upgrade or repairs. Used where construction timing is critical and budget is a priority.	Owner deals with a single entity. Shorter construction time.	Owner has less control over design process and specification.
Design-build-fund-operate Suitable for new stopbanks with low financial risk or upgrades where owner funding options are needed.	Owner deals with a single entity. Shorter construction time. Owner has more funding options including amortising costs until user fees are generated.	Owner cedes control over entire process to the selected constructor.
Cost reimbursable Suitable for emergency stopbank repairs or very simple upgrades or repairs with low design requirements.	Owner can direct changes as work progresses.	Owner assumes risks of costs and programme performance.
Direct labour Suitable for emergency stopbank repairs, or very simple upgrades or repairs with low design requirements.	Owner has unfettered control over all project details.	Owner assumes all risk of cost, programme, and technical performance.

Points to note when deciding contract type are as follows:

- A policy decision should be made regarding the size of the day labour workforce required, and whether the owner can undertake the work in-house.
- A decision should be made to split contracts into major and minor works, based on dollar value and/or complexity of work required. This will facilitate development of contract documentation, avoiding overly complex contracts for small or minor works.

Clear policies dealing with the these matters, together with a knowledge of the roles and responsibilities of the principal, engineer and contractor, in the contractual processes, should lead to the successful development of projects, tenders and the eventual construction of these assets. Regional Council, for example has its own procurement procedures and policies that staff use when engaging contractors to construct stopbanks.

4.3 Specification

Specifications for stopbank construction are typical of those associated with earthworks with the added focus on ensuring the stopbank safely retains flood water without failing. The content of the specification therefore focuses on what's required to assure correct:

- Site preparation;
- Material selection and placement;
- Seepage control and drainage control installation; and
- Erosion protection.

Typical requirements of a stopbank specification are provided in Appendix F. The specification is reasonably generic and can be adopted for use with most of the contract types described above.

4.4 Schedule of quantities

The schedule of quantities for stopbank construction is structured in a manner similar to that of other construction projects that have an earthworks section. Typically tenderers are expected to submit the following (but not exclusive to) rates for:

- Compliance with resource consent conditions, such as mitigation against construction erosion, sediment control, treatment and discharge.
- Stopbank earthfill material testing.
- Moving earth fill material of varying quality e.g. material quality ranging from that suitable for constructing the stopbank to material deemed unsuitable for stopbank construction.
- Adjusting the moisture content of earth fill suitable for stopbank construction (normally paid for on an hourly basis).
- Fill placement based on the total volume (based on m^3 rate) placed and compacted in accordance with the drawings and specifications, with the finished levels confirmed by survey.
- All stopbank shaping, topsoiling, harrowing and grass sowing (based on m^2 rate).
- All appurtenant structures such as pump stations, flood gates and stopbank penetrations such as culverts and discharge pipes.

4.5 Conditions of contract

Contract documentation to NZS 3910 Conditions of Contract for Building and Civil Engineering Construction, or similar, should be used for the General Conditions of Tendering, and General Conditions of Contract, where size and/or complexity places the works above a “minor“ works category.

4.6 Types of construction

Good construction practices related to the four types of stopbank activities (new build, repair, adaptation and decommissioning) have many common characteristics. They are derived and adapted from other earthwork activities such as foundation excavation and embankment construction; however they require more specialised attention to details.

This section focuses on procedures recommended for the repair and adaptation of stopbanks as these are the most commonly undertaken activities associated with stopbanks in the Bay of Plenty.

4.6.1 Repair of stopbanks

The goal is to restore the levels of protection and dimensions of existing stopbanks after damage or deterioration. This activity is concerned with restoring missing or damaged stopbank features using materials that do not add any additional risk of stopbank damage or flooding. Some procedures include:

- Keeping a stock of emergency repair materials (sandbags, riprap etc.) on hand.
- Removal of adverse soils, such as organics, to eliminate slip surfaces.
- After repairs are completed, monitoring of stopbank performance by topographical survey, seepage measurements and visual inspection.

4.6.2 Adaptation of stopbanks

When the objective is to raise or strengthen existing stopbanks without reducing the levels of flood protection during construction then relevant procedures include:

- Clearing the existing stopbank surfaces of vegetation and roots and stripping topsoil layers. (The contractor should avoid stripping topsoil over the entire length at one time as to do so would make stopbank vulnerable to erosion during rain or flood.) The work should be carried out at the best times of year for grass re-establishment.
- Stockpiling stripped topsoil and riprap for future use.
- Forming a series of ‘benches’ in the stopbank face to reduce the risk of preferential slip planes forming.
- Having in place temporary/emergency measures for erosion protection that may be required during stopbank construction.
- Avoiding the implementation of the adaptation work during periods of high tide or during wet seasons.
- Maintaining existing drainage features (ditches, drainage pipes, etc.) until new features are in place and fully operational. Cleaning and completely filling or plugging all abandoned features including wells, piles, ditches etc.

Part 5: Operation and maintenance

5.1 Asset Management Plan

Asset management is defined as (CIRIA, 2013):

> *'the systematic and co-ordinated activities and practices through which an organisation optimally manages its asset's condition, performance, risks and expectations and expenditures over the life cycle of the asset for the purpose of its achieving its organisational strategic plan'.*

Operation and maintenance (O & M) of stopbanks is therefore a critical part of asset management. Despite stopbanks remaining unused for long periods, they can be required to operate to a predetermined level, often at short notice. To ensure the stopbanks can perform adequately, it is essential to provide appropriate maintenance.

The O & M manual describes stopbank service levels, design assumptions and details and outlines what maintenance is required to maintain service levels.

5.2 Operations and Maintenance Manual

The development of an O & M manual should be an integral part of the design and construction process for a stopbank. The O & M manual should contain details, such as:

- The location of the stopbank.
- The outcome the works are expected to achieve.
- The design details, including design levels.
- Cross-sections.
- As-built plans.
- Details of drainage systems and any temporary pumping that may be required.
- Specific maintenance tasks.
- Environmental considerations that affect O & M practices such as when in-river work can be carried out.
- A list of contact people and actions to be taken.

A manual covering these details should provide the basic information required by emergency agencies, during a flood event, as well as a sound basis for setting priorities for the future maintenance of the system.

5.3 Condition assessments

Apart from the day to day observations and reports of repairs required, it is important to carry out condition assessments in the form of regular inspections, say at least once a year. This inspection should be carried out by an experienced person, with a check sheet to record information. Refer Appendix G for a sample checklist. The inspection should cover associated works including drains, floodways and waterways, transitions and penetrations to ensure that there are no problems in these areas; e.g. rabbit burrows, trees, scour of banks, build-up of debris or weed growth, which would affect the capacity, and consequently the function of the stopbank.

Inspections should also be carried out during and after major flood events to record the event and stopbank performance, as well as any works required as a result of the event.

Where there is adequate warning time before a flood event, an inspection should be carried out to ensure all necessary preventative actions have been taken and no repair works remain undone.

The annual inspection will provide the basis for updating the maintenance program, which enables stopbanks to be maintained to provide the required level of protection over time.

Sections 5.4, 5.5 and 5.6 outline maintenance typically prescribed for addressing issues identified during visual inspections of stopbanks.

5.4 Stopbank slope maintenance

Stopbank slope maintenance is generally confined to a range of routine tasks, which are carried out on a needs basis, or as part of the Annual Maintenance Programme. The following listing indicates the general range of activities. The priority of work will depend on the location of the stopbank and the assessment of the responsible maintenance personnel.

5.4.1 Batter slope slumping

Slope slumping may appear following a flood event when waters return to their normal levels. The slumped section of bank should be fully inspected, excavated and reconstructed using suitable material and, where possible, with a flatter batter slope to improve the stability of the bank section. Figure 3.29 provides an example of how batter slopes can be repaired safely without reducing stability of the stopbank.

5.4.2 Mowing

The main areas that require mowing on stopbanks are at road crossings, to ensure visibility for safety reasons. Mowing should be carried out as part of the normal maintenance activities. The cut grass adds mulch to the batters assisting grass growth and improving stability of the stopbank, as well as reducing moisture loss.

5.4.3 Tree removal

Trees growing on a stopbank should be removed at the earliest possible opportunity. Mature trees in a stopbank, will lead to cracking by increasing the drying out of the soils and could also be blown over, damaging the stopbank.

Trees including all root systems should be removed to ensure that no seepage paths remain.

5.4.4 Grazing of stock

Generally, grazing should not be permitted on stopbanks, because it destroys the vegetative and mulch cover on the batters, as well as the underlying bank. Grazing cattle can also cause settlement which reduces the freeboard. The most difficult feature of grazing is managing the level of activity the stopbank can tolerate. If this can be achieved, grazing of stopbanks by light stock, on an occasional basis, may be acceptable, particularly in periods of heavy grass growth.

5.4.5 Rabbit burrows

Rabbit burrows in a stopbank can lead to a weakening of the structural integrity of the stopbank by the creation of a weak spot in the bank.

Repairs should be carried out immediately and should consist of clearing the burrows by fumigation or poison, digging them out and filling the resultant holes with properly compacted clay. If it is found that the rabbits prefer a particular soil layer for burrowing, the placement of a firm cohesive or rocky overlay across the layer can deter burrow excavation.

5.5 Crest maintenance

Irrespective of the type of crest protection, the objective of crest maintenance is to maintain the required relative level of the stopbank, as well as the crest profile that enables rainfall to be shed from the bank. Maintenance is basic and consists of backfilling low areas, light grading, as required, and filling of potholes, to avoid ponding of water and possible piping failures.

In the case of a gravelled crest, periodic re-gravelling may be required, and for top-soiled banks, re-topping to maintain the crest level.

5.6 Drainage systems

Stopbanks interfere with drainage channels and drainage outfalls located under stopbanks are potential weak spots within the stopbank. All drainage structures need to be inspected regularly, to ensure their effective operation in a flood event. The inspection should cover:

- Earthworks.
- Headwalls.
- Cut-offs.
- Beaching/riprap.
- Operation of valves or stop logs, to ensure the integrity of the structure is satisfactory and not just that the valve operates.

During a flood event, where drains pass through a stopbank, it may also be necessary to provide pumping facilities to enable drainage flows to be pumped over the stopbank after the control gates have been closed.

Pumping arrangements, including the timing of gate closures, need to be detailed in the operational procedures. The inclusion of this information ensures that staff is aware of potential problems and can then deal with them as required.

Part 6: Emergency works

6.1 Emergency preparedness

Apart from the previous arrangements, there are a number of important subsidiary activities that affect the ability of a community to satisfactorily manage a significant flood event. These include areas such as flood monitoring, communication, road monitoring/closures, media releases, evacuation and relief, livestock management, asset protection, registration of volunteers, feeding etc.

These activities rely heavily on a community that is aware of the nature of the emergency and the plan to combat it, as well as having the minimum core of skills necessary to carry out the various tasks involved.

To improve community response in a flood event, it is necessary to develop a strategy which will increase their general knowledge, awareness and basic skills. Development of a strategy or program, which will do this, should consider the following points:

- A Regional and Territorial Flood Emergency Management Plan with details of current emergency contacts (names, position titles and phone numbers including after hours).
- The preparation of inundation maps available to the public.
- Procedures for the evacuation of camping and caravan holiday parks and other low lying areas.
- Media releases, bulletins etc. pre-prepared.
- Media interview techniques for selected positions.
- Support agency training.
- Revision/training on sandbag laying techniques.
- The development of inter-agency liaison arrangements.
- Dissemination of handbooks and awareness material.
- Consideration of addresses to community groups and schools.
- The arrangement of pre-flood briefings.
- The arrangement of pre-flood public meetings.

Many of the areas mentioned in this section are covered in the various Regional and Territorial Emergency Management Plans and Sub-Plans, which have been developed over time. These plans should include all of the appropriate criteria used in the design of stopbanks, together with any plans, levels and other information considered useful in an emergency.

6.2 Emergency flood barriers

Temporary flood barriers can be installed to provide a flood defence barrier in areas where the predicted height of the rising river exceeds the stopbank crest level or in areas where no flood protection exists. Sandbags are probably the most commonly deployed means of erecting an emergency flood barrier. However there are other technologies that use modern materials and innovative design. These include filled tubes and containers and portable barriers. An array of these measures used internationally is provided in Appendix H.

Often the flood barriers can be purchased and placed in storage ready to deploy where needed in a flood event. The key points to consider when selecting a flood barrier are that they be easy to store, transport, construct, stable when under load and preferably re-useable.

6.3 Emergency stopbank repairs

A well designed stopbank should be able to hold up during a flood up to its design level with freeboard. However there will always be some degree of residual risk of an emergency arising during the life of a stopbank subject to flood loading. The risk increases with rising flood level, lengthened duration of the flood and increased intensity of wave action against the stopbank.

There are three main potential failure modes that are associated with stopbanks and to which stopbank owners must give prior thought as to how they will manage them should they eventuate:

- External erosion – includes erosion triggers such as overtopping, wave wash and scour.
- Internal erosion – includes erosion triggers such as seepage, piping and sand boils.
- Instability – includes slope failure.

Potential stopbank failure may be avoided if prompt action is taken and proper response methods are employed. Table 6.1 outlines the response measure that can be used as an intervention for the three potential failure modes noted above.

Table 6.1 Measures that can be used as intervention during an emergency response (CIRIA, 2013).

Failure mechanism	Applicable intervention	Measures
External erosion	Raise the stopbank crest (locally only, or if carefully planned at a larger scale).	Place and compact bulk fill on stopbank crest.
		Construct sandbag stopbank on top of crest.
		Use novel material: lightweight concrete blocks, straw bales, tyre bales on top of stopbank crest.
		Drive piling through waterside slope (hear toe) or crest of stopbank.
		Construct a flashboard structure on stopbank crest.
		Construct any one or combination of the Emergency Flood Barriers discussed in Section 6.3 and Appendix G.
	Provide erosion protection.	Construct a rock riprap berm on waterside slope of stopbank.
		Place an asphalt/bitumen layer on waterside slope of stopbank.
		Construct small groyne to deflect current away from stopbank.
	Provide protection against overtopping erosion.	Place plastic sheeting on the crest and landward slope of stopbank.
		Construct an emergency spillway.
Internal erosion	Reduce infiltration to reduce through – seepage.	Place impermeable plastic sheeting on the waterside slope of stopbank.
	Increase seepage path to reduce through – seepage.	Construct seepage berm on the landward toe area of the stopbank.
	Reduce hydraulic gradient to reduce under-seepage.	Ringing sand boils, allowing associated seepage water level to rise and pond within confined ring.
Instability	Reduce slope inclination and steepness on landward slope of stopbank. Place rock fill at the waterside toe.	
	Reduce hydraulic gradients under the stopbank and the risk of heave beyond the stopbank by constructing a seepage berm at the landward toe.	
	Reduce the saturation of the stopbank by reducing through seepage via placement of impermeable plastic sheeting on the waterside slope of stopbank. This measure may only be possible at low flood levels and if safe access to the waterside slope is still possible.	
	Initiate a controlled breach at suitable location along the stopbank's length to reduce watercourse level and landward damage.	

Regional Council personnel follow their in-house Safe Operating Practices for Emergency Works whenever they undertake flood mitigation activities.

References

Austroads (1994) Waterway Design – A Guide to the Hydraulic Design of Bridges, Culverts and Floodways.

BC (2000) Riprap Design and Construction Guide, Public Safety Section, Water Management Branch, Province of British Columbia, Ministry of Environment, Lands and Parks, March 2000. http://www.env.gov.bc.ca/wsd/public_safety/flood/pdfs_word/riprap_guide.pdf

BOPRC (2012) Rivers and Drainage Asset Management Plan, Bay of Plenty Regional Council.

BOPRC (2008) Bay of Plenty Regional Council Floodway and Drainage Bylaw 2008, Bay of Plenty Regional Council, adopted 19 June 2008.

BOPRC (2012) Hydrological and Hydraulic Guidelines, Bay of Plenty Regional Council, Environmental Hazards Group, Guideline 2012/02, ISSN 1179 9609.

CIRIA (2013) The International Levee Handbook, 2013, CIRIA, US Army Corp of Engineers, French Committee for Dams and Hydraulic Works, CIRIA C731, ISBN 978 0 86017 734 0.

MWD (1979) Code of Practice for the Design of Bridge Waterways, Issue C November 1979, Water & Soil Division, Civil Division Publication, CDP 705/C, November 1979.

NRE (2002) Levee Design and Construction Maintenance, State Government Victoria, Department of Natural Resources and Environment, ISBN 0 7311 50414. http://www.water.vic.gov.au/__data/assets/pdf_file/0018/15264/Levee-Design.pdf

DWR (2012) Urban Levee Design Criteria, State of California, The Natural Resources Agency, Department of Water Resources, May 2012, http://www.water.ca.gov/floodsafe/leveedesign/ULDC_May2012.pdf

USACE (2000) Engineering and Design Construction of Levees, 30 April 2000, Department of the Army, USACE, Ref: EM 110-2-1913. http://publications.usace.army.mil/publications/eng-manuals/EM_1110-2-1913_sec/Sections/basdoc.pdf

Glossary

Appurtenances	Structures and equipment on a project site, other than the stopbank itself. They include but are not limited to facilities such as water control and release structures such as pump stations, drainage gate structures, culverts and flap gates. Also included are mechanical and electrical and standby power supply equipment located inside pump stations and drainage gate structures.
Average Recurrence Interval (ARI)	The long-term average number of years between the occurrence of a flood as big as (or larger than) the selected event. For example, floods with a discharge as great as (or greater than) the 20-year ARI design flood will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event. (See also annual exceedance probability).
Annual Exceedance Probability (AEP)	A statistical measurement of the annual chances (in %) of a flow of a specified size being equalled or exceeded in any given year.
Cohesive Soil	A sticky soil, such as clay or silt; its shear strength equals about half its unconfined compressive strength.
Cumec	A cumec measures water flow. One cumec equals one cubic metre of water passing a given point every second (1 m^3/sec).
Riprap	Rock specifically designed and placed against water retaining banks in order to protect the slope from surface erosion.
Runoff	The amount of rainfall from a catchment that actually ends up as flowing water in the river or creek.

Appendices

Appendix A – Stability analysis of stopbanks

A1 Embankment slope stability

Many stopbank owners have established standard stopbank-sections for particular stopbank systems, which have proven satisfactory over the years for the general stream regime, foundation conditions prevailing in those areas and for the soils available for stopbank construction.

In many cases the standard stopbank section has more than the minimum allowable factor of safety relative to slope stability, its slopes being established primarily on the basis of construction and maintenance considerations. That said it is still prudent for the asset owner to undertake stability analysis to re-assure themselves that the asset will remain reliable when in operation.

Typical global factors of safety for slope stability on new or existing stopbanks subject to hydraulic and/or seismic loads are provided by the likes of USACE and the State of California's Department of Water Resources (DWR) published together in the CIRIA Levee Handbook (2013). A simplified table combining parameters from both authorities has been produced in Table A1.1.

Table A1.1 Global factors of safety and allowable hydraulic gradients based on DWR and USACE criteria (CIRIA, 2013).

Parameter	**Criteria**			
Seepage exit gradient at stopbank toe.	At DWSE		At HTOL	
	ϒ ≥ 17.6 kN/m3	ϒ< 17.6 kN/m3	ϒ ≥ 17.6 kN/m3	ϒ< 17.6 kN/m3
	i ≤ 0.5	FS ≥ 1.6	i ≤ 0.6	FS ≥ 1.3
Seepage exit gradient at seepage berm toe.	i ≤ 0.8	FS ≥ 1	<20% FS degradation for berms less than 30.5 m	<10% FS degradation for berms less than 30.5 m
End of construction.	FS ≥ 1.3			
Long-term (steady state seepage) slope stability on landside+.	FS ≥ 1.5^		FS ≥ 1.2	
Rapid draw-down slope stability on waterside.	FS ≥ 1.2 (prolonged high stage sufficient for steady state conditions to develop). FS ≥ 1 (short lasting high stage insufficient for steady state conditions to develop).			
Frequent large, tidal fluctuations rapid drawdown slope stability on waterside.	FS ≥ 1.4 #			
Seismic vulnerability.	No significant deformation, usually limited to 0.91 m maximum with 0.3 m of vertical settlement.			

Key: DWSE = design water surface level.
HTOL = hydraulic top of stopbank (normally crest level).
ϒ = saturated unit weight of soil (shoulder layer).
I = exit gradient.
FS = factor of safety.

Notes:

+ these stability factors of safety are irrespective of whether stopbank is loaded frequently or intermittently.

^ for existing stopbanks where either sliding or large deformation has occurred previously, and back analysis have been performed to establish design shear strengths, lower factors of safety may be used. In such cases probabilistic analysis may be useful in supporting the use of lower factors of safety for design.

this is an additional criterion that applies to stopbanks exposed to a range of tidal level fluctuation (not the DWSE).

The acceptable exit gradient values in given in Table A1.1 may not be suitable for light pumice based or diatomaceous soil. A critical gradient of 0.4 is commonly used for the pumiceous soils in the Bay of Plenty.

The various loading conditions to which a stopbank and its foundation may be subjected and which should be considered in analyses are designated as follows:

- Case I, end of construction;
- Case II, sudden drawdown from peak flood stage;
- Case III, steady seepage from peak flood stage, fully developed phreatic surface;
- Case IV, earthquake;
- Case V, low river level (this is often more critical than the peak flood stage).

Each case is discussed briefly in the following paragraphs. The minimum required factors for the preceding design conditions along with the portion of the embankment for which analyses are required are detailed in Tables A1.1 Applicable design shear strength are described below:

Case I

End of construction. This case represents un-drained conditions for low permeability embankment and foundation soils; i.e. excess pore water pressure is present because the soil has not had time to drain since being loaded. Results from laboratory unconsolidated-un-drained shear tests are applicable to fine-grained soils loaded under this condition while results of consolidated-drained shear tests can be used for permeable soils that drain fast enough during loading so that no excess pore water pressure is present at the end of construction. The end of construction condition is applicable to both the riverside and landside slopes.

Case II

Sudden drawdown. This case represents the condition whereby a prolonged flood stage saturates at least the major part of the water side slope and then falls faster than the soil can drain. This causes the development of excess pore water pressure which may result in the water side slope becoming unstable. For the selection of the shear strengths see Table A1.2.

Case III

Steady seepage from the full flood stage (fully developed phreatic surface). This condition occurs when the water remains at or near peak flood level long enough that the embankment becomes fully saturated and a condition of steady seepage occurs. This condition may be critical for landside slope stability. Design shear strengths should be based on Table A1.2.

Case IV

Earthquake. Earthquake loadings are not normally considered in analysing the stability of stopbanks because of the low probability of earthquake coinciding with periods of high water. Stopbanks constructed of loose cohesionless materials or founded on loose cohesionless materials are particularly susceptible to failure due to liquefaction during earthquakes. Depending on the severity of the design earthquake and the importance of the facilities the stopbank is protecting, seismic analyses to determine liquefaction susceptibility may be required. The analyses should include the estimation of the amount of lateral spreading and cracking of the stopbank.

Table A1.2 Summary of design cases to be analysed (USACE, 2000)

Table 6-1a
Summary of Design Conditions

Analysis Condition	Shear Strength[a]	Pore Water Pressure
During and End-of-Construction	Free draining soils - use effective stresses	Free draining soils - Pore water pressures can be estimated using analytical techniques such as hydrostatic pressure computations for no flow or steady seepage analysis techniques (flow nets, finite element analyses or finite difference analyses).
	Low permeability soils - use undrained strengths and total stresses[b]	Low permeability soils - Total stresses are used; pore water pressures are set to zero in the slope stability computations.
Steady State Seepage Conditions	Use effective stresses. Residual strengths should be used where previous shear deformation or sliding has occurred.	Estimated from field measurements of pore water pressures, hydrostatic pressure computations for no flow conditions, or steady seepage analysis techniques (flow nets, finite element analyses or finite difference analyses).
Sudden Drawdown Conditions	Free draining soils - use effective stresses	Free draining soils - First stage computations (before drawdown) - steady-state seepage pore pressures as described for steady state seepage condition. Second and third stage computations (after drawdown) - pore water pressures estimated using same techniques as for steady seepage, except with lowered water levels.
	Low permeability soils - Three stage computations: First stage use effective stresses; second stage use undrained shear strengths and total stresses; third stage use drained strengths (effective stresses) or undrained strengths (total stresses) depending on which strength is lower - this will vary along the assumed shear surface.	Low permeability soils - First stage computations - steady-state seepage pore pressures as described for steady state seepage condition. Second stage computations - Total stresses are used pore water pressures are set to zero. Third stage computations - Use same pore pressures as free draining soils if drained strengths are being used; where undrained strengths are used pore water pressures are set to zero.

[a] Effective stress parameters can be obtained from consolidated-drained (CD, S) tests (either direct shear or triaxial) or consolidated-undrained (CU, R) triaxial tests on saturated specimens with pore water pressure measurements. Direct shear or Bromhead ring shear tests should be used to measure residual strengths. Undrained strengths can be obtained from unconsolidated-undrained (UU, Q) tests. Undrained shear strengths can also be estimated using consolidated-undrained (CU, R) tests on specimens consolidated to appropriate stress conditions representative of field conditions; however, the "R" or "total stress" envelope and associated c and ö, from CU, R tests should not be used.
[b] For saturated soils use ö = 0; total stress envelope with ö > 0 is only applicable to partially saturated soils.

A1.2 Stopbank slope stability analysis

The principal methods used to analyse stopbank embankments for stability against shear failure assume either:

- A sliding surface having the shape of a circular arc within the foundation and/or the embankment; or
- A composite failure surface composed of a long horizontal plane in a relatively weak foundation or thin foundation stratum connecting with diagonal plane surfaces up through the foundation and embankment to the ground surface.

Various methods of analysis can be chosen for use where determined appropriate by the designer.

Computer programs are available for these analyses with the various loading cases so the effort of making such analyses is greatly reduced and primary attention can be devoted to the more important problems of defining the shear strengths, unit weights, geometry and the limits of possible sliding surfaces.

A1.3 Measures to increase stopbank slope stability

Methods of improving stopbank stability by changing the embankment cross-section are described as follows:

- Flatten embankment slopes. Flattening embankment slopes will usually increase the stability of an embankment against a shallow surface type failure that takes place entirely within the embankment. Flattening embankment slopes reduces the down slope gravity forces and increases the length of potential failure surfaces, therefore increasing the resistance to sliding.
- Stability berms. Berms essentially provide the same effect as flattening embankment slopes but are generally more effective because they concentrate additional weight where it is needed most and force a substantial increase in the length of the failure path. Thus, berms can be an effective means of stabilization not only for shallow foundation and embankment type failures but for more deep-seated foundation failures. Berm thickness and width should be determined from stability analyses and the length should be great enough to encompass the entire problem area, the extent of which is determined from the soil profile. Foundation failures are normally preceded by lateral displacement of material beneath the embankment toe and by noticeable heave of material just beyond the toe. When such a condition is noticed, berms are often used as an emergency measure to stabilize the embankment and prevent further movement.

A2 Internal erosion/piping

Internal erosion is related to all processes that involve soil particles detaching from each other and being transported by seepage within the stopbank. Transportation of soil particles can lead to instability and failure of the stopbank. There are three potential internal erosion failure modes that should be checked in the stopbank.

They are:

- Internal erosion through the stopbank.
- Internal erosion through the stopbank foundation.
- Internal erosion of the stopbank into or at the foundation.

In addition there are four different internal erosion processes that can be present for each of the above failure modes, namely:

1 Backward erosion: Detachment of soil particles when seepage exits at an unfiltered surface leading to retrogressively growing pipes and sand boils. Refer Figure A2.1.

2 Concentrated leak erosion: Detachment of soil particles through a pre-existing seepage path (e.g. animal burrow) in a stopbank. Refer Figure A2.2.

3 Suffusion: Selective erosion of the fine particles from the matrix of coarse particles under the action of a hydraulic gradient. Refer Figure A2.3.

4 Contact erosion: The selective erosion of fine particles from a soil at the location through contact with a coarser layer e.g. between say a fine graded stopbank core material and coarser graded filter and/or between a fine graded stopbank core material and coarser graded foundation. Refer Figure A2.4.

For internal erosion to become a plausible failure mode(s) the following sequence of events must all occur:

Step 1: Initiation

First phase of internal erosion, when one of the phenomenon of particle detachment occurs.

↓

Step 2: Continuation

Phase where the relationship of the particle size distribution between the base (core) material and the filter controls whether or not erosion will occur.

↓

Step 3: Progression

Phase of internal erosion where hydraulic shear stresses within the eroding soil may or may not lead to the erosion process being ongoing and, in the case of backward and concentrated leak erosion to formation of a pipe. The main issues are whether the pipe will collapse, or whether upstream zones may control the erosion process by flow limitation.

↓

Step 4: Breach

Final phase of internal erosion

Stopbank failure by internal erosion/piping can be rapid, even in a matter of hours from beginning of the initiation phase. For example anecdotal evidence suggests that Sullivan's Breach could have been less than an hour from heave in the landside paddock to actual stopbank collapse. Thus geotechnical assessment should be carried out if there is any doubt as to the propensity of stopbanks to fail due to this particular failure mode.

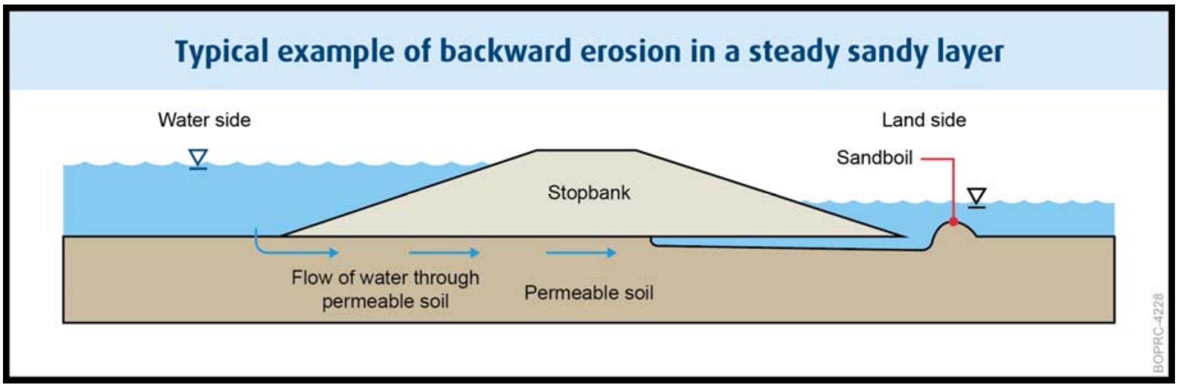


Figure A2.1 Typical example of backward erosion in a steady sandy layer (CIRIA, 2013).

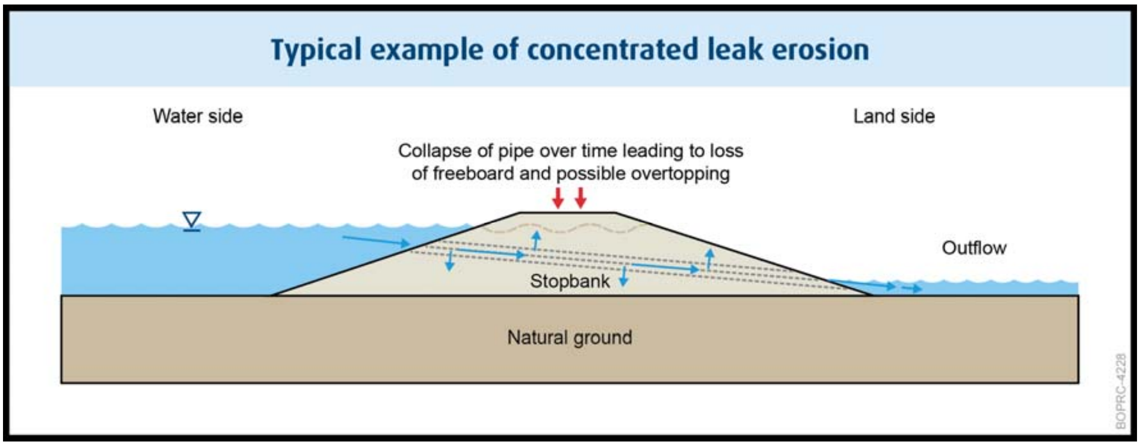


Figure A2.2 Typical example of concentrated leak erosion (CIRIA, 2013).

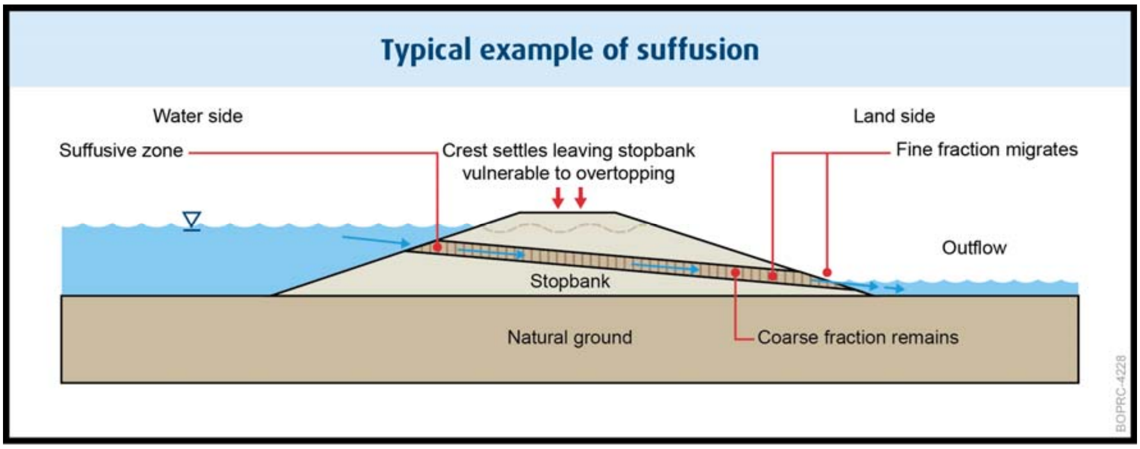


Figure A2.3 Typical example of suffusion (CIRIA, 2013).

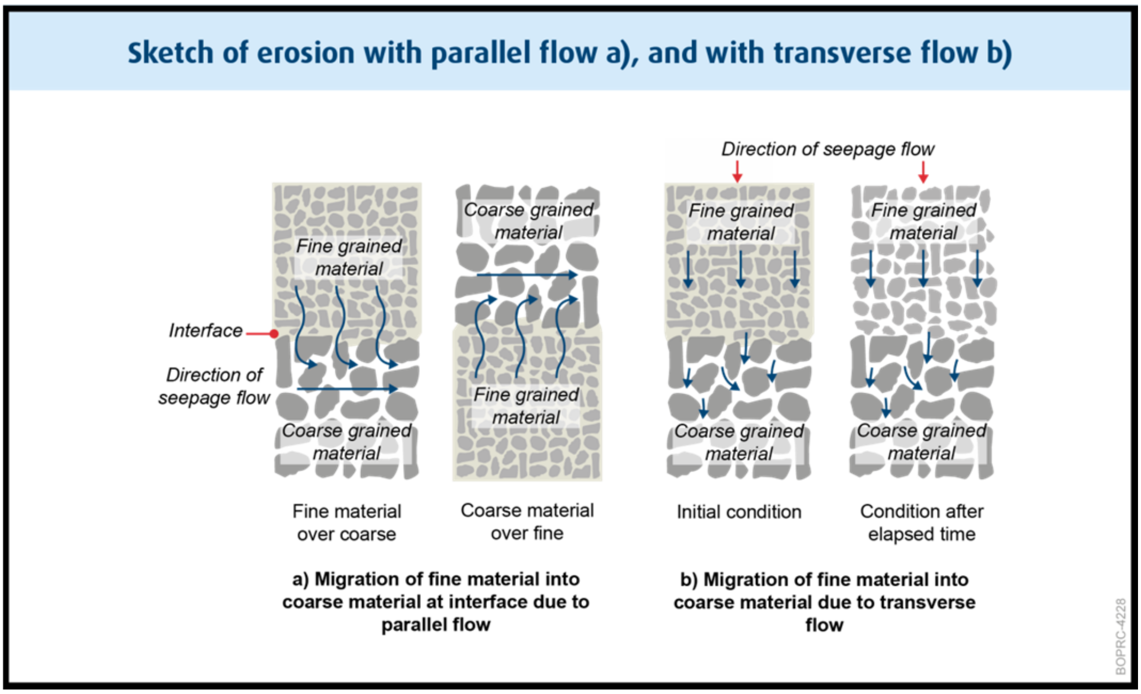


Figure A2.4 Sketch of contact erosion with parallel seepage flow (a), and with transverse seepage flow (b) (CIRIA, 2013). In both cases seepage transports fine grains through the coarser graded material.

A2.1 Internal erosion/piping stability analysis

The approach taken in this guideline to determine stability against internal erosion/piping in the stopbank is qualitative and is based on the methodology outlined in Chapter 9 of CIRIA's Levee Handbook (2013). Steps are summarised briefly as follows:

1. Assess the permeability of the stopbank fill and foundation soils.
2. Assess the ratio of vertical and horizontal permeability (i.e. anisotropy) in the foundation. Note any aquifers and associated layers of varying permeability (less permeable layers could support the roof of a potential piping path).
3. Define the design flood conditions to be applied in the internal erosion analysis.
4. Identify potential seepage issues e.g. long periods of high flood level against the stopbank.
5. If appropriate carry out seepage analysis identifying phreatic surfaces and hydraulic gradients and internal flow velocities.
6. Consider the likelihood of suffusion of stopbank soils.
7. Assess the possibility of one or more of the four internal erosion processes acting for each failure mode.
8. Determine the exit velocity of any stopbank or foundation seepage to evaluate the possibility of hydraulic heave, boiling or internal erosion.
9. Check the potential for contact erosion between the stopbank and foundation soils. Assess the filter characteristics of the stopbank materials, considering the potential for fill material to be self-filtering.

A2.2 Measures to reduce internal erosion/piping risk

If the potential seepage volume through the stopbank and/or foundation is considered too great and the threat of internal erosion/piping failure causing stopbank failure too high, then the designer should implement remedial measures. Three main groups of mitigation are possible:

- Lowering seepage pressures in and under the stopbank by using berms or various types of seepage drain.
- Reducing the hydraulic gradients by lengthening the drainage paths by using low permeability layers and seepage cut-off walls.
- Managing the interface between material types by appropriate filter design to prevent internal erosion.

Figure A2.1 shows how stability berms can be combined with seepage control measures on a stopbank.

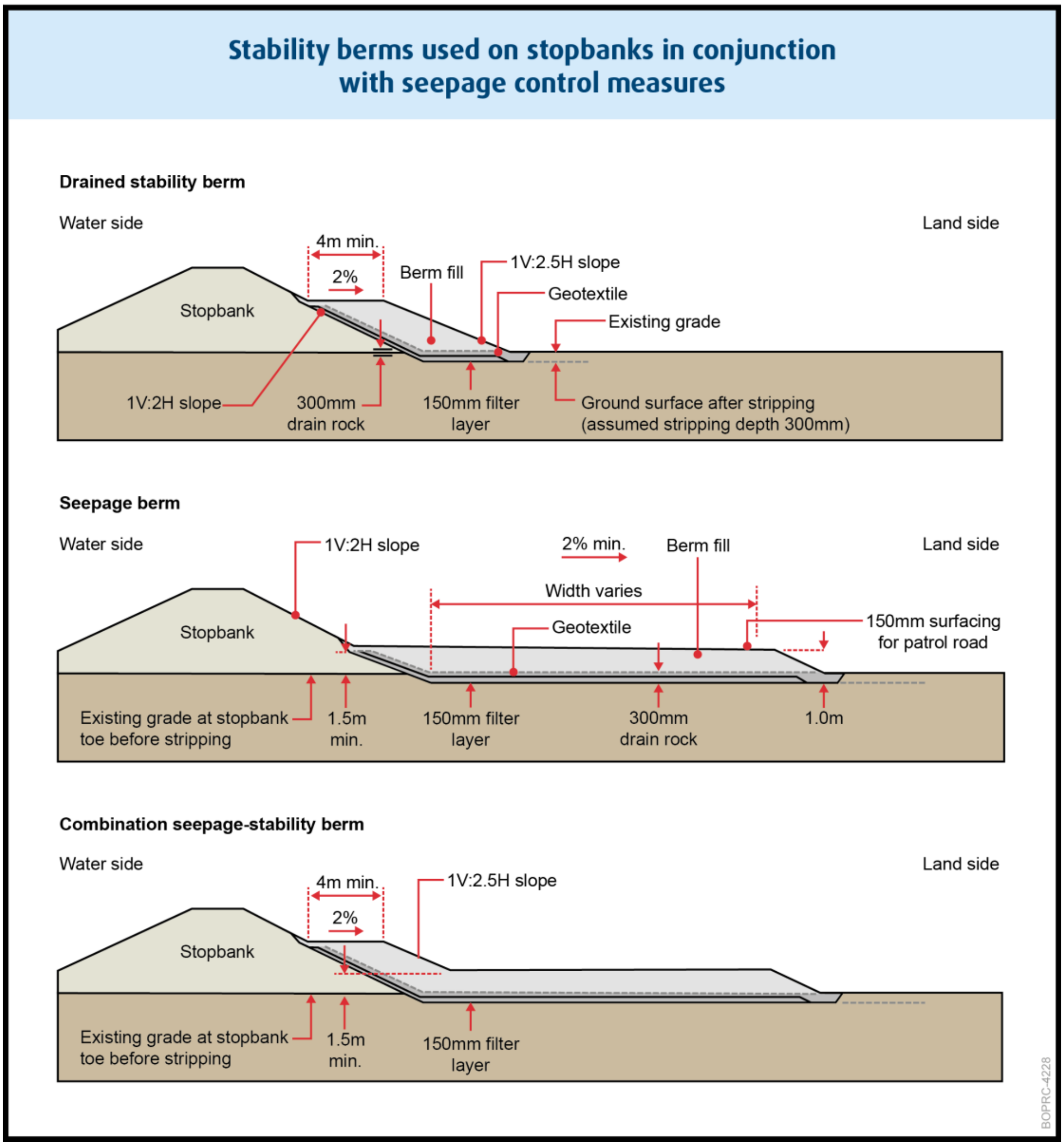


Figure A2.1 Stability berms used on stopbanks in conjunction with seepage control measures (CIRIA, Figure 9.99).

A3 Floodwall stability

The design of floodwalls usually requires consideration of static and dynamic forces. Static forces comprise the level of stationary water on the waterside of the wall. Dynamic forces comprise the effect of moving water on the wall such as those generated by wave action. In this section stability will be discussed only in terms of static forces. The effect of waves will not be considered due to the low height of the floodwalls typically used in the Bay of Plenty wherein the effect of waves is considered negligible.

Stability requirements for a simple T-shaped floodwall are provided below:

A3.1 Forces on floodwall

The hydrostatic force, Fr acts at the centroid of the pressure distribution as shown in Figure A4.1. Also shown is the resulting uplift pressure acting beneath the floodwall, U of width B and passive earth pressure, Rp acting on the landward side of the wall foundation.

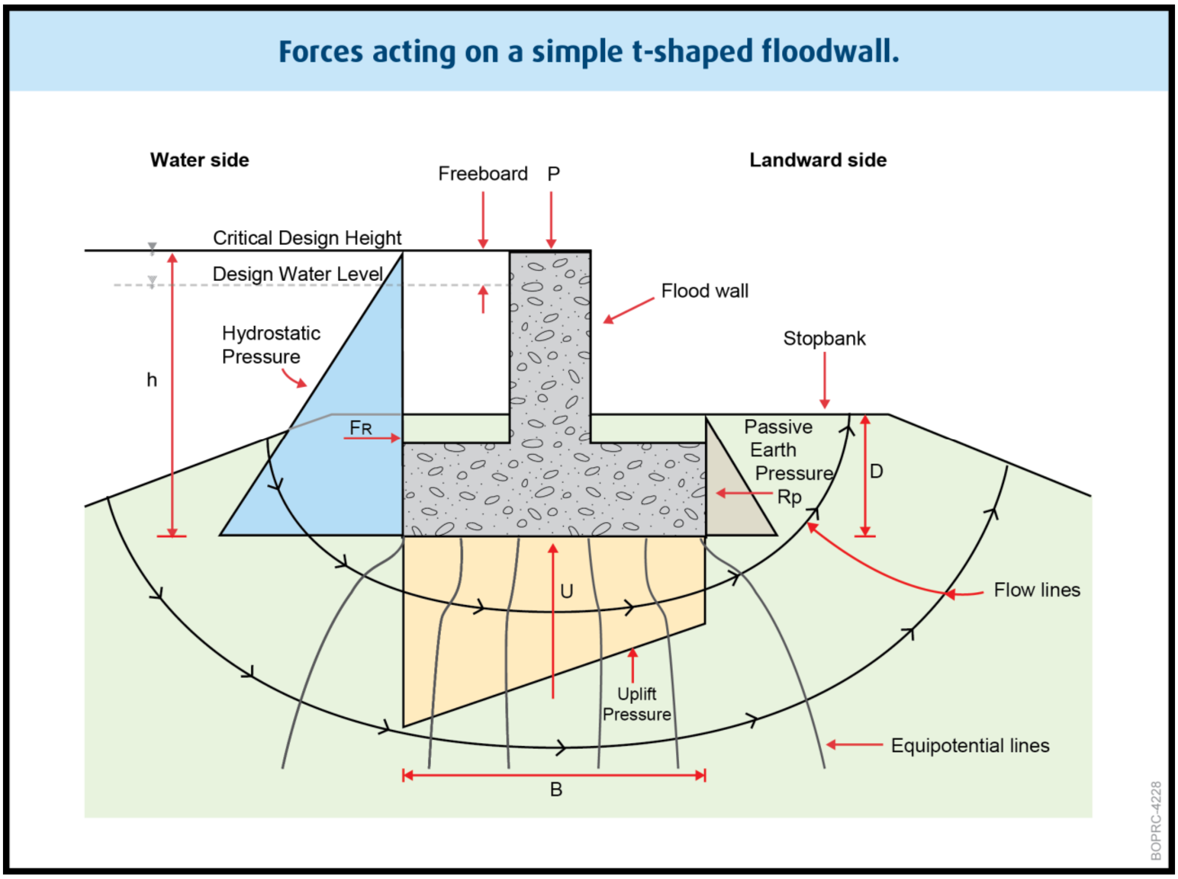


Figure A4.1 Forces acting on a simple T-shaped floodwall.

The hydrostatic force, Fr acting on the flood wall should be considered for the case where the water equals the top of the wall. This critical height is generally equivalent to the design level plus freeboard height. Also acting on the wall is uplift, U that arises from seepage passing under the footing of the wall. Uplift can be calculated by firstly constructing a flow net comprising flow lines and equipotential lines beneath the flood wall. Secondly an equivalent uplift pressure distribution is created and U is placed at the centroid of this distribution.

A3.2 Stability criteria for floodwall

In the analysis of T-shaped floodwalls the following limit states should be considered:

- Bearing capacity failure.
- Sliding failure.
- Overturning failure.

Bearing capacity

Bearing capacity failure could occur if the wall is founded on a low strength foundation. Bearing capacity limit state verification is made by checking that the applied vertical stress applied by the floodwall (q) does not exceed the ultimate limited strength of the soil (q_{ult}) i.e.

$$\mathbf{q \leq q_{ult}}$$

The ultimate bearing capacity of soil can be calculated by empirical means using classic soil bearing capacity theory. The solution relies on a physical understanding of the failure mode, which is generally considered schematically as shown in Figure A4.2 below. As the vertical loads on a flood wall foundation are not applied uniformly across the foundation the effective width of the foundation, 'B' needs to be calculated using the method given in Section B1, VM4 of the New Zealand Building Code.

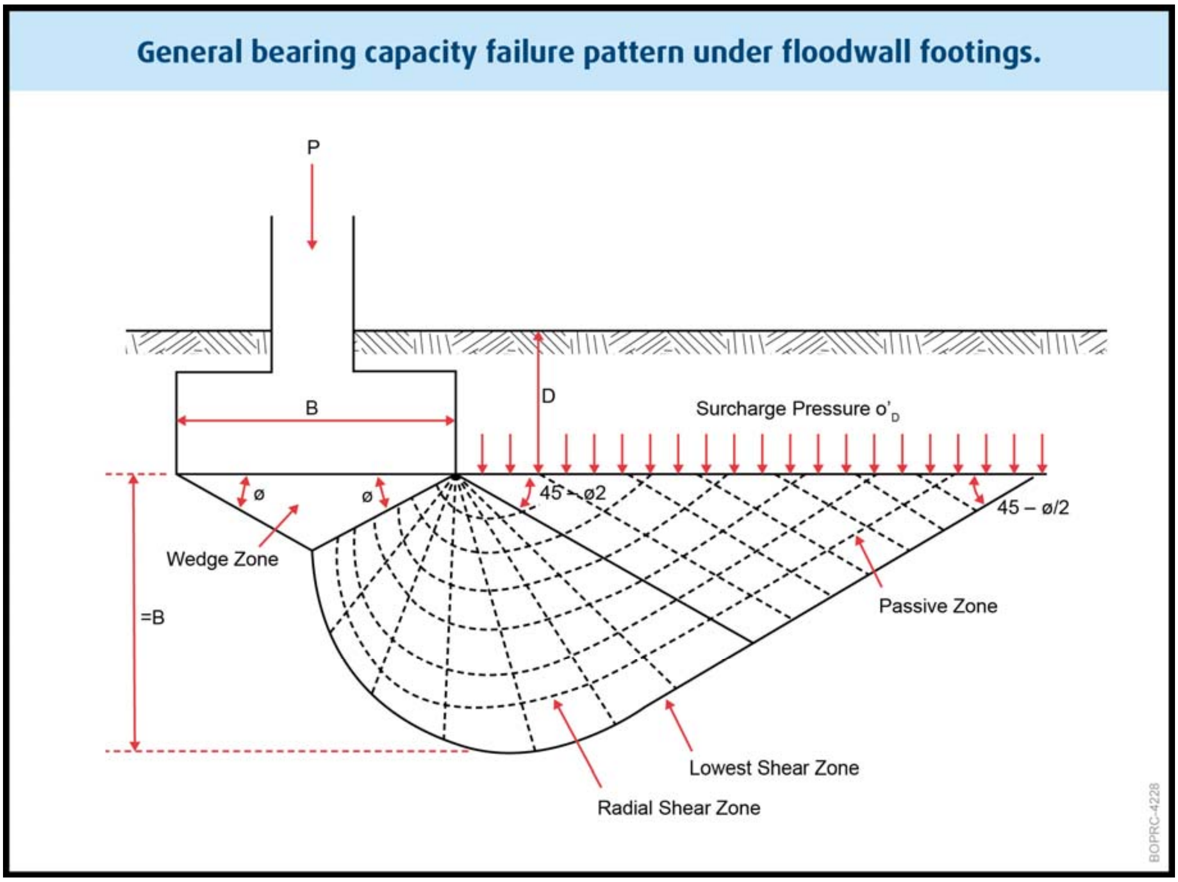


Figure A4.2 General bearing capacity failure pattern under floodwall footings.

Horizontal sliding capacity

Sliding of the foundation due to water pressure on the face of the wall shall be checked in accordance with Section B1: VM4 using the appropriate capacity reduction factors.

$F_r \leq \phi_{sl} S + \phi_{pp} R_p$

$S = c'B' + (P-U)\tan\delta'$ for drained conditions.

$S = B's_u$ for un-drained conditions.

Where:

F_r = horizontal force (kPa).

P = vertical force (kPa).

U = uplift force (kPa).

R_p = resistance due to passive earth pressure on the land side of the foundation.

δ = soil friction angle for cast in situ concrete foundations, but for smooth precast foundations, it may be equal to 0.75 x δ.

ϕ_{pp} = passive pressure capacity reduction factor.

ϕ_{sl} = sliding capacity reduction factor.

c' = effective cohesion. For most drained conditions any effective cohesion should be neglected.

s_u = un-drained shear strength.

Overturning capacity

Avoiding failure by overturning can be assured by ensuring total overturning moments, M_o are less than total restoring moments, i.e.

$M_o < \phi_M M_r$

ϕ_M = capacity reduction factor dependent on the loading case being considered.

Overturning moments comprise hydrostatic water force and uplift forces acting around the bottom edge of the foundation slab on the landward side of the floodwall.

Restoring moments comprise the weight of the floodwall and the resistance of soil pressure (passive pressure) acting around bottom edge of the foundation slab on the landward side of the floodwall.

Appendix B – Seismic analysis of stopbanks

B1 General

Seismic impacts on a stopbank are:

- Slope stability;
- Crest stability; and
- Earthquake induced liquefaction, causing loss of soil strength and lateral spreading.

Methods of analysis for each effect are discussed below:

B2.1 Stopbank slope stability analysis – seismic effects

The analysis of seismic impacts ranges from simple pseudostatic analysis to more complicated permanent displacement analysis. The most useful approach is the method that represents the physical mechanisms of a particular stability problem using material information that can be obtained practically and economically.

(a) **Pseudostatic approach**

The oldest and most widely used slope stability methods used by engineers. The approach applies unidirectional accelerations (horizontal and vertical) expressed in terms of kh and kv, to a mass of potentially unstable material. The resulting inertial forces act in directions to destabilise the slope and, numerically equal to the ratios of the inertial force of the weight of potentially unstable material. By solving force and/or momentum equilibrium of the potentially unstable soil, a pseudostatic factor of safety can be calculated.

The seismic inertial Forces F_H and F_V acting on the soil sliding mass (Figure B2.1) for the horizontal and vertical direction respectively, in pseudostatic analysis is therefore:

$F_H = k_H W$.

$F_V = k_V W$.

Where:

k_H = pseudostatic horizontal seismic coefficient (g).

k_V = pseudostatic vertical seismic coefficient (g).

W = total weight of the sliding mass (kN).

Selection of appropriate seismic coefficients are crucial and these can be found in NZS 1170.5:2004 Structural Design Actions Part 5: Earthquake Actions – New Zealand. It is considered that due to the low risk of a significant earthquake occurring at the same time as a flood, stopbanks should be designed to suffer no damage under a Serviceability Level Earthquake. In most situations this would equate to a 1-in-25-year earthquake. Stability analyses should also be carried out for the Ultimate Level Earthquake, usually a 1-in-500-year event, to determine if there would be problems with slope stability, liquefaction or lateral spreading. If possible problems are identified the critical level earthquake should be determined and a risk assessment carried out to estimate the risk and consequences of a flood occurring at the same time or within the repair period following an earthquake.

A decision can then be made about stopbank redesign or relocation, or the installation of expensive remediation works.

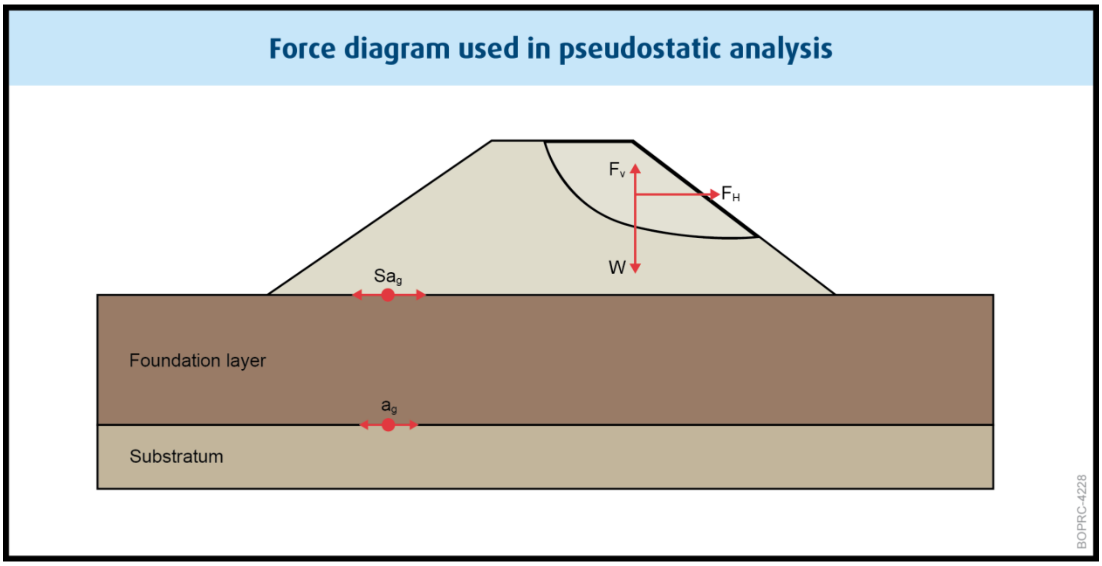


Figure B2.1 Force diagram used in pseudo-static analysis.

Many of the slope stability analysis methods used for static analysis can be used by adjusting weight, W of each slice to accommodate the seismic inertia forces F_H and F_V.

Pseudostatic slope stability analysis conservatively evaluates the potential for failure due to earthquake loading as it does not allow for the brief time that the vertical and horizontal accelerations are applied in each direction. If the analysis indicates a factor of safety less than one then the potential for slope movement exists, but the displacements could be very small. An assessment of permanent deformation may then be required.

(b) **Pseudo-dynamic approaches**

This approach is based on the analogy of a rigid block resting on an inclined plane representing a potential mass of sliding mass of soil. Refer Figure B2.2. A simple procedure for estimating displacement of slopes during earthquakes is based on concept of critical (or yield) acceleration (a_c) originally proposed by Newmark. The yield acceleration is the minimum pseudo-static acceleration required to produce a displacement of the block (factor of safety = 1).

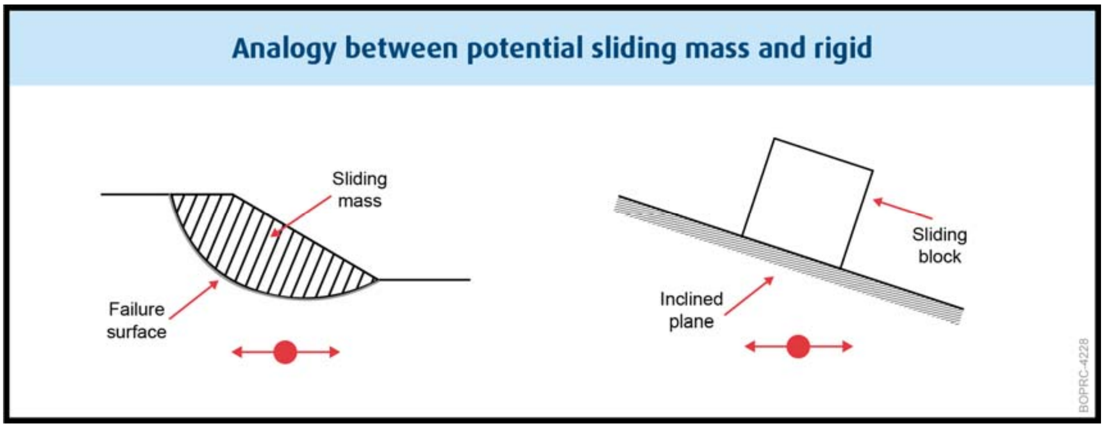


Figure B2.2 Analogy between potential sliding mass and rigid.

With the soil mass being rigid, the permanent displacement is obtained from double integration of excess acceleration. Refer Figure B2.3. Given that an earthquake can exceed the yield acceleration many times, it may produce a number of increments of displacement. Hence the total displacement is influenced by the strong motion duration as well as the amplitude and frequency content of the earthquake acceleration spectra.

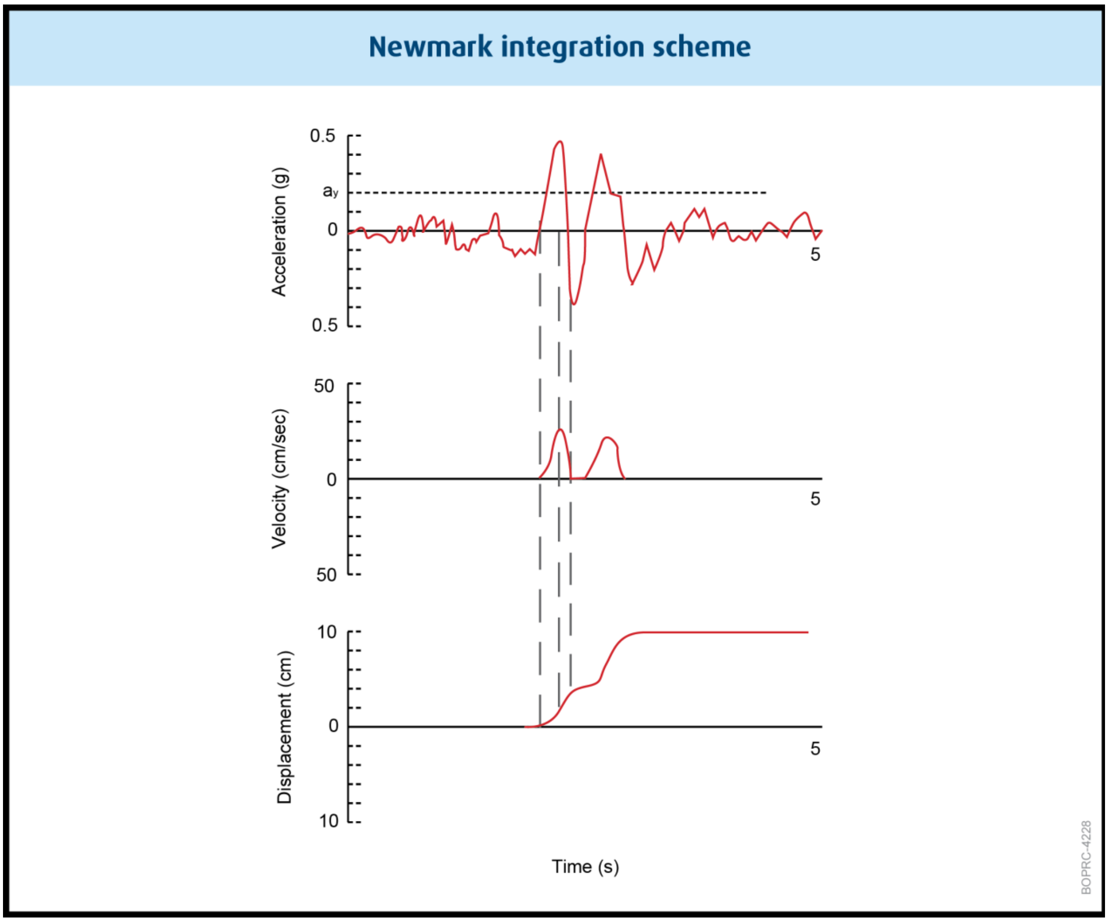


Figure B2.3 Newmark integration scheme.

Numerous methods have been employed to undertake pseudo-dynamic analysis of stopbanks. One example is the Makdisi & Seed approach (1978) which used a dynamic finite element analysis to calculate the horizontal component of the dynamic stresses acting on a potential failure surface. By simplifying assumptions about the results Makdisi & Seed were able to estimate permanent displacements of earth dams and embankments.

An estimate of the stopbank displacements can be made once the critical acceleration is known, (that at which the factor of safety is 1.0) using the methods of Ambraseys and Menu[4] or Jibson[5] or similar. Allowance should be made for the development of elevated pore water pressures or complete liquefaction of susceptible foundation layers and cyclic softening of cohesive layers when the critical acceleration for use in deformation estimates is derived.

[4]Ambraseys N.N. and Menu J.M. (1988) Earthquake induced ground motions. Earthquake Engineering and Structural Dynamics, Vol. 16.
[5]Jibson R.W. (2007) Regression models for estimating co-seismic landslide displacement. Engineering Geology, Vol. 91.

Methods for the estimation of lateral spreading displacements following liquefaction are given in the New Zealand Geotechnical Society, Geotechnical Earthquake Engineering Practice, Module 1 - Guideline for the identification, assessment and mitigation of liquefaction hazards, July 2010.

Stopbanks and floodwalls that are already going to be repaired or improved to provide an urban level of flood protection and that are vulnerable to seismic damage should be repaired or improved with alternatives that are more resistant to seismic damage and/or are more easily and economically repaired following an earthquake compared to other alternatives (e.g. a berm is usually preferable to a seepage cut-off wall).

B2.2 Seismic considerations for intermittently loaded stopbanks

The Californian Department of Water Resources (DWR, 2012) recommends that if seismic damage from 200-year-return-period ground motions is expected on existing stopbanks subject to intermittent water loads then, a post-earthquake remediation plan is required. Although the post-earthquake remediation plan must address 200-year-return-period ground motions at a minimum, engineers should consider a range of earthquakes significantly exceeding the 200-year return period. The purpose of the seismic vulnerability analysis is to develop a rough estimate of seismic damage to the stopbank or floodwall system, so as to anticipate the scale and location of damage to be addressed in the post-earthquake remediation plan.

At a minimum, the post-earthquake remediation plan should contain provisions for emergency preparations, mobilization, data gathering, actions, interim repairs, long-term repairs, and public notifications. Included in this plan is an estimate of the amount and extent of damage that might be sustained following an earthquake, and the general magnitude of earth and other materials that would be required to restore a modest level of flood protection within eight weeks. This plan should include a general set of repair procedures for the interim remediation of cracked and slumped stopbank sections, including general procedures for excavating and filling cracks, removing disturbed or slumped ground, and keying in new fill. During each periodic review, the post-earthquake remediation plan needs to be reviewed and updated as appropriate. Specific considerations for the interim repairs for intermittently loaded stopbanks include:

- An estimate is to be developed of the general magnitude and locations of damage expected throughout the stopbank system along with the amounts and locations of material needed to restore the stopbank system's height and dimensions (e.g. appropriate crest width – such as 3 m along a major stream – and 3H: 1V stopbank slopes) sufficient for protection against the 10-year flood, with 300 mm of freeboard.
- The interim repairs would need to restore 10-year grade and dimensions within eight weeks or less to avoid prolonged exposure of the community during flood season.
- Borrow areas and/or stockpiles that could easily provide the materials needed for interim repairs need to be identified.
- Haul routes for fill placement need to be identified.
- Slope protection for the newly placed fill needs to be included.
- To the extent that seismic damage to the stopbank system would be so significant and widespread that it would be infeasible to restore 10-year level and dimensions within eight weeks, seismic strengthening is required to provide the urban level of flood protection.

- The public should be informed as quickly as possible after a damaging earthquake as to system damages and the resulting interim level of protection that will be provided.

B2.3 Seismic considerations for frequently loaded stopbanks

Frequently loaded urban stopbanks (and floodwalls), are required to have seismic stability sufficient to maintain the integrity of the stopbank and its internal structures without significant deformation. In most cases, for frequently loaded stopbanks with less than 1.5 m of freeboard, earthquake-induced deformations should be limited to less than 1 m of total deformation and about 0.3 m of vertical displacement. Stopbanks with rigid penetrations or appurtenances may require smaller allowable seismic deformations. Considerations of potential transverse and longitudinal cracking are even more important for frequently loaded stopbanks and such assessments are required to provide an urban level of flood protection. However, frequently loaded stopbanks with larger cross-sections and freeboard may be allowed larger seismic deformations subject to engineering analyses, risk assessment and sound engineering judgment.

For frequently loaded stopbanks and floodwalls, design ground motions higher than the 200-year-return-period level should also be considered based on the potential consequences of a stopbank breach or floodwall failure.

B3.1 Crest settlement

During earthquakes dam crest settlement has been shown to be related to:

- Peak ground acceleration.
- Earthquake magnitude.

An empirical equation has been formulated by Swaisgood[6] (2003) to estimate the embankment crest settlement as follows:

$S = \exp(6.07\ a_{max} + 0.57M - 8)$.

Where:

S = crest settlement (%) of stopbank height.

a_{max} = peak ground acceleration (g) at the foundation rock.

M = earthquake magnitude (surface wave magnitude).

As reliability of this formula was based on a particular database, the approach only provides an order of magnitude of the crest settlement. Differences between calculated and measured settlements ranging between one and six are possible. Due to its exponential trend this formulae may be limited to moderately seismic zones. It is recommended that the formulae only be used as a rule of thumb in early phases of the project or rapid assessment.

[6]Swaisgood JR (2003) Embankment Dam deformations caused by Earthquakes, In proceedings of the 2003 Pacific Conference on Earthquake Engineering, 13–15 February 2003, Christchurch, New Zealand, National Society for Earthquake Engineering, Wellington New Zealand.

B4.1 Earthquake induced liquefaction

Liquefaction is the term used to describe the loss of strength of cohesionless soils due to excess pore pressure caused by cyclic loading. Liquefaction and the resulting lateral spreading has been observed in many earthquakes and has caused significant damage to infrastructure and buildings.

Liquefaction generally occurs in cohesionless soils, particularly silts and fine to coarse sands especially when such materials have a uniform size. Figure B2.4 shows a section of the geological map QMap 5 prepared by GNS Science (2010). The light yellow areas on the map are young deposits which could contain liquefiable layers. Liquefaction potential depends on several factors including:

- Site parameters, including the thickness and depth of the layer, its saturation and morphology.
- Load parameters such as the type, frequency and duration of loading.
- Soil parameters such as soil's physical properties (e.g. particle size), density, age and strength.

Assessment of liquefaction potential of a stopbank and/or its foundation requires specialist knowledge of this particular phenomenon. Thus stopbank owners should consult an appropriate geotechnical engineer if liquefaction is a concern.

Liquefaction analysis requires deep in-situ testing. Cone penetrometer tests (CPT) and standard penetration tests (SPT) are commonly used to estimate the potential for liquefaction in a design earthquake using internationally accepted analysis methods. There is computer software available for this analysis. An example of an analysis for a 500-year return period earthquake on the soils adjacent to the lower Reid's Canal is shown in Figure B2.5. This shows several liquefiable layers within 10 m of the ground surface.

It should be noted that these in situ test methods can significantly under-estimate the strength/density of pumiceous soils and they should be used with caution. Shear wave testing methods are likely to produce more reliable analysis results.

Once the layers of possible liquefaction have been identified, strengths need to be assigned to these layers and stopbank slope stability analyses carried out. In addition to this, the amount of lateral spreading due to movement along the liquefied layers towards the water course needs to be estimated using established methods.

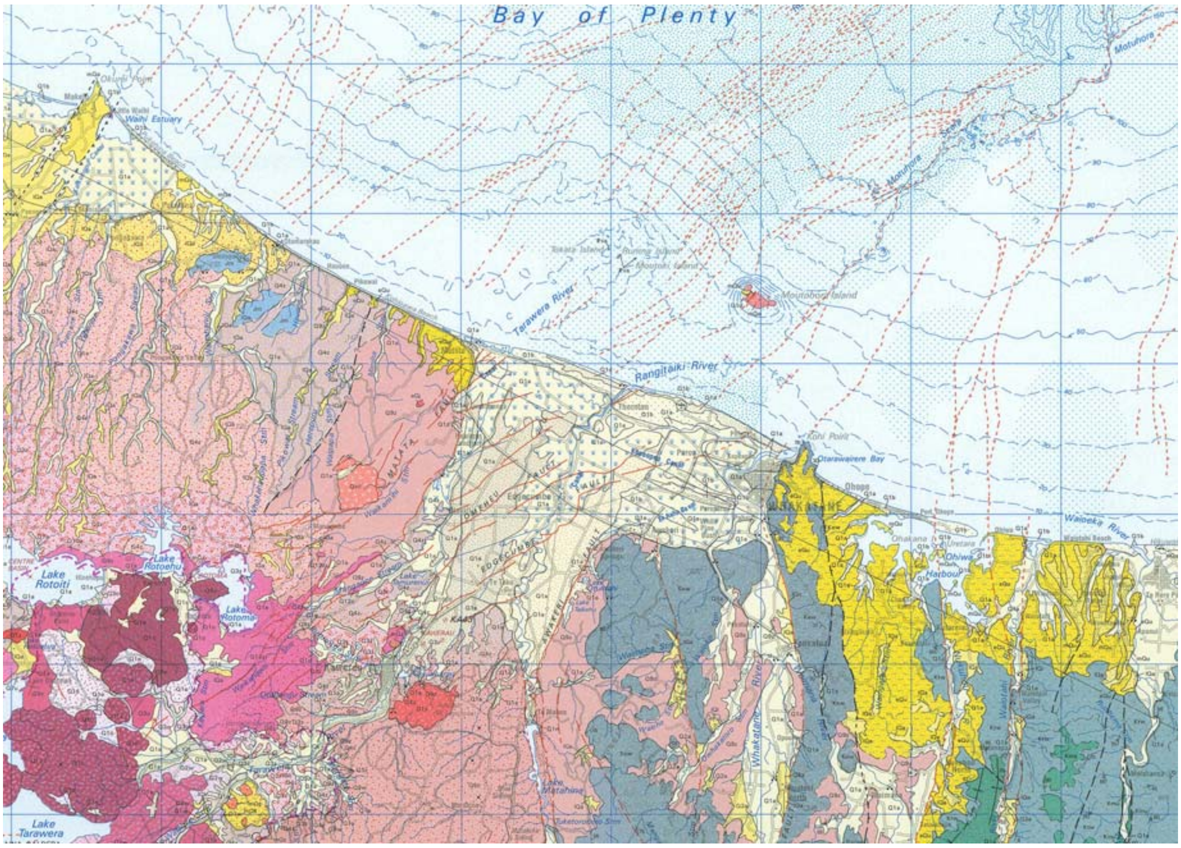


Figure B2.4 Geological and Nuclear Sciences QMap 5 showing geological units and fault lines in Eastern Bay of Plenty (GNS Science, 2010).

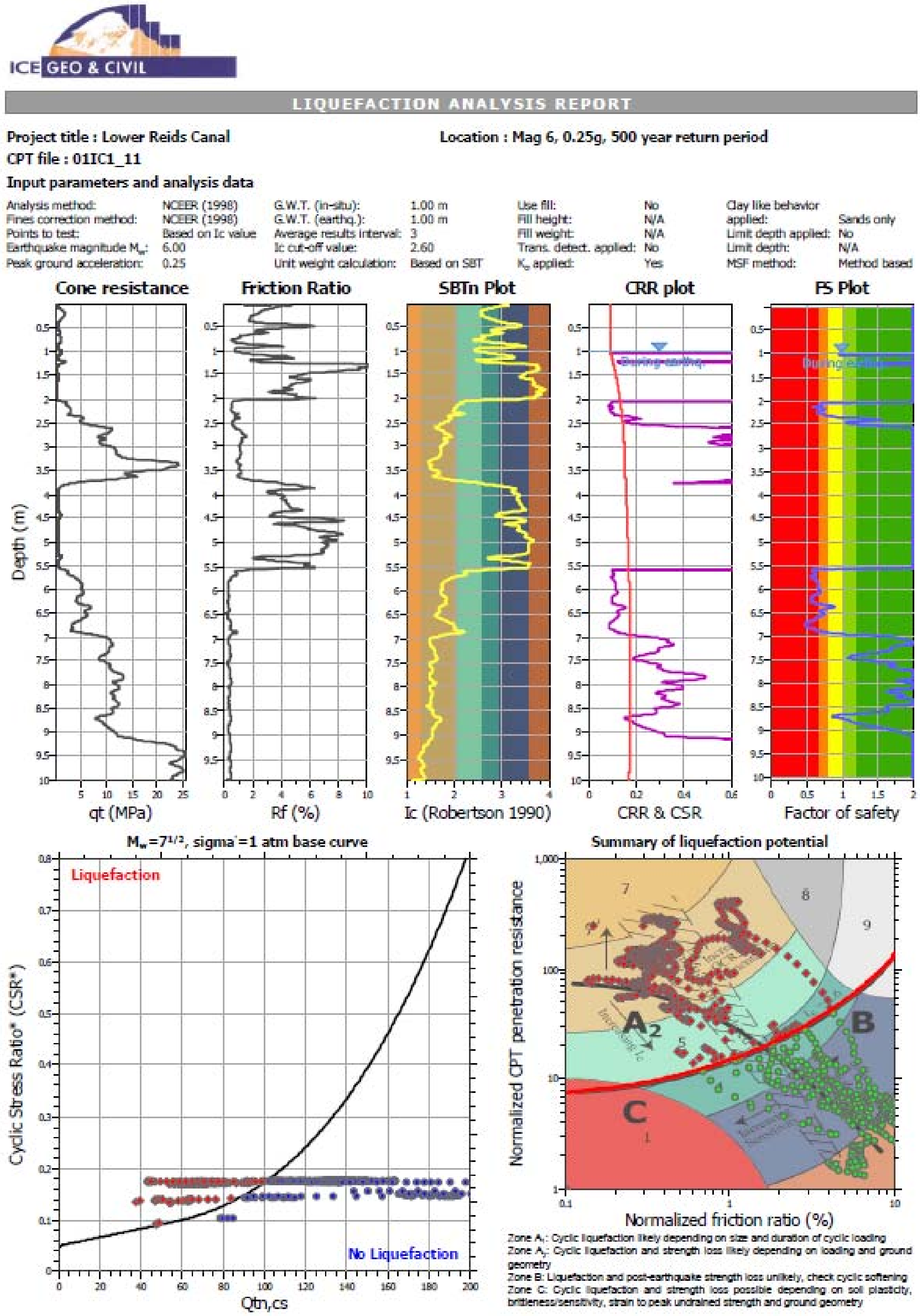


Figure B2.5 Example of a liquefaction analysis carried out on soils near Reid's Central Canal.

Appendix C – Seepage control of stopbanks

C1 Seepage control measures through and below stopbanks

Stopbank seepage assessment may identify the following:

- Seepage discharge exceeds acceptable limits.
- Groundwater pressures are too high.
- Uplift pressures beneath the landward slope and adjacent ground are too high.

In these cases seepage control measures should be incorporated in the stopbank design. These include:

- Construction of impervious layers on the stopbank face.
- Stabilising berms.
- Seepage cut-off walls through permeable layers.
- Insertion of internal drains and toe drains in permeable layers.
- Relief wells.

A description of each stopbank control measure follows:

(a) **Impervious layers**

Impervious layers are usually placed on the waterside slope and penetrate the upstream toe. Refer Figure C1.1. The layers reduce the volume of seepage entering the stopbank and foundation. Slope stability analysis is needed to check the impact of rapid drawdown on the impervious layer.

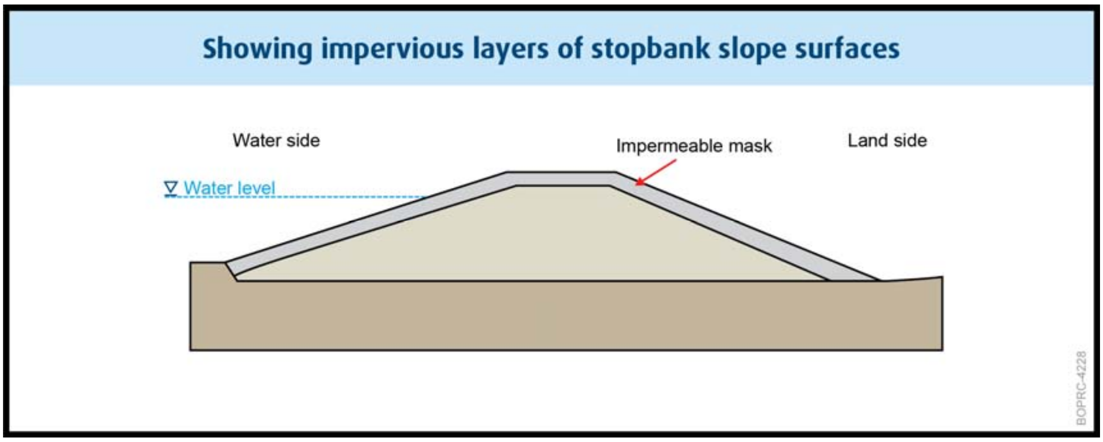


Figure C1.1 Showing impervious layers of stopbank slope surfaces.

(b) **Stabilising berms and overlays**

Stabilising berms are constructed out of permeable soils placed at the toe of the waterside and the landward stopbank slopes. Refer Figure C1.2. The berm area is often wide due to the need to increase the length of the seepage path and reduce the risk of piping occurring. Along the Rangitāiki River and Reid's Canal stopbanks extensive use has been made of soil overlays up to 1.5 m thick which butt up to the landward toe of the stopbank. These are to reduce the risk of heave due to high water pressures in underlying highly permeable layers and the subsequent development of piping. The overlays are typically 20 m to 40 m wide.

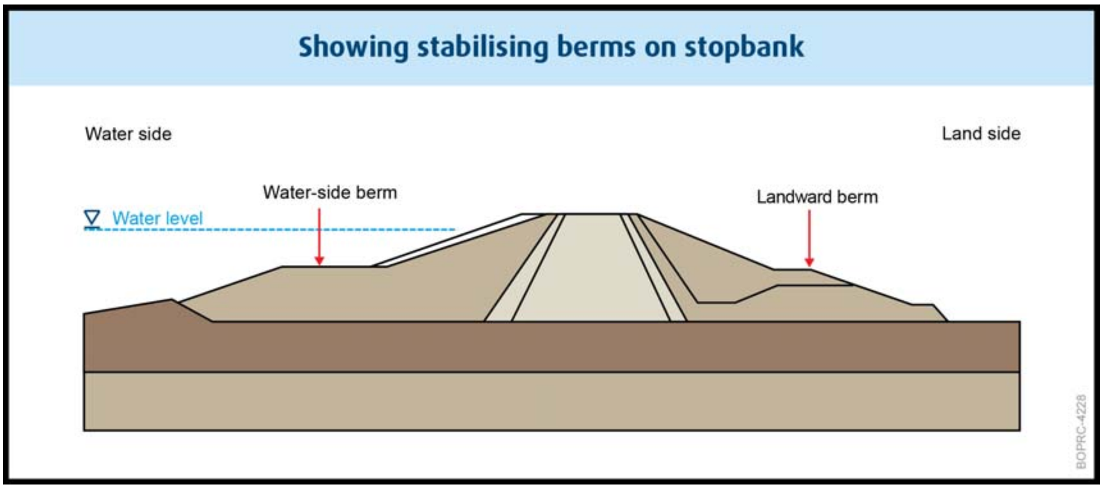
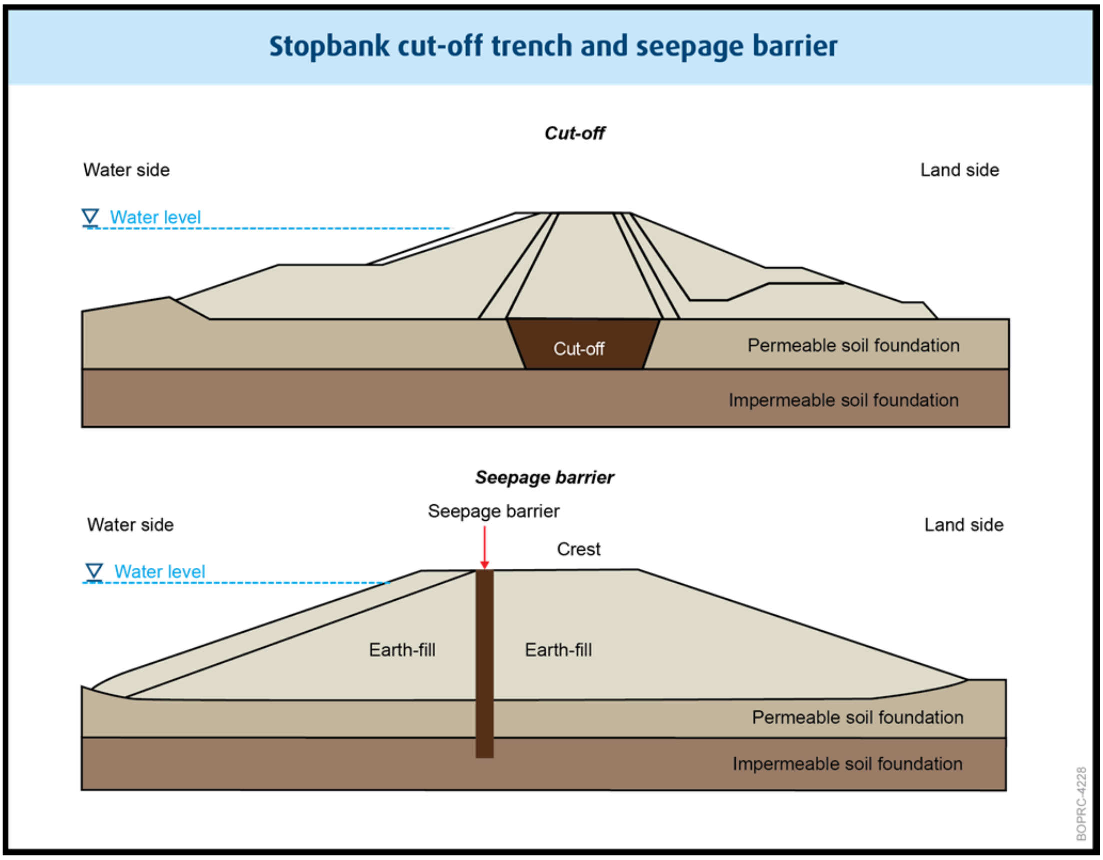


Figure C1.2 Showing stabilising berms on stopbank.

(c) **Cut-off walls**

Cut-off walls comprise barriers such as sheet piles or slurry trenches constructed along the longitudinal axis of the stopbank that penetrate through the stopbank ideally to a less pervious layer in the foundation. Refer Figure C1.3 and C1.4. Cut-off walls reduce seepage through and beneath the stopbank. Seepage analysis can confirm whether the increased seepage path is sufficient to reduce uplift pressures beneath the landward slope and adjacent ground to an acceptable level.

Regional Council does not recommend installation of sheet piles in existing stopbanks unless a thorough seepage analysis has been undertaken beforehand. Stopbank owners need to satisfy themselves that sheet piling will not cause concentration of seepage and high pore pressures within the stopbank that could increase risk of piping failure.



Figures C1.3 Showing cut-off trench and Figure C1.4 showing seepage barrier.

(a) **Internal drains and toe drains**

Internal drains are generally used to control internal erosion in the stopbank. Refer Figure C1.5. Toe drains are placed at the toe of the landward slope. Seepage calculations can determine how much seepage will be drawn down and discharged out the toe drain in a controlled manner.

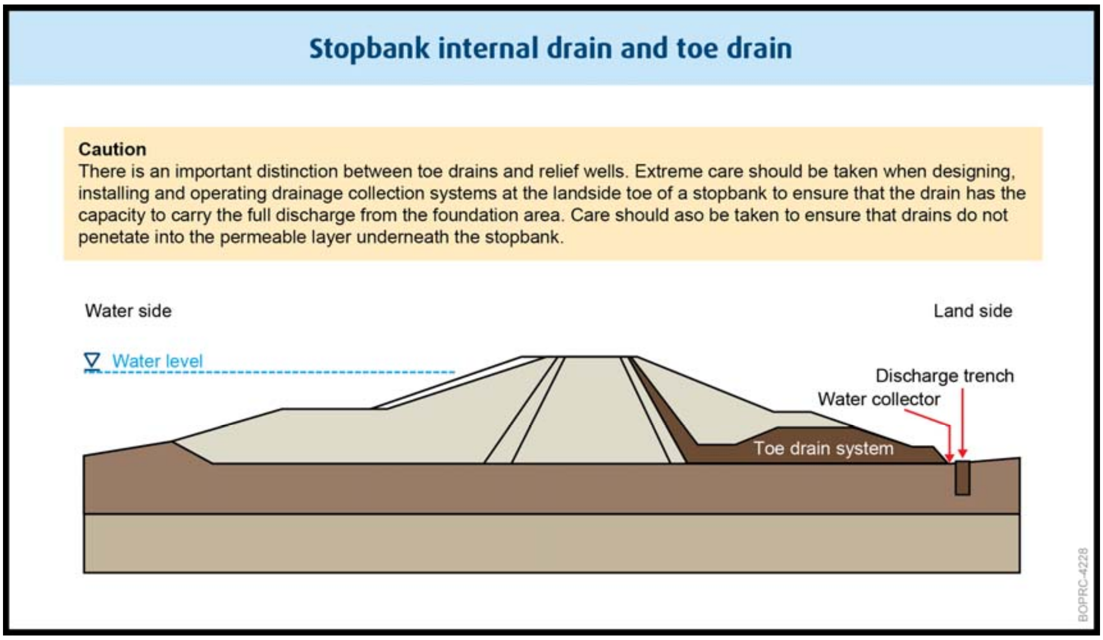


Figure C1.5 Showing internal drain and toe drain.

(b) **Relief wells**

Relief wells or trenches are installed in the foundation at or near to the toe of the landward slope. Relief wells reduce the risk of uplift at the stopbank toe and adjacent ground. Refer Figure C1.6. Water collects in the wells that vent to the ground surface. Water can either drain to a common sump and be pumped back into the river or allowed to flow freely into neighbouring fields. Regional Council has installed pressure relief trenches through Edgecumbe along the left bank of the Rangitāiki River, downstream of SH2. Some individual relief wells have been installed in Edgecumbe along Hydro Road on the right bank of the Rangitāiki River.

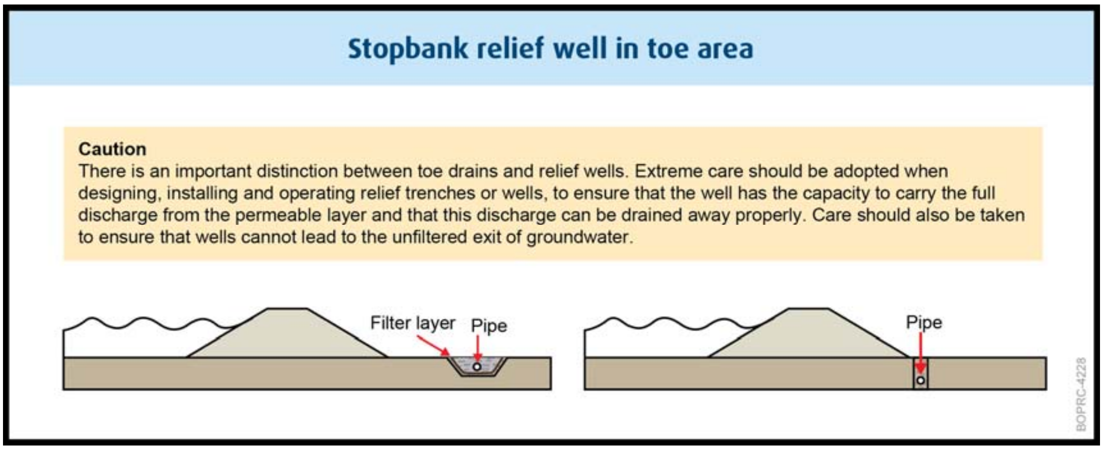


Figure C1.6 Showing a relief well in toe area.

C2.1 Seepage analysis

The design of seepage control measures in stopbanks is based on steady-state conditions assuming the soil is saturated. This is conservative since stopbanks for the most part remain unsaturated only experiencing seepage during floods. Thus even though hydraulic formulae for saturated soils are not strictly applicable to stopbanks they are applied for stability analysis with the knowledge they provide a conservative estimate of seepage. An alternative approach is to carry out a transient analysis which predicts how pore pressures within the stopbank will behave relative to flood levels. Steady state analysis is simpler and easier to validate than the transient approach.

In the Bay of Plenty the soil and stopbank conditions are often such that steady state analyses indicate seepage related problems. Transient analyses using the design flood flow hydrograph are therefore often carried out.

Output from a seepage analysis should:

- Assess the vertical and horizontal permeability in both the stopbank and foundation soils. This is important when determining what seepage control measure is best suited to the particular site in question. Permeability measurements should be conducted on materials in a condition similar to their actual or eventual in-situ state once the stopbank is operational.
- Identify the critical phreatic surfaces within the stopbank for use in stability assessment.
- Prepare a flow net that allows assessment of the internal pore water pressures, seepage velocities and flow that could occur in the stopbank or its foundation.
- Determine critical hydraulic gradients and flow velocities for use in uplift, hydraulic heave, internal erosion and filter design calculations.

Seepage analysis is described in numerous geotechnical references. Phreatic surfaces are based on energy conservation and Bernoulli's equation. Hydraulic gradients and seepage flow rates are based on Darcy's equation.

Permeability

Permeability has a significant effect on seepage through a stopbank. Two of the most significant effects are:

- Low permeability soils may only become partially saturated during flood events resulting in no seepage whereas high permeability soils often result in full stopbank and foundation saturation, producing seepage in a flood.
- High permeability soils can lead to slope instabilities and internal erosion. Figure C2.1, Case a) shows how the phreatic surface develops within the stopbank on the rise and falling limb of a flood hydrograph. Case b) shows anisotropic permeability wherein horizontal permeability is not the same as vertical permeability. In stopbanks horizontal permeability can be many times greater than vertical because construction of the stopbanks usually involves placing and compacting horizontal fill layers. If the ratio of the horizontal to vertical permeability is high, elevated seepage can occur in the landward slope.

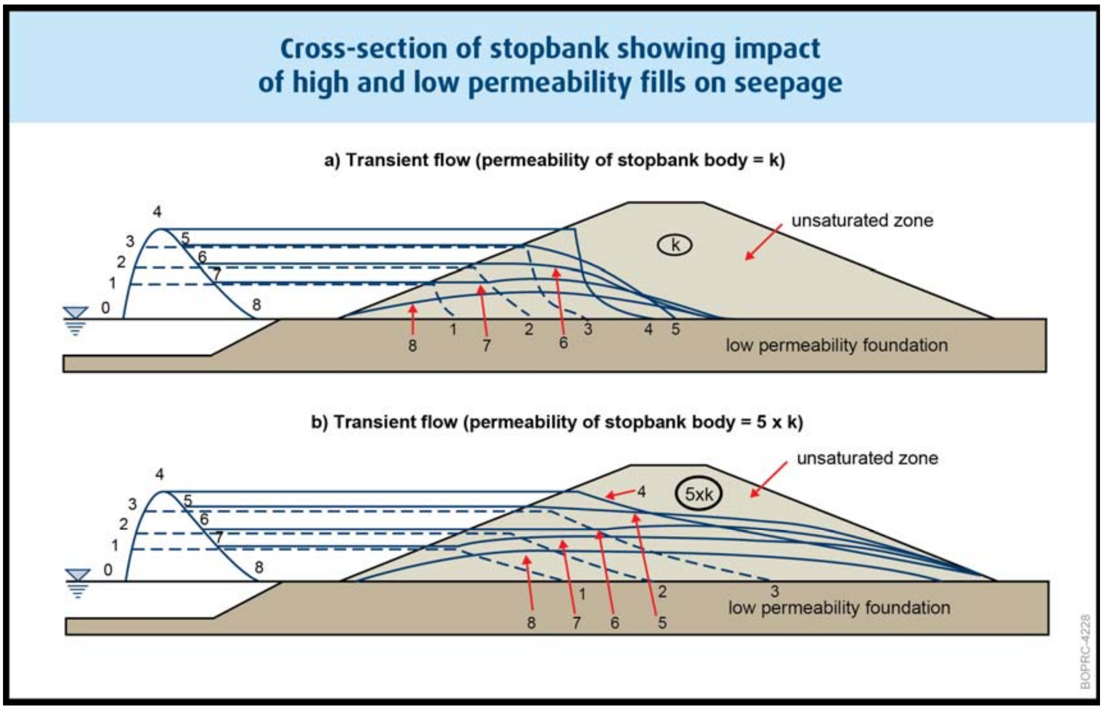


Figure C2.1 Cross-section of stopbank showing impact of high and low permeability fills on seepage.

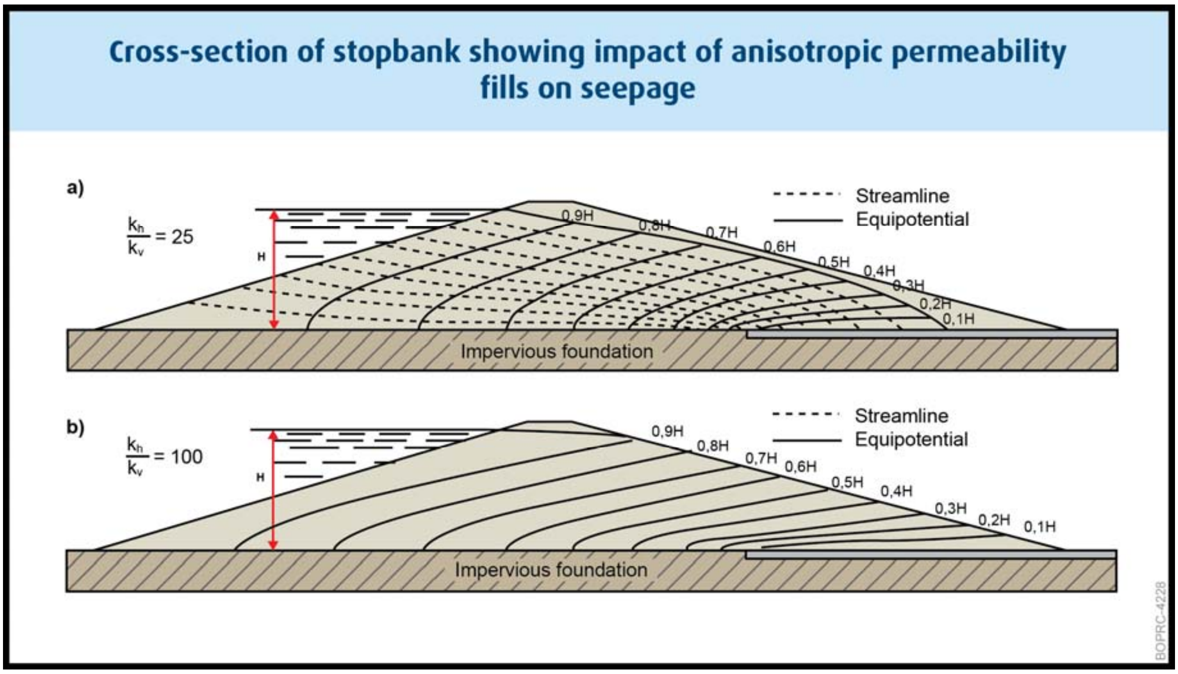


Figure C2.2 Cross-section of stopbank showing impact of anisotropic permeability fills on seepage.

Phreatic surfaces and flow net

For stability and seepage analysis it is conservative and safer to assess the stopbank assuming the flood level sets up steady state seepage flow within the stopbank. Several methods are available to determine the phreatic surface including geometrical, analytical and numerical methods.

Once the phreatic surface has been established a flow net can be drawn. The flow net shows streamline and internal pore pressure distribution (equipotential lines) which enables seepage velocities and total flow to be calculated.

The flow net allows the pore pressure to be calculated at any position within the stopbank. Excessive internal pore pressures or flow velocities through or below a stopbank can result in slope instability, internal erosion, hydraulic cracking, heave and uplift. Seepage control devices are then required to collect this flow and reduce internal pore pressure.

Critical hydraulic gradients

For stopbank design that entails complex features such as penetration, transitions or say interfaces with drainage systems, it may be necessary to evaluate local hydraulic gradients as well as exit gradients. The hydraulic gradient, i is defined as the change of total hydraulic head, dh, divided by distance along the direction of flow, dx.

$i = dh/dx$

For stopbank slope stability at the landward toe, many geotechnical textbooks recommend that the exit gradient not be greater than 1. Table A1.2 (CIRIA, 2003) recommends lower gradients to provide stopbank security and still lower gradients are considered necessary for light weight soils.

Seepage analysis software

Simple flow nets may not be appropriate for stopbanks that:

- Are complex;
- Comprise anisotropic material; or
- Are subject to transient state conditions.

Several software packages are available to undertake seepage analysis. The use of software which is mainly Finite Element Analysis based is much more rigorous and quicker than hand analysis methods; however the software requires much more sophisticated input data. Caution needs to be exercised in its use and results should be validated with simple calculations.

Currently several software packages are available that allow engineers to calculate seepage through and beneath stopbanks. Examples include Seep/W, Plaxis and Plaxis Flow, Cesar LCPC. Each program has its limitations and the analyst should read the user manual to become familiar with these.

For certain programs, the results defining pore pressure during a flood can be coupled with classical 2D stability programs e.g. Slope with Seep/W.

Appendix D – Stopbank erosion protection measures

D1 Erosion protection measures

Once surface protection measures have been constructed it is important that the stopbank continue to be protected from erosion, caving (local slope sliding) and scouring in order to protect the stopbank from damage and potential failure. Table D1 outlines the causes of erosion and provides suggestions for prevention.

Table D1 Causes and prevention measures for stopbank erosion (CIRIA, 2013).

Observations	Prevention measures
Flood flow and wave action erodes stopbank.	Carry out condition monitoring assessments of stopbank, berms and river banks. Note any changes in river geometry. Pay particular attention to convex channel zones and narrow reaches (where flow velocities are higher). Mitigate adverse hydraulic effects to reduce stopbank damage e.g. re-shape waterway cross-section, limit boat speed.
Rainfall run-off.	Carry out routine condition monitoring assessments of stopbanks. Report any new run-off damage. Carry out stopbank maintenance. Repair any damaged drainage assets e.g. blocked culverts or malfunctioning drainage pumps, valves etc. Maintain stopbank surface protection on slopes, crest and berms. Ensure grass cover is maintained. Divert all drainage from surrounding areas away from stopbank slopes.
Fallen trees uproot the bank/slope.	Identify and remove trees that could collapse and damage stopbank. Remove and backfill roots of trees that may rot and initiate scour and erosion.
Frequent access (e.g. vehicles, foot traffic, grazing livestock).	Restrict traffic accessing stopbank surfaces. Restrict heavier livestock (e.g. dairy cattle) from grazing on stopbanks as this could create cattle tracks on the stopbank faces, depressions and reductions of freeboard. Consider erecting signage near stopbanks outlining restrictions.
Slope instability (above the waterline).	Inspect stopbanks regularly in accordance with operational and maintenance requirements. Promptly repair areas where instability identified. Identify historic instability problems, cause and prepare longer term mitigation plan. Avoid over-steepening slopes when repairing unstable areas.
Obstructions, curves of the river, new construction nearby.	Coordinate with stakeholders to: • Maintain or remove vegetation in river bed. • Remove log jams and other debris creating flow obstructions. • Request that owners of new construction consider effects of new asset during the design stage e.g. new bridges can reduce flow area causing velocities against stopbanks to increase.
Rising water level (flood, riverbed changes, climate change).	Monitor water level changes. Ensure landward slope of stopbank can handle laminar runoff in the event of overtopping. Provide specific spillway sections with erosion protection.
Toe scour.	Monitor any modification to the stopbank toe. If practical, protect the stopbank toe before erosion affects the stopbank.

Appendix E – Methods of general scour estimation

E1 Methods of general scour estimation

These are semi-empirical, being based on regime theory. Details on these methods are provided in the Ministry of Works & Development publication titled 'Code of Practice for the Design of Bridge Waterways' (1979). Two methods are re-produced here in this guideline since the original document is out of print and difficult to acquire. They are the NZ Railways method and the Maza and Echavarria's method.

E2 NZ Railways method

The New Zealand Railways Department developed a method for estimating total scour based on field data collected from scour failures at a number of railway bridges. The method considers not only general scour, but also local and constriction scour. The method is based on New Zealand field conditions for a wide range of sediment sizes Refer Figure E1 for key to formulae parameters.

$D_s = D_{s1} + d_s$

Where:

D_{s1} = scoured depth, the greater of Yr V_1 K/(A/W)$^{0.5}$ or the depth of flow D in m.

d_s = depth of local scour = 0.8 (V1 b)$^{0.5}$ in m.

Yr = water level rise from low to flood stage in m.

K = factor dependent on waterway width and Lacey regime width.

= ((W/(4.83 Q$^{0.5}$))$^{0.5}$but not greater than one.

W is width in m and Q is flow rate in cumecs.

V_1 = approach velocity = (Q/A) (D/(A/W))$^{2/3}$ x C, in m/s.

b = width or diameter of bridge pier or structure.

C = 1.2 where converging flows are encountered and one for other cases.

Note: It may be worth increasing width b to allow for debris build around pier which increases risk of scour.

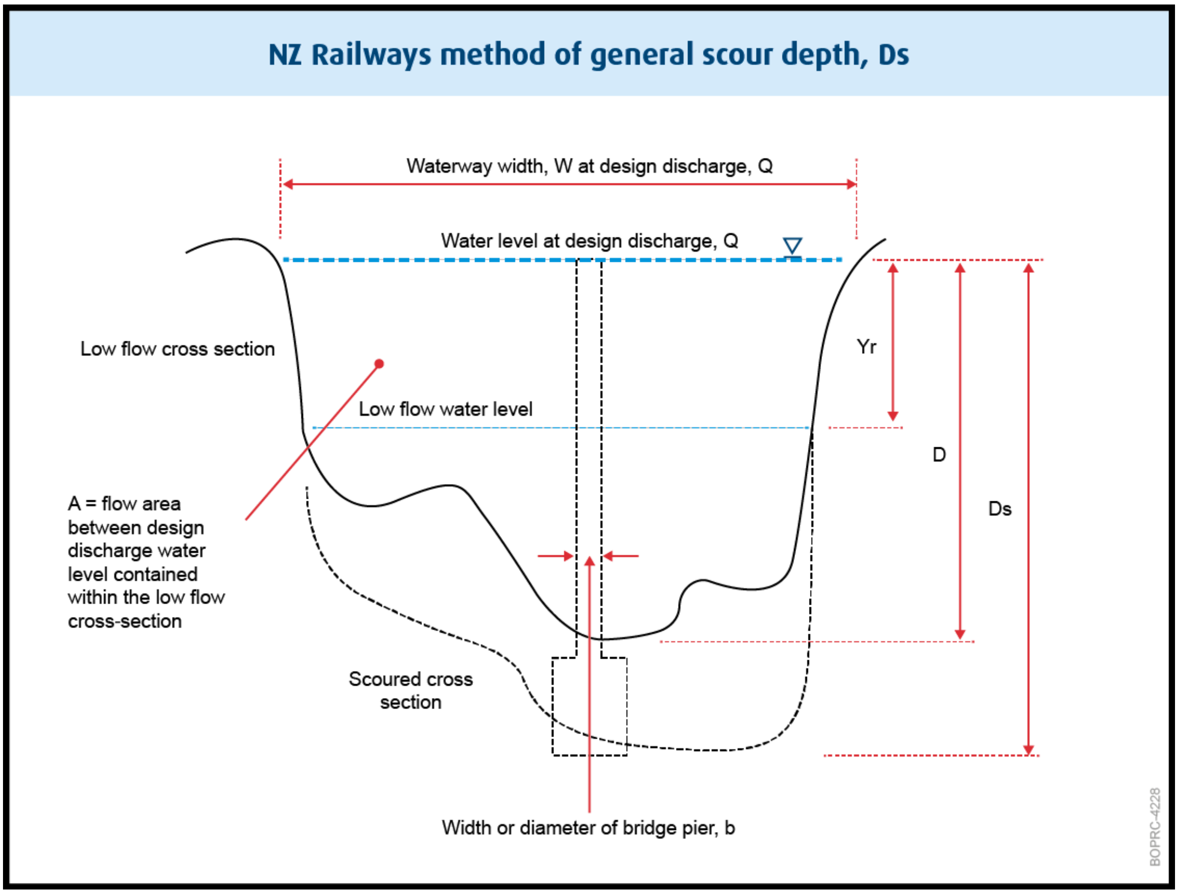


Figure E1 Key to NZ Railways general scour formulae.

E3 Maza and Echavarria's method

This method was developed as a design procedure from a number of other methods, together with field data from South American river scour measurements. Sediment sizes ranged from fine silts to coarse sands (d75 < 6 mm). This method has also been proven to be adequate with gravel beds in New Zealand. Refer Figure E2 for key to formulae parameters.

The maximum depth of flow in a straight reach (not including constriction or local scour is:

$$Ds = 0.365\ (Do/Dmo) \times Q^{0.784} / (B^{0.784}\ d50^{\ 0.157})$$

Where:

Do = depth from design water level to low flow channel low point in m.

Dmo = depth from design water level to low flow channel mean bed level in m.

Ds = maximum depth from design water level to scoured bed level in m.

d50 = sediment size in m.

B = waterway width.

Q = discharge flow rate.

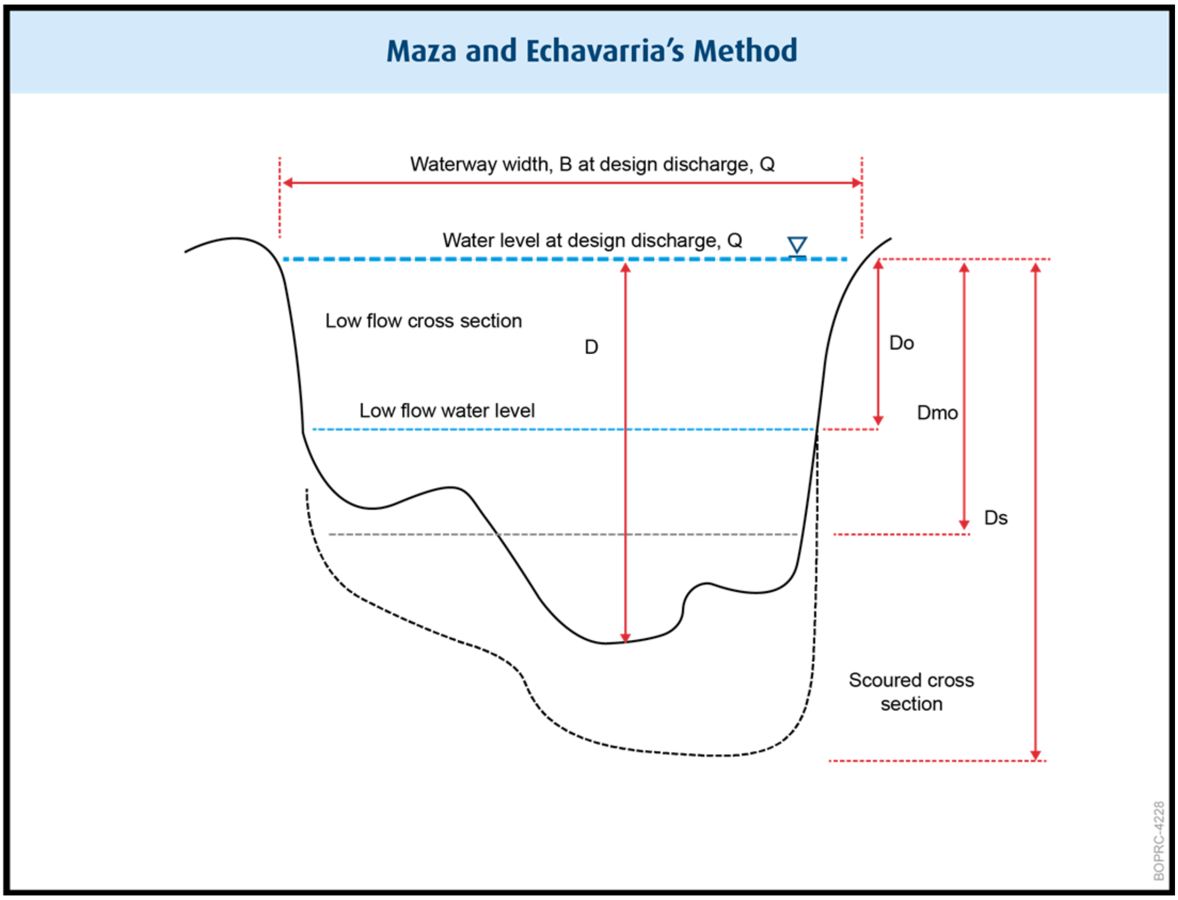


Figure E2 Key to Maza and Echavarria's general scour formulae.

Appendix F – Components of a typical stopbank specification

F1 General

Stopbank specifications vary from contract to contract depending on the type of contract being let e.g. design-tender-build versus direct labour and the type of structure being constructed e.g. a concrete wall and/or earth fill embankment. That said there will always be sections that are generic to many stopbank contracts as well as other additional optional sections that are dependent on what appurtenant structures are to be included in the same stopbank reach e.g. pump stations, embedded pipelines.

The following sections outline:

- Specification components that are typically found in many stopbank contracts; and
- An example of additional specification sections that may be necessary to cover appurtenant structures such as an embedded pipeline.

F2 Components of an earthworks specification

It is difficult to develop a generic document that covers all of the possible variations in sites and materials, likely to be encountered for the earthwork component of a stopbank specification.

There are many sections of such specifications that are common, and by modifying other more specific sections to suit the site conditions and materials of a particular project, the required elements of a good specification can be covered.

The broad sections and their contents which need to be considered include the following:

F2.1 Preliminary sections

These sections are generally common to almost all specifications. They include clauses dealing with:

- Requirements.
- Scope of the contract.
- Drawings.
- Site conditions.
- Site access.
- Commencement and completion of the work.
- Establishment.
- Liquidated damages.
- Standards of work.
- Supervision.
- Site amenities and construction facilities.
- Setting out.
- Statutory and OH & S compliance.

- Soil conservation.
- Fencing.
- Practical completion.
- Defects liability period.
- Final acceptance.

F2.2 Clearing and grubbing

This section covers the clearing grubbing and removal from the site of trees, tree stumps, tree roots, fallen trees, scrub, weeds, rubbish, obstructions, disused structures, fences and various items including service pipes. Specifications should cover:

- Area to be cleared.
- Method of trimming.
- Depth of grubbing.
- Filling of grubbed holes.
- Methods of disposal of materials from the operations.

F2.3 Earthworks

This section is the most critical of the stopbank specification and covers the activities of, stripping, excavation and placement of earthworks to construct the stopbank to the standards and the dimensions specified.

Clauses similar to the following should be included in this section to cover the various activities that constitute this section of the works.

F2.4 Working in watercourse bed

The Principal shall commence construction of works in the bed of the stream if the flow is low and there is at least four days of fine weather forecast by the New Zealand Metrological Service (MetService) for the water body's catchment.

F2.5 Flood Contingency Plan

The principal shall prepare a flood contingency plan which will incorporate procedures which will be carried out to ensure that adjacent property and infrastructure are not put at risk during a flood event while the construction phase of the work is in progress.

F2.6 Standards

Materials and workmanship covered by the Earthworks section of the contract shall conform to the following standards:

- NZS4402 - Methods of testing soils for engineering purposes.
- TNZ F/1 (1997) Specification for Earthworks Construction, as modified by this specification.

F2.7 Borrow areas (source of material)

All material for stopbank construction is to be excavated from borrow areas located as indicated on the drawings or where defined by the engineer.

Before excavating fill material from engineer borrow areas for the stopbank, all trees, plants, scrub and root material shall be removed from the site. Also, topsoil and any other material unsuitable for use as fill shall be stripped and stockpiled adjacent to the borrow area for later re-spreading or removal to an approved dump site as appropriate.

Following the completion of filling, borrow areas shall be left in a neat and tidy condition contoured to the approval of the land owner with batters no steeper than three horizontal to one vertical.

Channels, if required, shall be dug by the contractor from the borrow area to an adjacent stream or drainage channel to enable the pit to drain to the maximum depth possible. Channels shall be constructed using a method considered acceptable to the engineer and which complies with Resource Consent conditions. Silt shall be removed from the water before it is discharged. All surplus topsoil shall be spread over the surface of the borrow area and graded to an even surface.

F2.8 Stripping of site

The area for the foundation/placement of the stopbank shall be stripped of all grass, roots, decayed vegetable matter and any other deleterious substances.

All wet or spongy material and topsoil should be removed so that a natural undisturbed surface suitable as a solid base for the proposed works is provided unless there is a considerable depth of weak material and the stopbank designer has allowed for it to remain.

Stripped topsoil is to be stockpiled in an approved area and used for top soiling of the stopbank. Minimum depth of topsoil to be placed will typically be 150 mm.

F2.9 Foundation treatment

The stopbank footprint shall be prepared by ripping to a minimum depth of 150 mm followed by watering and rolling to bring it to the required moisture content. The engineer shall confirm moisture content of the ripped surface is acceptable. The surface may then be scarified to provide a good bond with the first layer of fill.

F2.10 Placing and compaction

The selected fill in stopbanks shall be placed in layers not exceeding 150 mm loose thickness and compacted with a sheepsfoot or tamping foot roller with a pressure of not less than 1.8 MPa.

Banks shall be constructed to achieve a density of not less than 95% laboratory maximum dry density as obtained by NZS 4402, test 4.1.1, standard or heavy compaction as required by the designer.

If, during or after placement, any material has become contaminated by topsoil or other unsuitable material from the passage of construction machinery, or by other means, the contaminated material shall be entirely removed and the contractor shall not be entitled to any additional payment.

If any layer is not compacted in accordance with the specification and other material is placed on top of that layer the contractor shall be required to remove any necessary material and carry out further compaction as directed by the engineer. The contractor shall not be entitled to any additional payment for this work.

At the start of construction the engineer will carry out compaction tests. If the results are not satisfactory, the number of passes of the roller shall be increased until satisfactory results are achieved and this shall be the minimum number of passes required for the placement of the particular soil tested.

Note:

As an alternative to the testing being carried out by the engineer, the contractor could undertake the tests and advise the Engineer of the results. Under this arrangement the following clauses could be included in the specification:

- A geotechnical test laboratory engaged by the contractor shall carry out the initial compaction testing. Current IANZ registration is necessary for the testing laboratory. Once the compaction standard has been set the density test results can be correlated to scala penetrometer test results and the contractor can carry out the remainder of the tests. Scala penetrometer testing shall be carried out at depths between 0.3 m and 0.75 m in accordance with NZS 4402:1998 Test 6.5.2. If the soil type changes a further set of density tests carried out by laboratory staff will be required.
- It should be noted that whilst a Clegg hammer is considered adequate for testing finished fill on stopbank surfaces they are not recommended for testing compaction of bulk fill within the stopbank or rock placed on top of the stopbank.
- The contractor shall supply to the engineer compaction test results at 30 m (maximum) intervals for each 0.6 m lift of the compacted stopbank over the entire length of the Works. The results shall be presented in a manner that allows the identification of the test locations so that gaps in the testing can be detected.
- During the testing of the compacted earthworks it will be the contractor’s responsibility to protect the testing officers from construction equipment and other traffic.

F2.11 Moisture control

The engineer shall notify the contractor of the optimum moisture content for compaction of the materials to be used in the stopbanks. The working range to be used by the contractor shall be +/- 2%.

The engineer shall carry out tests of the moisture content and density of the compacted materials.

When tests indicate that results for the prepared foundation or any layer are outside the limits set by the specification, the Engineer may order the following steps to be taken:

- If the moisture content is below optimum, or the soil surface is too dry or smooth to bond properly with the layer of material to be placed thereon, it shall be moistened or worked with a harrow, scarifier or other suitable equipment, in an approved manner to a sufficient depth to provide a satisfactory bonding surface before the next layer is placed.
- If the moisture content is above optimum, or is too wet for proper compaction and bonding to the layer of material to be placed thereon, it shall be removed, allowed to dry or worked with a harrow, scarifier or other suitable equipment to reduce the moisture content to the required level and then re-compacted to provide a satisfactory bonding surface before the next layer of material is placed.

If any material in the embankment cannot be brought to the specified moisture it shall be removed from the embankment at the direction of the engineer.

If the surface of a previously placed and compacted layer has been sealed or has been left for some time and has dried out or wetted up, the surface shall be treated by scarifying and watering or drying to the satisfaction of the engineer.

Care shall be taken to shape and seal the placed fill at the end of each working day or when rain is imminent to prevent water ponding on the fill surface.

F2.12 Topsoil placement

Areas to be top-soiled shall be finished 100 mm below finished surface level so that after the topsoil is placed and firmed with a light roller the finished surface conforms to that specified.

Suitable topsoil, specified by the engineer shall be placed on the batters to a uniform depth of 100 mm and areas, when finished, shall present smooth surfaces, free of stones, timber and lumps of soil, gradually blending into adjoining ground and left ready for grassing.

Topsoil shall not be placed until the engineer has checked the lines and levels of the embankment and approved the bank.

F2.13 Tolerances

Earthworks shall be finished to a reasonably smooth surface that conforms to the lines, grades and cross-sections shown on the drawings or directed by the Engineer.

Tolerance limits are as follows:

- Crest levels:
  - Minimum level: Design level.
  - Maximum average level: Design level + 100 mm.
  - Variation from maximum average level: +/- 50 mm.
- Batters:
  - No steeper than specified.
- Crest width:
  - + 200 mm – 0 mm
- Topsoil thickness:
  - + 25 mm – 0 mm
- Base width:
  - + 500 mm – 0 mm

F2.14 Additional sections

There are a number of additional areas to be covered in a comprehensive Earthworks Specification. These areas include:

- Storage and disposal of excavated material, waste material and salvage rights.
- Measurement and payment for completed work.
- Construction equipment schedule.
- Hours of work.

A specification that clearly indicates the requirements of the principal, either by inputs or outcomes, is critical to the achievement of a satisfactory result in the construction of stopbanks. Lack of detail or other shortcomings in a specification, could result in difficulties administering the contract and could adversely affect the quality of the asset.

F3 Other useful components of a stopbank specification

Stopbank construction contracts may include other appurtenant structures that will require separate sections in the specification. Examples include pump stations, control valve and stop log structures, drainage channels, spillways, access roads/pathways, gates and fences, other utility services (e.g. gas mains) and embedded items such as culverts. The following section provides an example of an additional specification section recommended for:

- Embedded pipelines.
- Riprap for stopbank toe protection.

F3.1 Components of an embedded pipeline specification

F3.1.1 Timing of the work

Work shall not commence if the long range weather forecast predicts rain.

Prior to pipeline works proceeding all materials and equipment must be sourced such that their availability will not cause a more than minor delay to construction.

F3.1.2 Compaction of backfill around the pipe

Practices for successful backfill compaction around buried pipes are outlined in NZS 4452: 1986 ‘Code of Practice for the Construction of Underground Pipe Sewers and Drains’. Although NZS 4452 has been withdrawn from print the principles outlined therein are still widely used today.

The trench for the pipe must be wide enough to allow good compaction of the backfill material around the pipe, and above the pipe up to the original ground level.

Backfilling shall not commence until the concrete bedding is hard enough that it will not crack under the forces applied by backfilling and compacting.

The backfill material shall be free of humus, vegetation and other organic material and consist of at least 30% silt or clay. The maximum thickness of each layer of fill, before compaction, shall be 200 mm.

The contractor shall provide the engineer with the results of the following tests on the fill and obtain his approval prior to reinstatement:

- Compaction curve that shows the relationship between dry density and water content, and identifies the maximum dry density and optimum moisture content of the material. This shall be done in accordance with Test 4.1.1, NZS 4402 (also known as the Proctor Test).
- The contractor shall carry out the following tests during reinstatement, and provide the engineer with the results as soon as possible:
    - o Confirmation that the fill is compacted so that its dry density is not less than 95% of NZ Standard Compaction. Upon the completion of each 0.60 m vertical lift, testing of the backfill shall be carried out at four well-spaced locations.

- o Confirmation that the number of blows per 150 mm penetration of compacted fill is more than six using a Scala Penetrometer, as per NZS 4402: 1988 Test 6.5.2.

Upon the completion of each 0.60 m vertical lift, testing of the backfill shall be carried out at an average of six but not less than five well-spaced locations.

Material failing the tests shall be removed, re-compacted and re-tested. The area of material to be removed shall extend in both directions, to the location of the nearest successful test, or to the inlet or outlet structure.

F3.1.3 Concrete bedding

The pipe shall be laid on a concrete bed extending from the granular drainage filter to the outlet structure at the river end of the pipe. A high strength of concrete (20 MPa or greater) is required, given the need to place and compact backfill as soon as possible after the pipe and concrete bedding have been placed. The concrete shall be poured directly against the bottom and sides of the trench, with no longitudinal boxing being used.

As recommended in NZS 4452: 1986 one third of the pipe circumference shall be bedded in concrete, and a minimum thickness of 200 mm of concrete placed under the pipe. The bedding shall have transverse construction joints at the pipe collars where necessary to accommodate shrinkage or settlement. The bedding shall extend the full length of the pipe, except at the landward side toe end where some of the pipe is to have a drainage filter placed around it (see below). If the bedding and the haunching are placed as two separate pours, keying will be required to ensure that the haunching does not crack longitudinally, and subsequently move relative to the bedding. The key shall consist of steel dowels extending the full depth of both concrete pours, less 50 mm cover at each end. The dowels shall be made from 20 mm diameter deformed steel, and placed at 300 mm centres on both sides of the pipe.

F3.1.4 Cut-off walls/seepage collars

There shall be no cut-off walls/seepage collars constructed around the pipe.

F3.1.5 Granular filter collar

Starting at the land-side end of the pipe, a collar of granular fill shall be placed so as to completely surround the pipe and the bedding for a length equal to one third of the base width of the stopbank. The thickness of the collar above, below and beside the pipe shall be sufficient to allow the necessary compaction, but not less than 300 mm. The granular material shall be compacted in 200 mm layers with a vibrating plate compactor.

Compaction of each layer shall continue until further passes of the compaction equipment produce no further discernable compaction.

The granular filter material shall conform to the grading nominated in NZTA's F/2 guideline or a grading and density specified by the stopbank designer to suit the soils being filtered.

F3.2 Components of a riprap toe protection specification

The contractor shall ensure that:

- The rock riprap consists of angular sound rock with a minimum density of **tbd** tonnes per cubic metre and median diameter (D_{50}) of **tbd** m with the rock evenly graded between **tbd** m.

- The rock is constructed at a maximum batter slope of **tbd** H: 1V in an interlocking layer to form a minimum layer thickness of **tbd** [2 x D_{50}] m and embedded a minimum of **tbd** m into the river bed.
- The rock lining is returned a minimum of **tbd** m into the riverbank at the upstream end.
- The rock lining is constructed so that it is structurally stable with minimal risk of collapse into the riverbed.
- The completed protection works is free of any significant projections out of the smooth line of the work and it shall tie in to the riverbank both upstream and downstream of the proposed work in a secure and hydraulically smooth fashion.

tbd denotes 'to be determined'.

Advisory note:

The rock diameter shall be measured by the geometric mean of the lengths of three principal orthogonal axes (being the cube root of these three dimensions multiplied together). It is not the largest dimension (BOPRC, 2012).

Appendix G – Example of a condition assessment checklist for stopbanks

Visual inspection field sheet			
Stopbank (name/reach):			
Watercourse condition			
Watercourse name:		Reach alignment, on straight or bend?	
Changes in reach alignment evident, Yes or No?		Flow obstructions in reach (e.g. bridge piers, trees, gravel beaches, other)?	
Comments:			
Stopbank condition			
Crest Width (m):		Location, on bend or straight?	
Upstream stopbank shoulder			
Upstream slope height (m)		Upstream slope (yV:1H)	
% Upstream slope has grass cover		% Upstream slope has shrub cover	
% Upstream slope has tree cover (>3 m height)			
Upstream slope disturbances (e.g. slumping, cracking, scour, caving, sinkholes and erosion)?			
Downstream stopbank shoulder			
Downstream slope height (m)		Downstream slope (yV:1H)	
% Downstream slope has grass cover		% Downstream slope has shrub cover	
% Downstream slope has tree cover (>3 m height)			
Downstream slope disturbances (e.g. slumping, cracking, scour, caving, sinkholes and erosion)?			
Comments:			

Berm condition			
Upstream berm			
Upstream berm width (m)		% Upstream berm has grass cover	
Condition of upstream edge protection		Upstream berm constrictions:	
Upstream berm scour erosion		Upstream berm run-off erosion	
Downstream berm			
Downstream berm width (m)		% Downstream berm has grass cover	
Condition of downstream edge protection		Downstream berm constrictions:	
Downstream berm scour erosion		Downstream berm run-off erosion	
Toe drains and/or seepage discharge drains			
Comments:			
Toe area			
Water ponding		Seepage	
Sponginess		Turbidity (colour, fines)	
Comments			
Transitions, penetrations, structures and access			
Transitions (floodwalls, pump stations, gate structures etc.):			
Penetrations (power cables, culverts, utility pipelines etc.):			
Access (roads, pedestrian, cycle paths):			
Structures (buildings, fences, steps, gardens, terracing etc.):			
Comments:			

Appendix H – Example of emergency flood barriers

Sandbags are still the most commonly used and readily available form of emergency barrier used by Regional Council today. Sandbags are used to protect property from increasing flood levels. Advantages of sandbags include:

- Being able to keep water out for short periods which can be lengthened by using them in conjunction with plastic sheeting.
- Being capable of filtering out some muddy sediments common in flood waters.
- Being cheap and easy to obtain.

However sandbags are relatively ineffective when compared to purpose designed flood protection products. Some disadvantages include:

- Takes two people to fill (unless a sandbag filling machine is available).
- Takes time to fill (approximately 1 hour to fill 12 sandbags).
- Can be difficult to handle.
- Laying them correctly can be time consuming.
- Sacking material is biodegradable and will perish if left in place for a long time.
- Difficult to place sandbags in water and particularly flowing water.
- Sandbags still seep even when well stacked and trodden in place.

Figure H1 shows typical stopbank arrangements with and without plastic sheeting.

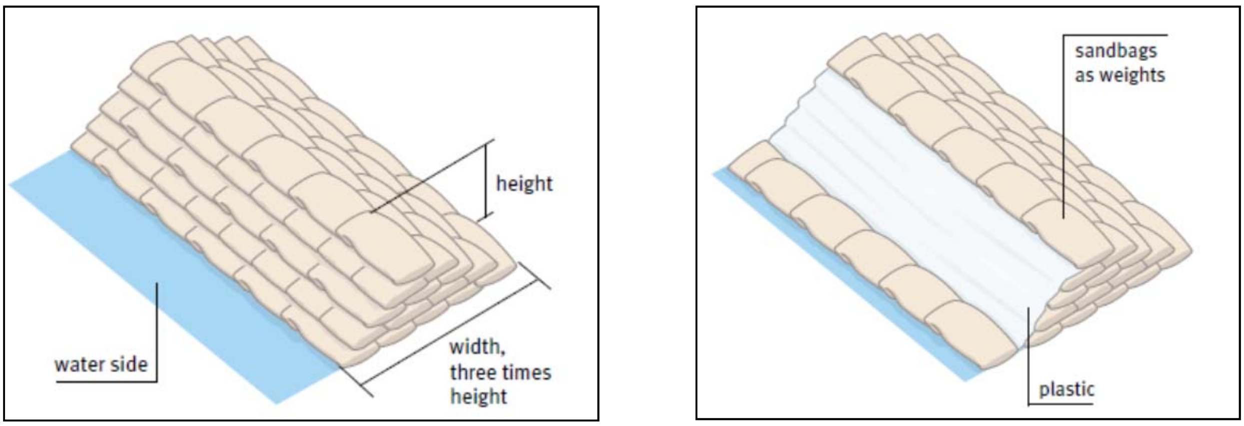


Figure H1 Emergency flood barriers – sandbags with and without plastic sheeting.

Emergency flood barriers used by others are described as follows:

Box 6.19 ***Open-celled plastic grid flood wall***

Details

- collapsible plastic grid 20.3 cm high
- expands into 1.2 m × 1.2 m or 1.2 m × 0.6 m sections
- interlocks
- filled with sand from the top with a loader, excavator, bottom-dump, or other piece of earthmoving equipment
- light enough to be handled by two people
- small enough to be manageable in the wind
- fits into a pickup truck bed or helicopter
- requires no special tools
- small footprint and cross-section.

Figure 6.47 *Plastic cell field setup (courtesy USACE)*

Advantages	Disadvantages
Easy and quick to construct	Some breakage of grid if handled roughly
Very stable, even on soft soils	Added weight may decrease slope stability
90 % reusable	Requires machinery to fill
1.8 m wide footprint (1.2 m high structure)	Some difficulty in removing fill from cells after use
Very low seepage	

Figure H2 Emergency flood barriers – open-celled plastic grid floodwall (CIRIA, 2013).

Box 6.20 ***Portable cofferdam systems***

Details

- uses a steel supporting structure
- continuous reinforced vinyl liner membrane
- means of water diversion, retention, or impoundment
- the support structure is designed to transfer hydraulic loading to a near vertical load, thereby creating a free-standing structure with no back brace to extend to work area
- the liner system is flexible, sealing most irregular contours
- this system can be installed almost anywhere, in any configuration, and to any length
- the equipment is offered as rental item in heights of 1 m, 1.5 m, 2 m and 3 m.

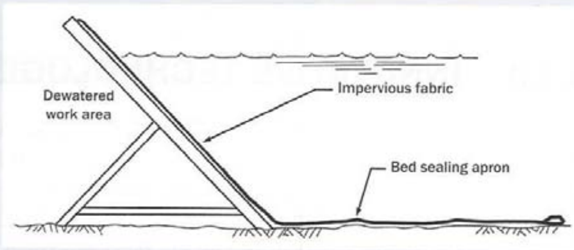


Figure 6.48 *Portable cofferdam diagram (courtesy USACE)*

Advantages	Disadvantages
Easy and quick to construct and remove	Height cannot be increased if flood worsens
Low seepage once bed seal established	Requires wide levee topwidth to be set up on levee crest
100 % reusable	May be damaged by floating debris
Stable, except on soft soils	Access to levee top limited when installed

Figure H3 Emergency flood barriers – portable cofferdam system (CIRIA, 2013).

Box 6.21 *Portable dam system*

Details

- rapidly deployed and removed
- assembled along pre-installed anchor line and seepage barrier
- a standard element is 2.1 m long
- 0.75 m to 1.2 m level of protection
- custom elements available
- 1.2 m wide foot print (1.2 m high structure)
- 100 per cent reusable and repairable.

Figure 6.49 AquaFence implementation (courtesy USACE)

Advantages	Disadvantages
Easy and quick to construct and remove	Should have pre-installed anchor line and barrier
Low seepage	Height cannot be increased if flood worsens
100 % reusable	Requires a large levee crest to setup

Figure H4 Emergency flood barriers – portable dam system (CIRIA, 2013).

Box 6.22 *Water-inflated barrier*

Details

- water inflated property protector – uses any water source
- industrial-grade, vinyl-coated polyester membrane material
- internal baffle system provides role over stability
- 0.3 m to 2.5 m high tubes provide protection to 75 per cent or 0.2 m to 1.8 m high
- rapidly deployed and removed
- 3.8 m wide foot print (1.5 m high protection)
- stores compactly.

Figure 6.50 Water inflated barrier field setup (courtesy USACE)

Advantages	Disadvantages
Uses readily available water as fill material	Height cannot be increased if flood worsens
Can be positioned very quickly	Requires wide levee topwidth to setup on levee crest
Very stable, even on soft soils	Added weight may decrease levee stability
100 % reusable	Access to levee top limited when installed
	Can be punctured by equipment or vandals

Figure H5 Emergency flood barriers – water inflated barrier (CIRIA, 2013).

Box 6.23 *Water-filled tubes*

Details

- uses any water source
- flexible interlocking tubes
- single tube 0.5 m diameter, 15.25 m long
- stack like a pyramid up to 6 m held together by straps
- rapidly deployed: 1.5 minutes from fire hydrant or three minutes by pump
- height easily added by strapping next row to current structure
- easily removed, using water for washing
- three tubes high: 1.5 m wide foot print (1.2 m high protection)
- stores compactly, 15.25 m delivered in 200 litre drum
- can be filled with concrete.

Figure 6.51 *Tiger dam system implementation (courtesy USACE)*

Advantages	Disadvantages
Easy and quick to construct and remove	Can be punctured by equipment or vandals
Can adapt installation to situation	Requires wide levee topwidth to setup on levee crest
100 % reusable	May be damaged by floating debris
Height of protection can be increased if flood worsens	Access to levee top limited when installed
Very stable even on soft soils	

Figure H6 Emergency flood barriers – water filled tubes (CIRIA, 2013).

Box 6.24 *Filled permeable container*

Details

- cellular barriers of permeable material
- lined with geotextile or geosynthetic fabrics
- filled with aggregates to form barrier
- containers strengthened and held in place by wire meshes, pins, frames
- impermeability controlled by fill material
- stackable, flexible, conform to foundation.

Figure 6.52 *Example of filled permeable container (courtesy USACE)*

Advantages	Disadvantages
Height of some systems can be increased by stacking	Clogging of material/effluents within the fabric can make cleaning difficult or impossible
Can be installed by relatively unskilled labour	Stacked defences require significant width, which may not always be available
Small storage space required	Some steel supports and pins may buckle or deform beyond reuse under stacking and service loading
Adapts to uneven terrain	Need to dispose of large volumes of probably contaminated material after flood event
Can use readily available fill material	Seepage can be a problem, but this can be minimised by using a suitable choice of geotextiles and fill
	High bearing pressure on bedding surface when stacked
	Some can be reused, but only a limited number of times

Figure H7 Emergency flood barriers – filled permeable container (CIRIA, 2013).

Box 6.25 *Demountable barriers*

Details

- rigid panels placed horizontally between stanchions
- permanent foundation with stanchion guides
- lined with seals to ensure water tightness
- stanchions can be permanently installed or attached to installed connections.

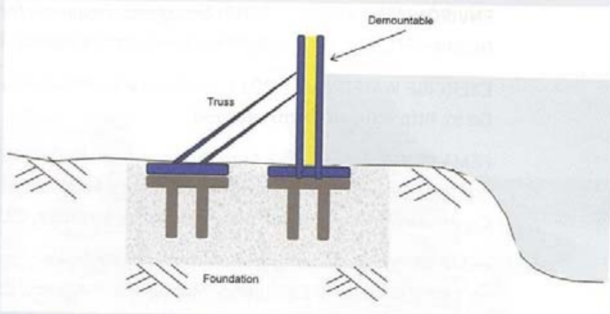


Figure 6.53 *Schematic of demountable barrier (see Chapter 4, Table 4.3 for field application)*

Advantages	Disadvantages
Generally robust and well engineered	Large storage area required
Good resistance to loading and impact	Heavy transportation and lifting requirements
Very durable	Long installation and mobilisation period
Can be increased in height by adding panels up to the height of the frame	Permanent parts susceptible to damage and vandalism
Very low seepage through and under the structure	

Figure H8 Emergency flood barriers – demountable barriers (CIRIA, 2013).