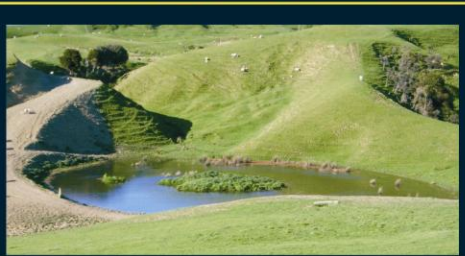
HAWKE'S BAY WATERWAY GUIDELINES

SMALL DAM DESIGN

HAWKE'S BAY
REGIONAL COUNCIL

SAFEGUARDING YOUR ENVIRONMENT KAITIAKI TUKU IHO



159 Dalton Street + Private Bag 6006 + Napier
Telephone (06) 835 9200
Fax (06) 835 3601
Regional Freephone (06) 0800 108 838

SAFEGUARDING YOUR ENVIRONMENT + KAITIAKI TUKU IHO

Hawke's Bay Waterway Guidelines

Small Dam Design

Prepared by:
Earl Shaver, Aqua Terra International Ltd

Reviewed by:
Gary Clode, Manager - Engineering

Note
This document is a living document and may be reviewed from time to time as industry standards change and best practice evolves. Please contact Hawke's Bay Regional Council to ensure the latest version is used.

April 2009
ISBN NO 1-877405-31-0
HBRC Plan Number 4105

Contents

1 Introduction

1.1 Purpose

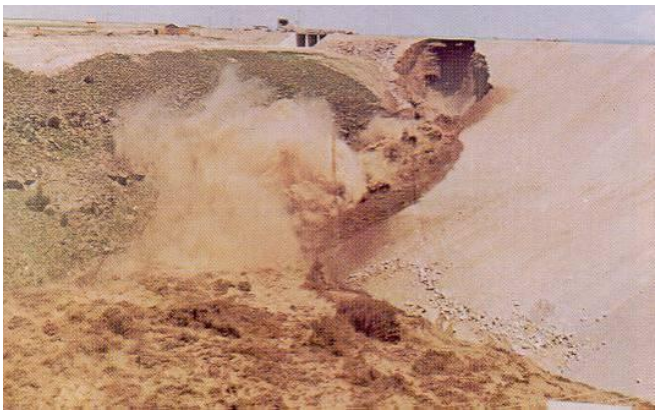
This guideline provides guidance for design, construction and operation of small dams in the Hawke's Bay Region. It does not provide guidance for excavated ponds as they do not represent a safety concern and they generally do not have an embankment associated with them.

Dams provide benefit for a number of reasons. They commonly provide the following:

- Water supply,
- Generation of power,
- Storage of floodwaters to reduce downstream flooding potential,
- Water quality treatment,
- Water for fire fighting,
- Provision of a fishery resource, and
- Aesthetic benefits.

While dams do provide potential benefits they also have a risk associated with their design, construction and operation. Dams store water behind their embankment and the water has a density of approximately 1 kg/litre or 1,000 kg/m^3. As such, the amount of water stored behind an embankment can exert a significant pressure on the embankment with the pressure being directly proportional to the depth of water in the dam.

Grand Teton Dam Failure
11 People Died as a Result



Dam safety is established via the weight associated with the embankment itself and minimisation of seepage through the dam. Having a large embankment cross-section in conjunction with adequate compaction and methods to eliminate seepage through the embankment are the safety features that ensure dam stability.

As a result of the more than 1150 large dams in New Zealand, the Building Act has placed requirements on large dams to obtain consents from the Regional Councils as discussed in Section 2 of these Guidelines.

Assurance of dam safety is provided at a number of stages including:

- Design,
- Construction, and
- Continued operation.

All three of these items will be discussed in Sections 5 and 6 of the Guidelines.

2 Resource Management Act and Building Act

2.1 Resource Management Act (RMA)

Section 14(1) of the RMA states that no person may take, use, dam or divert any

a) Water (other than open coastal water), or
b) Heat or energy from water (other than open coastal water), or
c) Heat or energy from the material surrounding any geothermal water

unless the taking, use, damming, or diversion is allowed by Section 14(3).

Section 14(3) states:

A person is not prohibited by subsection (1) from taking, using, damming or diverting any water, heat, or energy if:

a) The taking, use, damming or diversion is expressly allowed by a rule in a regional plan and in any relevant proposed regional plan or a resource consent, or
b) In the case of fresh water, the water, heat, or energy is required to be taken or used for:
    i. An individual's reasonable domestic needs, or
    ii. The reasonable needs of an individual's animals for drinking water,

    and the taking or use does not, or is not likely to have an adverse effect on the environment.

Section 15 of the RMA discusses the discharge of contaminants into the environment. This is important as dam safety is important in reducing potential environmental impacts in the event of a dam failure.

It is important to recognise that the focus of the RMA is on environmental issues and not necessarily on public safety issues, which are more directly addressed in the Building Act.

2.2 Building Act

Recently the Building Act has taken a much more direct approach to dam safety. The Act introduced new requirements for dam construction and dam safety management in 2004 and in July 2008 passed Building (Dam Safety) Regulations. Those Regulations commence on 1 July 2010.

Section 7 of the Building Act gives a precise definition of the type of dam that will trigger the provisions of the new scheme, including flood control dams, significantly modified natural features and canals. Section 7 states that a 'dam':

a) Means an artificial barrier, and its appurtenant structures, that –

    i. Is constructed to hold back water or other fluid under constant pressure so as to form a reservoir, and
    ii. Is used for the storage, control, or diversion of water or other fluid, and

iii. Retains 3 or more metres' depth, and holds 20,000 or more cubic metres volume, of water or other fluid, and

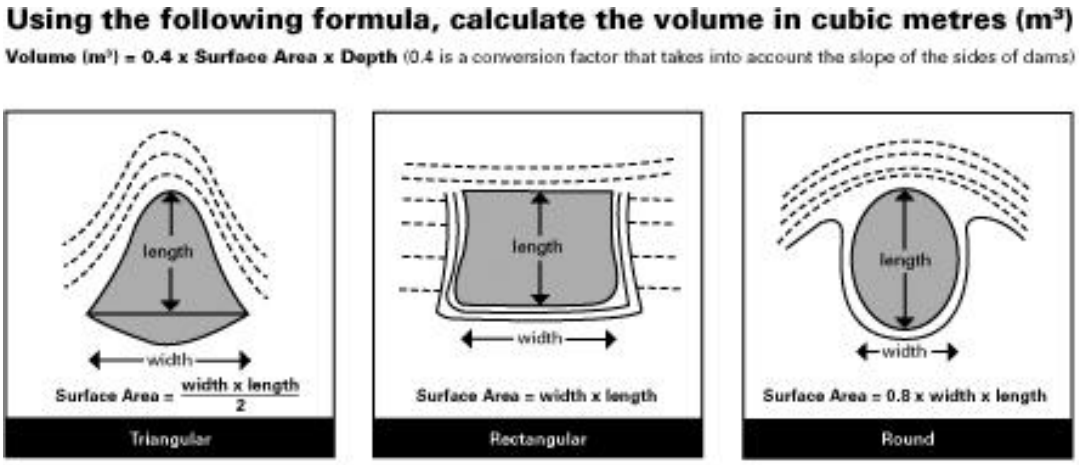
b) Includes –

i. A flood control dam, and
ii. A natural feature that has been significantly modified to function as a dam, and
iii. A canal, but

c) Does not include a stopbank designed to control floodwaters.

To repeat, the Dam Safety regulations only address large dams that hold more than 20,000 m^3 and retaining greater than 3 metres depth of water. Hawke's Bay Regional Council considers water depth to be determined by the vertical distance between the emergency spillway invert and the invert of the original stream bed or gully at the centreline of the dam. Figure 2-1 provides information (Department of Building and Housing, 2008) on calculating ponded volumes.

Figure 2-1
Calculation Approach for Pond Volumes (Department of Building and Housing, 2008)



The Regulations classify dams through the dam owner undertaking the following steps:

a) Identify the effect that an uncontrolled release of the reservoir due to a failure of the dam when full would have on specified categories.
b) Determining the assessed damage level by assessing whether the damage level in each of the specified categories is catastrophic, major, moderate or minimal when selecting the highest damage level.
c) Estimating the population at risk, and
d) Determining the dam classification by correlating the assessed damage level with the estimated population at risk.

Table 2-1 provides the required dam classification approach.

Table 2-1 Dam Classification Determination of Assessed Damage Level					
Damage Level	Residential Houses	Critical or major infrastructure		Natural Environment	Community Recovery Time
		Damage	Time to restore operation		
Catastrophic	More than 50 houses destroyed	Extensive and widespread destruction of and damage to several major infrastructure components	More than 1 year	Extensive and widespread damage	Many years
Major	4 to 49 houses destroyed and a number of houses damaged	Extensive destruction of and damage to more than 1 major infrastructure component	Up to 12 months	Heavy damage and costly restoration	Years
Moderate	1 to 3 houses destroyed and some damaged	Significant damage to at least 1 major infrastructure component	Up to 3 months	Significant but recoverable damage	Months
Minimal	Minor damage	Minor damage to major infrastructure	Up to 1 week	Short-term damage	Days to weeks

Table 2-2 then provides determination of the dam classification.

Table 2-2 Dam Classification*				
Assessed Damage Level	Population at Risk			
	0	1 to 10	11 to 100	More than 100
Catastrophic	High potential impact	High	High	High
Major	Medium potential impact	Medium/High	High	High
Moderate	Low potential impact	Low/Medium/High	Medium high	Medium High
Minimal	Low potential impact	Low/Medium/High	Low/Medium/High	Low/Medium/High
• There are several caveats to the classification so the Regulations should be read to clarify any uncertainties				

In addition to the Dam Classification tables, the Regulations contain forms that need to be completed. Those forms include the following:

- Dam classification certificate,
- Dam safety assurance programme, and
- Annual dam compliance certificate,

2.3 Hawke's Bay Regional Council

While the RMA and Building Act provide a level of national interest in dams, the Hawke's Bay Regional Council is responsible for meeting requirements of both those acts. In addition, the Hawke's Bay Regional Council also has concern on dams smaller than those regulated under the Building Act.

These Guidelines provide minimum criteria for all small dams constructed in the Region.

3 Components of dams

3.1 Introduction

A dam is much more complicated than just being a barrier across a drainage area. They include a number of key components and their nature and function can depend on a dam's purpose (ARC, 2000). The principal components are the following:

- The reservoir area,
- The embankment structure,
- Spillways,
- Conduits, and
- Other elements that form part of the dam.

All of these items are discussed in the following subsections.

3.2 The reservoir area

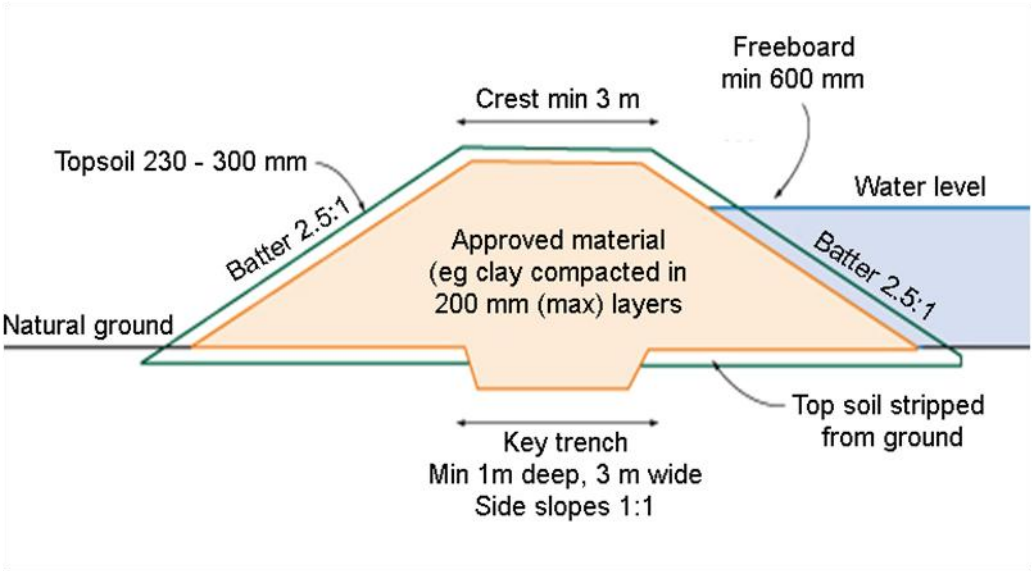
The most common purpose of a dam is to hold water behind it. The storage capability determines the hazard category listed in Tables 2-1 and 2-2. Changes in water level can induce slope instability and impact on groundwater levels in surrounding areas.

In extreme situations the dam location can impact on earthquake potential.

3.3 Embankment structure

The embankment is the barrier behind which the water is stored. Earthen embankments are highly compacted structures that would normally have key trenches to resist lateral movement of the dam resulting from water pressure. An example of a dam embankment is shown in Figure 3-1.

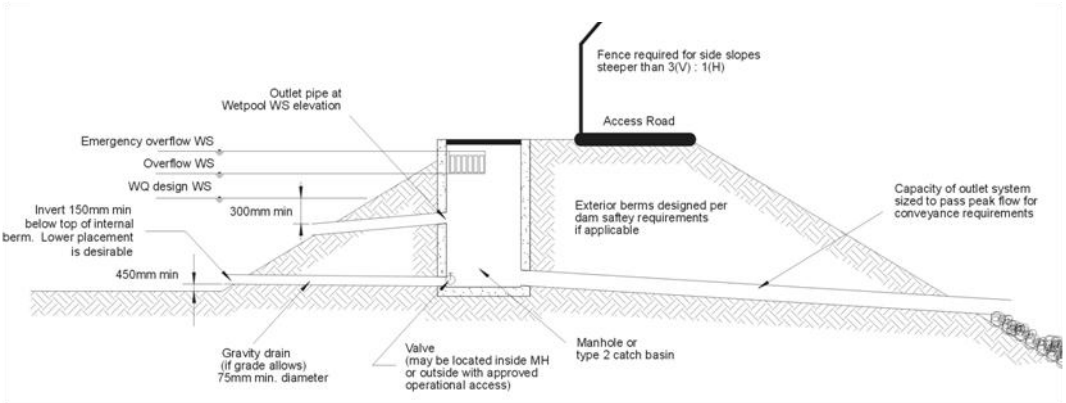
Figure 3-1
Pond Embankment Cross-section (ARC, 2000)



3.4 Principal spillway or conduit

Most dams have one or more spillways or conduits passing through the dam embankment. The purpose of these conduits is to pass base stream flow and/or frequent storm events when the dead storage ability of the dam is exceeded. These pipes are normally called the principal spillway as flows are principally conveyed by these pipes. These conduits are normally made of concrete or metal and pass the flows through the embankment downstream. An example of this is shown in Figure 3-2.

Figure 3-2
Embankment Cross-Section Showing the Principal Spillway



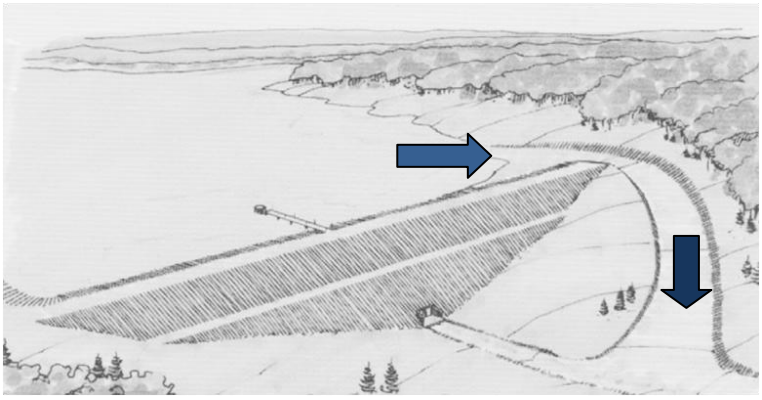
3.5 Emergency Spillway

Regardless of the design criteria for the dam, there will come a time when the ability of the principal spillway to pass storm flows is exceeded. All dams should have an emergency overflow spillway to convey floodwaters in a manner that does not cause structural damage to the dam itself.

The most common form of emergency spillway is a trapezoidal channel in natural ground that is designed to safely convey infrequent storms. When designing an emergency spillway design considerations must include capacity and velocity of flow during operation.

An emergency spillway schematic is shown in Figure 3-3.

Figure 3-3
Schematic of an Emergency Spillway



3.6 Dam drawdown

It is important that all dams have an ability to drain completely in the event that sediment removal must occur or there is a structural problem with the dam that would necessitate draindown for repair. The most common way to drain the water is to have a drain valve in the bottom of the principal spillway that can be opened as needed to reduce the permanent storage volume.

Example of a Dam Drain Pipe to Drawdown Water Level

3.7 Foundation

The area of ground on which the dam is located and the area of ground adjacent to the dam form part of the total water barrier. If the foundations do not adequately support the basic dam structure, or are themselves weak or prone to high seepage flows and forces, then they can create an area of high risk. (NZSOLD, 2000).

The risks associated with poor foundation conditions can be extensive and include:

- Geological defects in rock structures which are points of weakness and/or of high seepage flow potential,
- Weaknesses in the abutments making them vulnerable to slope failures, and
- Weaknesses in the foundation that are susceptible to liquefaction during earthquakes.

3.8 Other structures

Other structures can include intakes on the upstream side of the dam, and powerhouses or pump stations often built into the downstream foot of the dam. All of these need to be considered carefully to ensure their location and construction does not adversely impact on dam function or stability.

4 Hazard Classification

4.1 Introduction

The discussion of dam hazard in Tables 2-1 and 2-2 provide a general view of determining dam hazard classification. The detail of determining whether those adverse impacts could be realised is the purpose of this discussion.

When considering potential dam failure the approach is normally to do a dam breach analysis of the dam to determine impacts related to a sudden failure of the dam.

Breach width and breach time have significant impacts on predicted outflow and inundation downstream. The time it takes for a breach to develop is considered to begin at the point where dam failure is imminent and end when the breach has reached its maximum size. For reservoirs with a relatively small storage, peak outflow from a dam break may occur before the breach fully develops due to a significant drop in reservoir levels during the formation of the breach, whereas in reservoirs with a large storage the peak outflow occurs when the breach has reached its maximum size.

4.2 Breach parameters

Models have been used to study the effects of breach parameter variations on the predicted peak outflow for eight hypothetical breached dams. They varied breach width, depth, failure time and overtopping head within ranged identified in analyses of 20 actual dam failure case studies (Singh and Snorrason, 1984)

4.3 Parameters for estimation of downstream flood wave

This method is only to be used for small dams that are permitted under the Building Act. Dams requiring consent due to being considered large dams are required to use modelling approaches that are generally accepted in the engineering community and by the Hawke's Bay Regional Council.

It is important to know definitions when considering hazard classification.

Dam height:	The measured distance (m) from the channel invert at the dam to the maximum storage elevation at the centrepoint of the dam.
Crest length:	Total horizontal distance (m) measured along the axis at the elevation of the top of the dam between abutments or ends of the dam.
Storage volume:	Maximum total storage volume (m^3) in the reservoir below maximum attainable water surface elevation including any surcharge elevation
Maximum spillway discharge:	Spillway discharge (m^3/s) when the reservoir is at maximum designed water surface elevation
Reservoir surface area:	Surface area (m^2) calculated based on reservoir volume and dam height.
Estimated failure time:	Time required for breach formation to form from the top of the dam to the base of the dam and depends on dam

height and type. This parameter has a significant impact on the discharge for which the danger reach calculations are derived from.

Estimated breach width: Final breach width. Breach width is dependent on dam height and type of dam.

Breach cross-sectional area: Assumed trapezoidal cross-section (see Figure 4-1) with 30° side slope and a top width equal to the dam crest length or a depth above the invert equal to the effective dam height.

Manning roughness coefficient: Manning's 'n' depends on the estimated channel slope. For slopes < 8 m/km n= 0.06. For slopes > 8 m/km n = 0.09.

Calculated peak discharge from the dam: Peak discharge (m^3/s) at the dam assuming failure occurs at maximum designated water surface elevation with the spillway flowing at maximum discharge.

Calculated peak flow depth at the dam: Peak flow depth reached by the maximum flow at the dam.

Calculated peak discharge at a downstream point: Peak flow rate (m^3/s) expected at the habitable structures downstream.

Calculated peak depth at a downstream point: Peak flow depth (m) reached by the maximum flow at habitable structures downstream.

Calculated travel time: Time (hours) required for peak flow to travel from the dam to the habitable structure downstream.

Table 4-1 shows the estimated width of a breach and the time of failure as a function of dam height.

Table 4-1
Breach Width at Creast and Time of Failure as a Function of Dam Height

Type of dam	Breach Width (m)	Time (minutes)
Earth	3 x dam height (H_d)	$3.28(H_d)^{0.5}$
Rockfill	3 x H_d	$3.28(H_d)^{0.5}$
Gravity	Crest length (CL)/3	$3.28(H_d)^{0.5}$
Buttress	CL/3	$3.28(H_d)^{0.5}$
Arch	CL	$H_d/15.24$

There are several assumptions in the approach:

- The dam is full of water,
- The spillway is discharging at its maximum rate of flow when failure occurs, and
- The breach cross-sectional area is as defined above.

Before providing the equations, some generalisations can be made that are useful in gauging whether a prediction is reasonable.

1. At the dam centrepoint, the maximum initial height of the flood wave will be no greater than approximately ½ the original height of the water behind the dam.
2. Average speed of the flood waive is approximately 6.5 km/hour. In mountainous areas the velocity may be higher. The flood wave will attenuate in height and spew very quickly if there is a defined floodplain around the downstream area.
3. The wave is reduced approximately ½ for each 16 km of travel downstream.

4. Reasonable breach widths for most earthen dams are between 3 – 5 times the height of the dam.

4.4 Design approach

There are several different equations that are used to determine downstream impact. They are:

- Breach width,
- Breach formation time,
- Calculation of breach discharge,

4.4.1 Breach width

$$b = 0.1803K\left(V_r\right)^{0.32}\left(H_d\right)^{0.19}$$

where:

K = 1.0 for piping or K = 1.4 for overtopping
V_r = Volume of reservoir (m^3)
H_d = Breach Head (m) - defined as Depth of Water at time of Breaching
b = Average breach width (m)

4.4.2 Breach formation time

$$t_f = \left[0.00254\frac{V_r^{0.53}}{H_d^{0.9}}\right]\times 60$$

where

t_f = Breach formation time in minutes
V_r = Volume of the reservoir (m^3)
H_d = Breach Head (m) - defined as Depth of Water at time of Breaching

4.4.3 Calculation of breach discharge

$$Q_p = 0.607\times\left(V_r^{0.295}H_d^{1.24}\right)$$

where:

Q_p = Peak discharge (m^3)
V_r = Volume of water stored in reservoir (m^3)
H_d = Breach Head (m) - defined as Depth of Water at time of Breaching

Once the discharge has been determined, impacts downstream can be determined. The danger reach should be extended downstream to a point of control, such as another dam, a highway embankment that has adequate storage capacity to dampen

flows or natural features in the catchment that would limit migration of the flood wave further downstream.

4.5 Hawke's Bay Regional Council requirements for breach analysis

Doing a breach analysis is not a requirement in every case for small dams but the Hawke's Bay Regional Council reserves the right to require one on a case-by-case basis. That basis will be predicated on potential downstream impacts and whether there are any control points downstream that would dampen further impacts.

Figure 4-1
Trapezoidal Shape of Bam Breach

The Hawke's Bay Regional Council should be contacted whenever a new dam is proposed to determine whether a breach analysis should be done for small dams. As mentioned earlier, dams that are addressed as large dams in the Building Act will need to do more sophisticated modeling to determine downstream potential hazards.

5 Design Guidance

5.1 Introduction

It is important to state that the guidance provided here is for earth dams. Rock or concrete dams are not covered and need specialised individual design by an engineer experienced in designing them. The Hawke's Bay Regional Council will review the engineer's experience to determine suitability for a given design.

There are a number of elements that need to be designed for in earth dam construction. These elements include:

- Foundations,
- Embankments,
- Spillways, and
- Dam drain capability.

All of these elements are critical to design, construction and operation of a dam.

5.2 Foundations

The foundation of a dam is that zone in which the dam embankment intersects with the ground. Common issues with foundations include:

- Bearing capacity,
- Foundation issues, and
- Piping and leakage.

These issues are discussed further in the following sections.

5.2.1 **Bearing capacity**

The dam must be built on material that is strong enough to bear the weight of the dam and impounded water. Subsurface investigations must be done in the vicinity of the dam to ensure that the ground can support the load being placed upon it. Earth dams have to be considered for stability of the embankment itself.

In terms of the foundation investigation, the following items need to be determined for low hazard dams.

- Foundation investigation involving pitting and hand boring in the embankment foundation along with a general appraisal of land stability and obtaining all local knowledge.
- Soil borings should be done for the embankment, usually along the centerline and to determine if an adequate cutoff trench can be constructed.
- Foundation drilling is desirable for larger or more important structures in the low risk category.
- Local knowledge is important.
- Under static loading, and where dam stability is analysed, calculated factors of safety for the dam should be greater than 1.5 under the worst loading condition.

5.2.2 Foundation issues

The foundation of the dam and the embankment itself will settle. This settlement can cause cracking in the fill and stress or even dislocate conduits that pass through the embankment or foundations.

If the foundation does not support the basic dam structure, or is itself weak or prone to high seepage flows and forces, then they can create an area of high risk. Areas of risk can be extensive and include aspects such as (NZSOLD, 2000):

- Geological defects which are points of weakness and/or high seepage flow potential, leading to poor structural performance and potential instability due to seepage.
- Weaknesses in the foundation that are susceptible to liquefaction during earthquakes.
- Potential long term chemical degradation of grouting undertaken to arrest foundation seepage or accelerated weathering or leaching at rock defects.
- Difficulties in interpretation of the nature and structure of foundations and their behavior following reservoir filling. Lack of adequate investigation or interpretation may result in instability or excessive leakage.
- Lack of information, inadequate identification or provision for seismic forces and movements.

To give an extreme example of the importance of foundation conditions, that question is now being asked in China regarding the Sichuan earthquake. A suggestion recently made by seismologists is that Sichuan's newest dam, completed in 2006, might be to blame for the earthquake that killed 70,000 people. The increasing load of water behind the dam might have been the final straw that provoked catastrophic release of the fault's local stresses New Scientist, 2009).

Adequate foundation analyses are essential to assurance of dam safety.

5.2.3 Piping and leakage

All dams will have some leakage. The intent is to limit seepages to a practical minimum and then control any remaining flows by targeted drainage. Excessive seepage can cause dam stability issues by 'piping' of stormwater through the foundation weakening the entire dam structure.

The most common way of controlling foundation seepage is to use a cut-off trench. The purpose of the cut-off trench is to replace a permeable or variable foundation material with engineered materials. It is recommended that a cut-off trench be incorporated into all small dams to reduce potential seepage through the foundation. Figure 3-1 shows a schematic of a cut-off trench.

Key elements of a cut-off trench are that they should be:

- A minimum of one metre deep,
- Three metres wide,
- 1:1 side slopes.

5.3 Embankments

When considering embankment design, there are several elements that have to be specified.

- Top width,
- Side slopes,
- Earth cuts,
- Impervious core,
- Seepage control,
- Wave protection
- Freeboard,
- Embankment vegetation, and
- Allowance for settlement.

Each of these will be discussed in the following section.

5.3.1 Top width

The minimum top width of the dam is shown in Table 5-1.

Table 5-1
Dam Top Widths versus Dam Embankment Height

Total Height of Embankment (m)	Minimum Top Width (m)
3 or less	2
3 - 6	3
6 - 8	4
Greater than 8	5

5.3.2 Side slopes

Dam side slopes should not be steeper than 2.5 horizontal to one vertical on either the upstream or downstream slope. If the dam is used as a roadway that is at least 8 metres wide the slopes can be steepened to 2 horizontal to one vertical on either the upstream or downstream slope.

5.3.3 Earth cuts

If cuts in existing fill or in natural ground are required for the rehabilitation of an existing dam spillway or the construction of a new dam, the slope of the bonding surfaces between the existing material in place and the fill to be placed shall not be steeper than 2 horizontal to 1 vertical.

5.3.4 Impervious core

Any impervious core within the embankment shall be located at the upstream from the centerline of the dam and should extend up the abutments to the 10-year water

surface elevation. The impervious core shall extend from the cutoff trench up to the 10-year water surface elevation throughout the embankment.

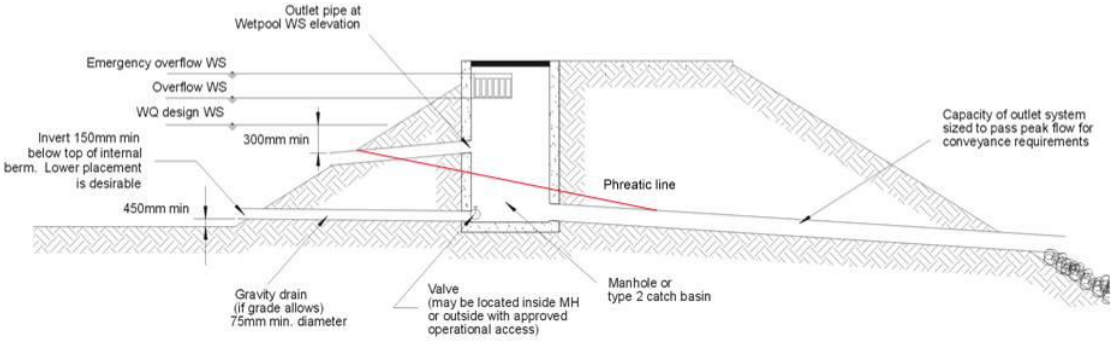
5.3.5 Seepage control

Seepage control is to be included if:

- Pervious layers are not intercepted by the cutoff,
- Seepage from the abutments may create a wet embankment,
- The phreatic line intersects the downstream slope, or
- Special conditions require drainage to insure a stable dam.

The phreatic denotes the zone of saturation on an embankment and the line should be drawn on a 4 horizontal to 1 vertical slope starting at the inside slope at the normal pool elevation. Figure 5-1 shows a phreatic line. For stormwater management ponds, the phreatic zone starting elevation should the 10-year water surface elevation.

Figure 5-1
Cross-section of an Embankment Showing a Phreatic Line



5.3.6 Wave action

Where needed to protect the face of the dam, special wave protection measures such as a bench, rock riprap, sand/gravel or special vegetation should be provided.

5.3.7 Freeboard

The top elevation of the settled embankment shall be at least 300 mm above the elevation of the 50-year storm elevation in the emergency spillway.

5.3.8 Embankment vegetation

Woody vegetation should <u>not</u> be planted on the embankment due to root penetration into the embankment. Roots could provide an avenue for seepage or cause dam instability when the tree dies and the roots deteriorate or the tree falls ripping a portion of the embankment out. Vegetation should be composed of grasses, either rye or fescue.

5.3.9 Allowance for settlement

The design height of the dam should be increased by the amount needed to ensure that after settlement has taken place, the constructed height of the dam will equal or exceed the design height. This increase should not be less than 5% of the height of the dam unless soil testing indicates that a lesser amount is adequate.

5.4 Spillways

When considering spillways, there are normally two spillways unless the dam outlet is controlled by a weir structure that functions for full flow conditions. The two spillways that are normally designed in dams are the following:

- Principal spillway, and
- Emergency spillway.

5.4.1 Principal spillway

5.4.1.1 Elevation and sizing

The principal spillway is normally a pipe conduit that is placed under or through the dam except where rock, concrete or other type spillways are used. The invert of the principal spillway determines the normal water level in the dam and this invert should be no less than 300 mm below the crest of the emergency spillway.

When design discharge of the principal spillway is considered in calculating peak outflow through the emergency spillway, the crest elevation of the emergency spillway should be such that the full flow will be generated in the principal spillway before there is any discharge from the emergency spillway. The inlets and outlets should be designed to function for the full range of flow and hydraulic head anticipated.

The capacity of the principal spillway shall be adequate to discharge long duration, continuous, or frequent flows without discharge through the emergency spillway. The diameter of the spillway pipe should not be less than 150 m. If the pipe diameter exceeds 300 mm its design discharge may be considered when calculating the peak outflow rate through the emergency spillway.

The pipe should be capable of withstanding the external loading without yielding, buckling or cracking. All pipe joints should be made watertight and remain watertight after joint rotation and elongation caused by foundation consolidation.

Where multiple pipes are used, there should be sufficient space between the pipes and installed seepage control to allow for backfill material to be placed between the pipes by construction equipment and for easy access by hand operated compaction equipment. The distance between pipes should be equal or greater than ½ the pipe diameter but not less than 1 metre.

In terms of flow, the principal spillway should be sized to covey the 10-year storm.

5.4.1.2 Seepage control

Seepage along the principal pipe spillway should be controlled by (1) filter drains preferably or (2) anti-seep collars.

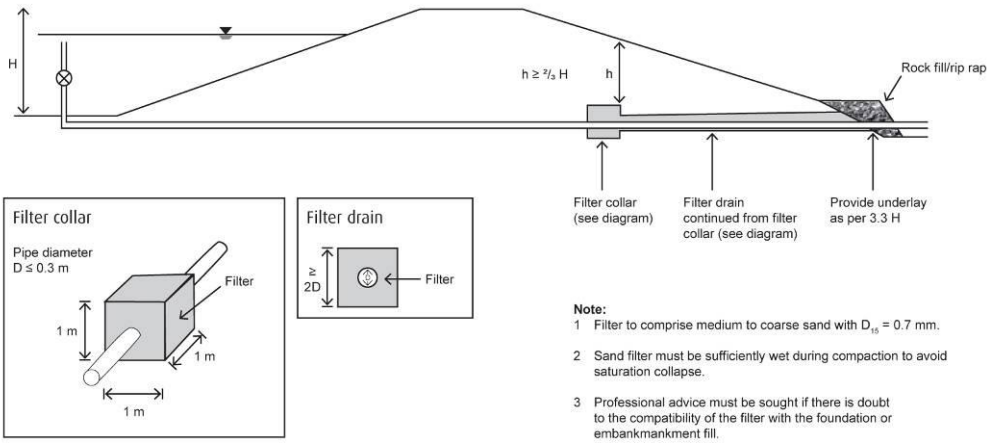
<u>Filter drains</u>

Filter drains along the principal spillway pipe allow some water seepage and prevent fines from being eroded along the pipe. Over time the filtering process leads to an increasingly effective seal against water flow but it is important for the filter drain (sand) to continue from the collar to the point where the pipe emerges downstream.

The Environment Bay of Plenty Fact Sheet on Filter Drains (Environment BOP, undated) specifies the following for filter drains:

1. Do not use earth fill materials susceptible to piping. Earth materials susceptible to piping include, but are not limited to, non-cohesive silts and fine sands.
2. To reduce the risk of seepage paths developing along the pipe, ensure backfill is adequately compacted along the entire length of the pipe especially beneath the haunches of the pipe and inlets and outlets.
3. Filter collars are to be constructed around any pipes embedded within the embankment or foundation. The purpose of the filter collar is to control seepage. The filter collar design is shown in Figure 5-2.

Figure 5-2
Filter Drain Schematic



a) The filter collar must be positioned along the pipe ensuring they start just after half way through the dam where h = 2/3 H, where H is the embankment height.
b) The filter collar should be 1m x 1m x 1m and allow for sufficient compaction around the pipe. Specific design is required if the pipe diameter is greater than 200 mm.
c) The filter material must be medium to coarse sand, e.g. a D15 = 0.7 mm is anticipated to provide a good filter. Seek professional advice if there is any doubt about the compatibility of filter materials with the local ground conditions or embankment fill.
d) The filter sands must be compacted sufficiently wet to optimize compaction and avoid saturation collapse.

e) The filter drain must continue to the outlet to allow for drainage from the filter collar to the downstream toe.
f) The outlet must allow for seepage from the filter drain and be stabilized against erosion and dissipate energy, e.g. rock fill riprap at the outlet with a heavy duty geotextile filter fabric.

Anti-seep collars

When anti-seep collars are installed around the principal spillway pipe through earth fills, they should be done according to the following criteria.

1. Sufficient collars should be placed to increase the seepage length along the pipe by a minimum of 15% of the pipe length located within the saturated zone.
2. Maximum collar spacing should be 14 times the required projection above the pipe. The minimum collar spacing should be 5 times the required minimum projection.
3. Anti-seep collars should be placed within the saturated zone. In cases where the spacing limit will not allow this, at least one collar should be in the saturated zone.
4. All anti-seep collars and their connections to the principal spillway pipe should be watertight and made from materials compatible with the pipe.
5. Collar dimensions shall extend a minimum of 600 mm in all directions around the pipe.
6. Anti-seep collars shall be placed a minimum of 600 mm from pipe joints except where flanged joints are used.
7. For pipes with concrete cradles, the projection shall be measured from the cradle.

5.4.1.3 Trash racks

All principal spillway pipes should have a trash rack. Openings for them should be no larger than ½ of the pipe diameter but in no case less than 100 mm.

5.4.2 Emergency spillway

5.4.2.1 Capacity

Emergency spillways should be provided for all dams to convey large flood flows safely past the embankment unless the principal spillway is large enough to pass the design storm and any trash without overtopping the dam. If there is any potential for the principal spillway to clog, an emergency spillway should be provided.

The minimum capacity of emergency spillways should be to pass the peak flow expected from the 100-year storm less any reduction that can be credited to principal spillway discharge and detention storage.

Emergency spillways are to provide passage for the 100-year storm at a non-erosive velocity to a point downstream where the dam will not be endangered.

5.4.2.2 Components and cross-section

Emergency spillways are generally earth spillways that are open channels and usually consist of an inlet channel, level section and exit channel. The minimum difference in elevation between the crest of the emergency spillway and the settled top of dam shall be 600 mm.

The emergency spillway should be trapezoidal and located in undisturbed earth. If used in fill material the emergency spillway must be protected from potential erosion with appropriate materials (riprap, concrete). The side slopes should be stable for the material in which the spillway is to be constructed, but not steeper than 2 horizontal to 1 vertical. The emergency spillway should have a bottom width of not less than 3 metres.

5.5 Dam drain capability

All dams should have a drain pipe with a suitable valve provided to drain the pool area for subsequent maintenance or for an emergency situation. The principal spillway may serve as the pond drain if adapted to do so.

6 Construction and maintenance inspection

6.1 Construction

6.1.1 Site preparation

Areas where embankment fill is being taken from and the foundation for the embankment itself should be cleared and stripped of topsoil. All trees, vegetation, roots and other objectionable material should be removed. All trees should be removed within 5 metres of the toe of the embankment.

Areas that will be under water should be cleared of all trees, brush, logs, fences, rubbish and other objectionable material. Trees, brush and stumps should be cut approximately level with the ground surface.

All cleared material should be disposed of outside and below the limits of the dam and normal pool. Topsoil should be stockpiled for use on the embankment for establishment of grass cover.

6.1.2 Earth fill

6.1.2.1 Material

The source of the embankment fill must be approved by the Hawke's Bay Regional Council. It should be free of roots, stumps, wood, rubbish or stones greater than 150 mm. Fill material for the centre of the embankment and the cut off trench should have soil particle sizes at least 30% of which are smaller than 75 um. Material used in the outer shell of the embankment should have the capability required to prevent erosion of the embankment.

6.1.2.2 Placement of material

Areas on which fill is to be placed should be scarified prior to placement. Fill materials should be placed in maximum 200 mm layers, which are to be continuous over the entire length of the fill. The most permeable borrow material should be placed in the downstream portion of the embankment. The principal spillway should be installed concurrently with fill placement and not excavated into the embankment.

6.1.2.3 Compaction

The movement of the hauling and spreading equipment over the fill should be controlled so that the entire surface of each lift should be traversed by not less than one tread track of heavy equipment or compaction should be achieved by a minimum of four complete passes of a sheepsfoot, rubber tired or vibratory roller. Fill material should contain enough moisture such that the required degree of compaction will be obtained with the equipment used. The fill material should contain sufficient moisture

so that if formed into a ball it will not crumble, yet not be so we that water can be squeezed out.

The minimum required density should not be less than 95% of maximum dry density with moisture content within +/- 2% of the optimum. Each layer of fill should be compacted a necessary to obtain that density.

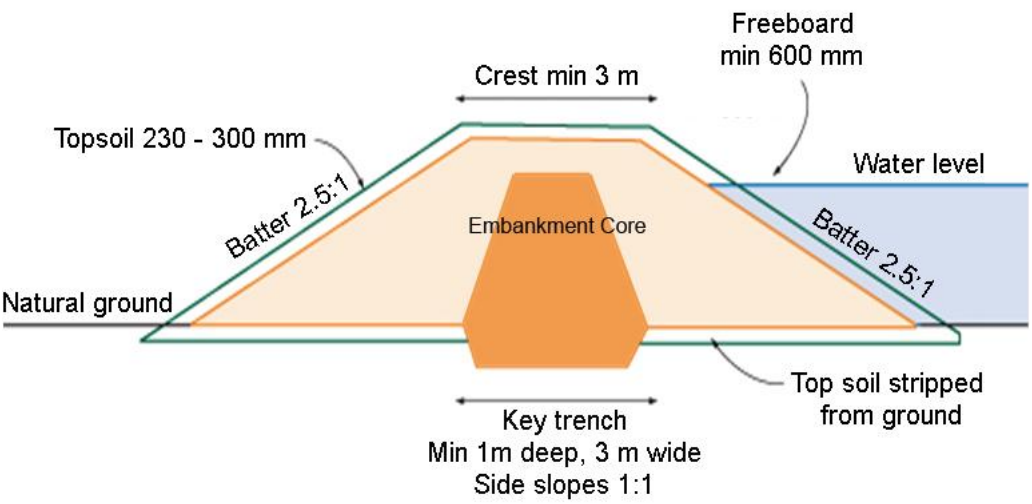
6.1.2.4 Cutoff trench

The cutoff trench should be excavated into impervious material along or parallel to the centerline of the embankment. The dimensions of the cutoff trench are those shown in Figure 3-1. The backfill should be compacted with construction equipment, rollers or hand tampers to assure maximum density and minimum permeability.

6.1.2.5 Embankment core

The core should be parallel to the centreline of the embankment and its top width should be at least 1 metre. The height should extend up to approximately the 10-year storm elevation and the side slopes should be 1 horizontal to 1 vertical or flatter as shown in Figure 6-1. The core should be compacted with construction equipment, rollers or hand tampers to assure maximum density and minimum permeability. In addition, the core should be placed concurrently with the outer shell of the embankment.

Figure 6-1
Schematic of a Dam Embankment Showing Embankment Core



6.1.3 Structural backfill

Backfill adjacent to pipes or structures should be the type and quantity conforming to that specified for the adjoining fill material. The fill should be placed in horizontal layers not to exceed 100 mm and compacted by hand tampers or other manually directed compaction equipment. The material needs to fill completely all spaces

under and adjacent to the pipe. At no time during the backfilling operation should driven equipment be allowed to operate within 1 metre, measured horizontally, to any part of the structure. In addition, no equipment should be driven over any part of a concrete structure or pipe unless there is compacted fill of at least 600 mm or greater over the structure or pipe.

6.1.4 Pipes

All pipes should be circular in cross-section. Coupling bands, anti-seep collars, end sections, etc. must be composed of the same material and coatings as the pipe.

Connections with pipes must be completely watertight. The drain pipe or barrel connection to the riser should be welded all around if metal is used. Anti-seep collars should be connected to the pipe and be completely watertight.

For metal pipes, the pipe should be firmly and uniformly bedded throughout its entire length. Where rock or soft, spongy or other unstable soil is encountered, all such material should be removed and replaced with suitable earth compacted to provide adequate support.

For concrete pipes, pipes should be laid in a concrete bedding/cradle for their entire length. The bedding/cradle should consist of high slump concrete placed under the pipe and up the sides of the pipe at least 50% of its outside diameter with a minimum thickness of 150 mm. With a geotechnical engineer recommendation, the concrete bedding/cradle may not be needed.

Concrete Pipe Showing the Concrete Bedding/Cradle

When laying concrete pipe, the pipe should have “bell and spigot” joints with rubber gaskets. The bell and spigot pipe should be placed with the bell end upstream. Joints should be made in accordance with the recommendations of the manufacturer. After the joints are sealed for the entire line, the bedding should be placed so that all spaces under the pipe are filled.

When a filter drain is used, an engineer experienced in its construction should supervise its construction.

6.1.5 Handling water during construction

Embankment construction has to be done in areas where water isn’t saturating the embankment location. The contractor should construct and maintain all dikes, levees, cofferdams, drainage channels and stream diversions necessary to protect the areas to be occupied by the permanent works. The contractor should install, operate and maintain all necessary pumping and other equipment required for removing water

from various parts of the work and maintaining the excavations, foundations and other parts of the work free from water.

6.1.6 Stabilisation

All exposed surfaces of the embankment, spillway, spoil and borrow areas and bunds should be stabilized by seeding, liming, fertilizing and mulching to establish an effective, erosion resistant ground cover.

6.2 Maintenance

When considering maintenance, there are several aspects to it that need to be considered (ARC, 2003). They include:

- Aesthetic maintenance, and
- Functional maintenance.

These two areas can overlap at times, but they are equally important. Aesthetic maintenance is important primarily for stormwater management ponds for public acceptance of the ponds and because it may also reduce needed functional maintenance activities. Functional maintenance includes routine (preventive) and corrective maintenance and is important for performance and safety reasons.

The dam owner should establish a checklist that will periodically be gone through to ensure that all dam elements are checked and, where necessary, maintained.

6.2.1 Aesthetic maintenance

Aesthetic maintenance enhances the visual appearance and appeal of a pond. The following activities can be included in an aesthetic maintenance programme.

- Graffiti removal,
- Grass trimming,
- Control of weeds, and
- Miscellaneous tasks to improve appearance.

6.2.2 Functional maintenance

Functional maintenance is necessary to keep a dam operational at all times. It has two main components.

- Preventive maintenance, and
- Corrective maintenance.

6.2.2.1 Preventive maintenance

Preventive maintenance is done on a regular basis and tasks can include upkeep of any moving parts, such as drain valves or hinges on grates. It can also include

maintenance of vegetative cover to prevent erosion. Examples of preventive maintenance include:

- Grass mowing,
- Grass maintenance,
- Vegetative cover,
- Trash and debris,
- Sediment removal and disposal,
- Mechanical components,
- Elimination of mosquito breeding habitats, and
- A dam and reservoir overall maintenance programme.

6.2.2.2 Corrective maintenance

Corrective maintenance is required on an emergency or non-routine basis to correct problems and to restore the intended operation and safe function of the dam. Corrective maintenance is done on an as-needed basis, not on a scheduled one. Failure to promptly address a corrective maintenance problem may jeopardize the performance and integrity of the dam. It may also result in a potential safety problem to those living by or below it. Corrective maintenance activities include:

- Removal of debris and sediment,
- Structural repairs,
- Dam, embankment and slope repairs,
- Elimination of mosquito breeding areas,
- Erosion repair,
- Fence repair,
- Elimination of trees or woody vegetation on the embankment, and
- General dam maintenance.

7 Bibliography

Department of Building and Housing, Dam Safety Scheme Guidance for Regional Authorities and Owners of Large Dams, September 2008.

Auckland Regional Council, Dam Safety Guidelines, Technical Publication #109, June 2000.

Singh, K., P., and Snorrason, A., Sensitivity of Outflow Peaks and Flood Stages to the Selection of Dam Breach Parameters and Simulation Models, SWS Contract Report 288, Illinois Department of Energy and Natural Resources, State Water Survey Division, Surface Water Section at the University of Illinois, 1982.

New Zealand Society on Large Dams, New Zealand Dam Safety Guidelines, November 2000.

Grayling, A., C., Throw Caution to the Wind, Risk the Whilrlwind, New Scientist, page 23, 31 January 2009.

Environment Bay of Plenty, Filter Drains to Prevent Piping Failure of Sediment Retention Ponds and Earth Bunds – Seepage Collars are no longer accepted best practice, Earthworks Fact Sheet, undated.

Auckland Regional Council, Stormwater Management Devices: Design Guidelines Manual, Second Edition, May 2003.