10 WATERWAY

10.1 INTRODUCTION

10.1.1 Control of Rivers

The responsibility for the control and management of rivers is held by the local Regional or District Council.

10.1.2 Types of Waterways

Waterways crossed by bridges and culverts can be rivers, lakes, estuaries or harbours. Each environment has its own unique characteristics with its own particular impacts on the crossing. Approximately 90% of this country's bridges cross waterways.

Rivers, however, are the most common waterway crossed by bridges (approximately 85% of the bridge stock) and culverts. In this environment the impact of the waterway on the structure is potentially the greatest. This section therefore concentrates on the river environment and river crossings. The problems, inspection, maintenance, records and evaluation procedures outlined can be applied to any waterway crossing. Waterway design is described in more detail in the Transit New Zealand "Bridge Manual" (SP/M/014).

10.1.3 Rivers: A Dynamic Environment

Rivers fall into two categories – alluvial and incised.

Alluvial rivers erode their banks, scour their beds and form their hydraulic geometry to suit the discharge, slope of valley and the sediment introduced from upstream. They have flood plains on either side of their channel and the flow sometimes overtops the channel banks to spread across the flood plain. Alluvial rivers are continually changing their position and shape as a consequence of the hydraulic forces which they generate. These changes may be slow or rapid and can be either natural or man-induced. The hydraulic forces result from a very complex and highly interactive combination of factors.

Incised rivers behave in a similar way, but the topography exercises a greater constraint on the channel flow and geometry. Such rivers are narrower and deeper than the alluvial type and rarely overtop their banks.

Both river categories can be classified as straight, meandering or braided, depending upon bed slope.

Because of their dynamic nature it is very important to have a good appreciation of the natural behaviour and variability of rivers as well as the potential impact of man-induced changes. Features and problems associated with rivers and waterways are described in Sections 10.2 and 10.3.

Figure 10.1: A typical meandering river.

Figure 10.2: A typical braided river.

10.2 FUNDAMENTAL CHARACTERISTICS OF RIVERS AND THE IMPACT OF BRIDGES AND CULVERTS ON THE WATERWAY

10.2.1 Hydrology

The water flowing in the river system and the sediment which it transports are intimately related to the catchment (or watershed) feeding the river system.

Factors which influence the stream hydrology are:

- Geology, soil types and depths, which affect infiltration and run-off;
- Vegetation, which affects the run-off of both water and sediment from the land to the river;
- Land use;
- Topography and slope, which affect the rate at which run-off reaches the river crossing;
- Shape and size of the contributing area;
- Rainfall characteristics, including magnitude, intensity, duration and distribution;
- In-stream modifications, particularly any changes which are caused by lakes, reservoirs, or water extraction at intake structures upstream of the river crossing, or extraction of gravel above or below the bridge site.

10.2.2 Hydraulic Geometry

The hydraulic geometry of a river channel describes the channel width, depth, cross-sectional shape, slope and alignment.

Hydraulic geometry depends on and is influenced by:

- Backwater effects caused by the sea, lakes, reservoirs, and natural or man-made structures that control flow behaviour downstream of the river crossing;
- Characteristics of bed material, bed form, bank material, bends, and channel and berm vegetation.

10.2.3 Aggradation and Sediment Load

The amount of material transported or deposited in the stream depends on the quantity of the sediment and on the capacity of the stream to transport it.

Aggradation is the raising of the stream bed or the narrowing of the stream channel caused by deposition of material by the stream.

As streams transport sediment to areas of flatter slopes, and in particular to bodies of water where the velocity and turbulence are too small to sustain the transport of the material, aggradation occurs as the material is deposited.

10.2.4 Scour, Erosion and Piping

Scour (or degradation) is the removal of bed material by the stream flow. It may occur naturally in a particular reach of the river where there is a local increase in velocity, or may be induced by gravel extraction or similar activity.

Lateral erosion leads to river alignment changes and is more usually associated with meandering or braided rivers.

Scour and lateral erosion can result from three distinct mechanisms:

- General scour;
- Constriction scour;
- Local scour.

General scour occurs without a crossing. Construction scour and local scour are usually associated with a crossing.

General scour occurs to a greater or lesser extent over the whole river system when the bed becomes mobilised. Increased flow or increased slope caused by changes in alignment or by gravel extraction are the main causes of aggradation problems. General scour includes the unevenness of the natural riverbed, deepening at bends and general bed motion during floods.

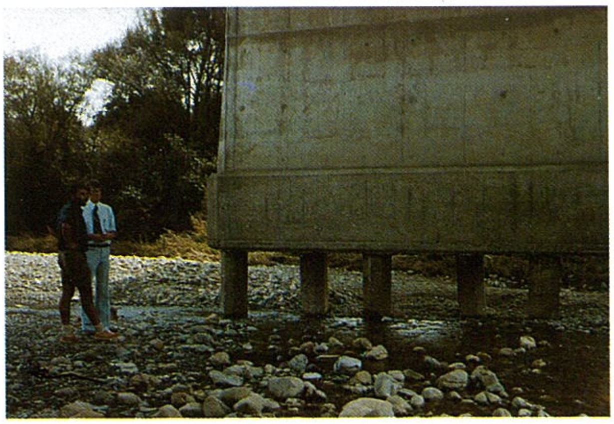

Figure 10.3: Degradation resulting from gravel extraction has left the pile cap high and dry – Ohau River Bridge.

Constriction scour occurs in the vicinity of the crossing and as a result of the structure. It is measured below the stream bed level that existed before construction of the structure.

Local scour occurs as a result of an obstruction to the flow, such as a pier, an abutment, the toe of an embankment of protection works, or an accumulation of debris. Local scour is measured below the level of constriction scour.

Figure 10.4: The Bulls Bridge over the Rangitikei River failed as a consequence of local scour around the pier foundations in 1973.

Piping is the removal of fines by the movement of water through the ground. It can affect abutment fill or fill containment works in the vicinity of an abutment.

10.2.5 Debris

Where debris, particularly trees, can enter the river, it has the potential to get caught on bridge piers where it can both aggravate local scour (potentially undermining the piers) and obstruct the flow (causing afflux). If water levels are already very high then debris may also strike the superstructure and cause damage.

Figure 10.5: Wairoa Bridge failure (1988). This bridge failed following scour of the bed which was exacerbated by debris.

Figure 10.6: Accumulation of debris against bridge piers.

10.2.6 Bridge Crossing

There is usually no reason to prefer a right-angled crossing of the river if road alignment considerations and cost suggest otherwise. A skewed crossing should provide bridge piers and abutments that are properly aligned with the principal direction of flow.

To minimise the structure cost, there may be significant encroachment of approaches into the river or flood plain. This constriction exacerbates scour in the vicinity of the crossing and this must be properly catered for.

Figure 10.7: The effect of piers on the flow of a river in flood.

Abutments and piers are obstructions to the flow and are subject to attack from the stream flow.

The training works and protection used at the river crossing are themselves structural elements which, to a greater or lesser extent, form obstructions to the flow and are therefore also subject to attack.

10.2.7 Culvert Crossing

The culvert forms a smooth artificial channel which normally contracts and speeds up the flow.

The purpose of the inlet structure is to:

- Avoid overtopping, outflanking or undermining by the flow;
- Avoid build-up of sediments or debris which could cause blockage and direct or indirect structural damage;
- Improve flow of water from the natural channel into the artificial channel.

The purpose of the outlet structure is to:

- Dissipate excess energy in the flow;
- Avoid undermining by the flow;
- Avoid excessive deposition of sediment;
- Avoid outflanking and bank erosion where there are backwater effects;
- Provide a smooth transition in flow from the barrel to the natural channel.

10.2.8 Swing Fences

It is common practice to hang swing fences below boundary fences to stop stock movement in the waterway. These should be located so that the risks to the structure are minimised. It is preferred they are located on the downstream side of the bridge and only lightly fixed.

10.3 PROBLEMS

10.3.1 General

Many of the problems found in bridge waterways may be explained by consideration of the natural behaviour of rivers and the impact of man-induced changes.

10.3.2 Scour

Scour is the most serious waterway problem (greater than 60% of reported failures can be attributed to it), and may be aggravated by another type of problem, e.g. debris or alignment, and may cause other problems, e.g. undermining or bank erosion.

10.3.3 Aggradation

Changes in alignment, upstream constrictions or the inability of the downstream section to transport material away are the main causes of aggradation problems. Transient aggradation can occur with the transport of material, such as from a land slide.

Aggradation may cause general instability of the river downstream.

10.3.4 Piping

Piping occurs where there is inadequate protection against the migration of fines. It can cause subsidence or settlement of the structure, approach fill, fill containment works or batter protection works.

10.3.5 Alignment Changes

These occur naturally due to meander migration and upstream aggradation, or they may be man-induced. They can cause significant increases in scour and place different parts of the structure at risk.

10.3.6 Blockage

Channel blockage can occur as a result of accumulation of debris or aggradation of the stream bed. This can cause or exacerbate other problems, e.g. scour or flooding.

10.3.7 Flooding

Flooding occurs when the structure waterway is incapable of accommodating the flow passing through it. This can lead to approach inundation, debris damage to the superstructure, and adverse effects to adjacent property.

10.3.8 Undermining

This is the progression of scour under the structure or protection foundation. It may also occur as a result of piping.

10.3.9 Swing Fences

Swing fences fixed upstream or close to a structure can generate significant changes in the waterway, exacerbating blockage and scour problems.

10.4 INSPECTION

10.4.1 Purpose

Inspections provide a visual assessment of the condition of the structure, approach batters, protection work and the waterway. They also allow the causes of problems and the rate of change to be evaluated so that the seriousness can be assessed and appropriate remedial action programmed.

10.4.2 Procedure

The inspection should look for changes in the following parameters in addition to reporting the problems:

- Land development or other changes (e.g. erosion) in the catchment area;
- Bed level at the structure as well as upstream and downstream;
- Alignment;
- Debris and vegetation;
- Bank erosion and the performance of bank protection and fill containment works;
- Maximum water level during recent floods, both against the structure and upstream where backwater effects occur. If the discharge or return period of the event is known, that should also be reported.

It is important for inspectors to record the likely causes or true nature of any problem to ensure the correct evaluation is made. To assist this it is suggested that full photographic sequences be taken of both the upstream and downstream channels. As a minimum, a photograph of the structure's elevation should be taken at each inspection to show the waterway cross-section.

Waterway inspections should extend a distance of at least three channel widths both upstream and downstream to look for changes in bed, alignment and bank stability.

When observing depth of scour following a flood event it is important to be aware that scour holes tend to refill with sediment as the water level subsides especially in the coarser bed material sizes.

Where significant bed degradation or scour is taking place and there is uncertainty on the founding depth of piles or spread footings, then inspection should include the determination of these depths. This information must be known to allow a true evaluation of the risk to the structure. Techniques using ground radar or cored holes are available for determining the extent of foundations. See also Section 9.2.

In some situations underwater inspections will be necessary.

10.4.3 Records

It is important that good records be kept to:

- See how the river is changing with time;
- Assist with evaluation of condition;
- Ensure planned action is appropriate, consistent and that it is in fact carried out.

The records should include:

- Original design drawings;
- A chronological list of significant events such as modifications to the structure or waterway and changes within the catchment;
- Inspection reports whether they be routine or periodic (flood-related);
- Channel profiles and cross-sections, taken periodically as appropriate;
- Photographs;
- Maximum water levels and their dates.

10.5 EVALUATION

Approximately 75% of reported bridge failures in New Zealand can be attributed to waterway problems. It is therefore important that the evaluation be undertaken with due care and consideration and with the best available information. In general, evaluations rely on experienced engineering judgement and may still involve a large degree of uncertainty. In some cases it may be necessary to call on specialist assistance to make the evaluation. It is important that conclusions are practical and economic.

The inspection report should suggest the level of evaluation required to assess the security of the structure, approach and protection works.

Inspection should identify changes that have occurred or problems that are evident in the waterway or in the structure. The photographs obtained should be compared to those from the previous inspection to confirm the nature and degree of change. Should the change be considered significant then the observations should be compared to the original design assumptions. This will enable the engineer to assess the nature and degree of change to predict future waterway changes, and thereby to assess the degree of risk to the structure, approach and protection works. Note that some problems are transient in nature and therefore make risk assessment difficult.

From this assessment of risk or impact on the structure, the appropriate course of action is determined. This might involve maintenance, securing, or structural modifications (e.g. underpinning or increasing waterway area) as described in Section 10.6.

10.6 MAINTENANCE AND DURABILITY ENHANCEMENT

10.6.1 Introduction

The waterway of a river crossing requires an on-going maintenance commitment in much the same way as a bridge structure.

The maintenance required can vary from the routine, to major design and construction work which may be required to prolong the life of the structure. A major problem in the waterway, such as severe degradation or channel movement, may require significant investigation, analysis and design effort to identify the cause of the problem and find an economic solution.

The extent and nature of the problems identified during the inspection and the subsequent evaluation will influence the repair and/or maintenance strategy. The most economic strategy will optimise cost and structure risk for the remaining life of the structure.

No significant work should be undertaken without the approval of the river controlling authority which is the local District or Regional Council.

10.6.2 Routine Maintenance

The channel should be kept clear so that the water will be allowed to flow freely.

Remove logs, trees or other debris from the waterway and upstream and downstream channel before they can alter the course of the river and exacerbate scouring and undermining. Flow disturbances occurring up to three meanders above a bridge site can affect alignment at the bridge site. Inspections, using divers where warranted, should be made as soon as possible after floods and log jams to ensure that all debris has been removed.

Monitor the condition of existing bank or bed protection regularly and carry out maintenance as necessary. This could include, for example, the topping up of slumped riprap protection, repair of groynes or gabions, or the thinning and inter-planting of willows.

Deposition of alluvial material (aggradation) can reduce the available waterway area. If aggradation reduces the flood clearance to less than what is acceptable, then as a short-term expedient, the material deposited at or near the crossing should be removed. Since this has not dealt with the cause of the aggradation, ongoing monitoring should be undertaken to check the rate of change. If the risks to the structure are high then a detailed investigation should be initiated.

Gravel bars can deflect the water from its normal channel to cause erosion of a bank or scouring of a foundation. Removal of gravel bars can reduce such risks.

10.6.3 Bank and Abutment Protection

10.6.3.1 Purpose

Since bridgework generally costs more per unit length than the approach embankments, maximum economy is usually achieved by minimising the waterway. Thus a moderately constricted waterway with bank protection and/or training works will, in many cases, have been the optimum solution available to the authority that installed the crossing. In a number of these crossings the abutment or approach fill will also need to be properly protected to ensure secure batters.

The bank protection and training works are themselves structural elements which, to a greater or lesser extent, form obstructions to the flow and are therefore subject to attack. Their ongoing purpose is to:

- Stabilise the river banks and channel;
- Protect road approaches from stream attack;
- Constrict the waterway to economise on bridge length;
- Align the flow to minimise afflux, scour and the trapping of debris;
- Direct the flow parallel to the piers to minimise local scour.

In addition to these purposes, protection works in the vicinity of structures generally need to accommodate run-off from deck drains or approach side drains.

Ongoing maintenance of the bank protection and river training works is essential to ensure the crossing as a whole continues to give good service.

10.6.3.2 Types

Commonly used types of flexible protection include:

- Riprap;
- Gabion baskets or gabion mattresses (stone-filled wire baskets);
- Concrete-filled bags or geotextile mattresses;
- Concrete blocks or slabs – loose or articulated;
- Vegetation – such as willows.

Occasionally rigid types of protection are used, including:

- Poured concrete slabs or walls;
- Soil cement;
- Asphaltic concrete;
- Timber walls.

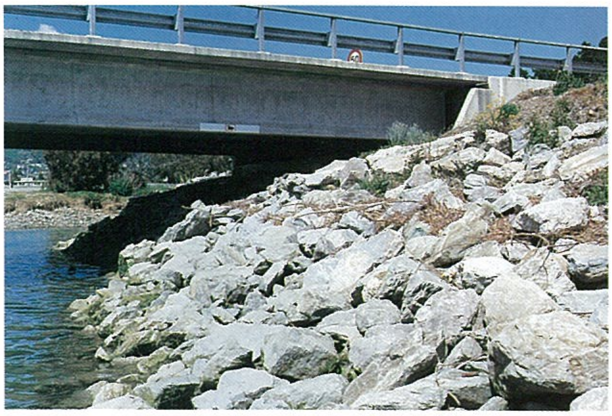

Figure 10.8: Moonshine Bridge – Hutt River illustrates the use of riprap to protect an abutment.

10.6.3.3 Maintenance of Bank Protection

Bank protection can fail because of uplift, undermining, outflanking, overtopping or washout.

Uplift can occur if the structural elements are too light to resist the uplift forces resulting from the high-velocity flow. Uplift can only be prevented by ensuring that the elements are large and heavy enough to withstand all the forces that the protection work may be subjected to, from all different angles of attack.

Scour is liable to occur at the following locations near banks:

- Alongside banks, in parallel flow;
- Around the ends of any projecting banks, where spiral currents occur caused by oblique flow;
- Under banks, by direct attack.

Methods of avoiding undermining include:

- Continue the protection down to or below scour level;
- Drive a "cut-off-wall" from the toe of the protection down to a basement level;
- Lay a flexible apron (also called a launching apron) horizontally on the bed at the foot of the protection. As the scour develops the material will settle and cover the side of the scour hole on a natural slope;
- Pave the entire bed. This is generally only economical for relatively small streams or where bed control is also required.

Care must be taken not to promote scour or progressive failure at the upstream and downstream ends of the protection. This can be achieved by turning the protection into the bank where it cannot be outflanked.

The protection should normally extend above design water level to avoid damage from overtopping.

To avoid washout or piping of the underlying soil, natural rock/gravel filters or synthetic filter fabric should be used under the protection layer.

10.6.4 Training Works

Training works are often employed to favourably align the flow with the bridge opening. Straightening, shortening of the flow line and increased velocities normally result. To offset the increased velocities and to maintain bank stability, some degree of stabilisation or channelling is often required.

The principal types of training works at bridge sites are:

- Guide banks (or spur dikes) – built to direct the flow smoothly through the opening and to minimise the scour depth at the river crossing;
- Groynes (or spurs) – constructed roughly perpendicular to the river bank;
- Stopbanks – to prevent flooding beyond a chosen zone;
- Diversions – man-made channels.

Maintenance and durability enhancement of training works use the same methods detailed in 10.6.3 on bank protection. Care is required with this type of work to ensure the training work functions are not compromised.

10.6.5 Protection Against Local Scour

Three basic methods may be used to protect structures from damage caused by local scour which occurs at piers and abutments. They are:

(a) Prevent vortices from developing by:

- Streamlining the piers, which can reduce scour depth by up to 20%;
- Placing sacrificial piles upstream of the crossing to collect debris and take the worst of the scour;
- Using scour dikes at the abutments to remove the worst of the local scour to points upstream of the crossing itself.

(b) Provide protection at or below the stream bed to arrest the development of the scour hole. One method is to pile riprap up around the base of the pier. The region beyond the riprap may scour but as the hole develops the riprap slides into it, eventually armouring the side of the hole adjacent to the pier. Other options such as structural concrete and rock-filled mattresses are also used in some circumstances but do not conform to the hole as readily.

Figure 10.9: Wai-iti Bridge – protection against local scour.

(c) Ensure that the foundations of structures are at such depth and of sufficient structural capacity that the deepest scour hole will not threaten the stability of the structure.

10.6.6 Protection Against General or Constriction Scour

It is possible to stop general or constriction scour from causing unacceptable lowering of the bed at the crossing by bed-level control. Methods could include:

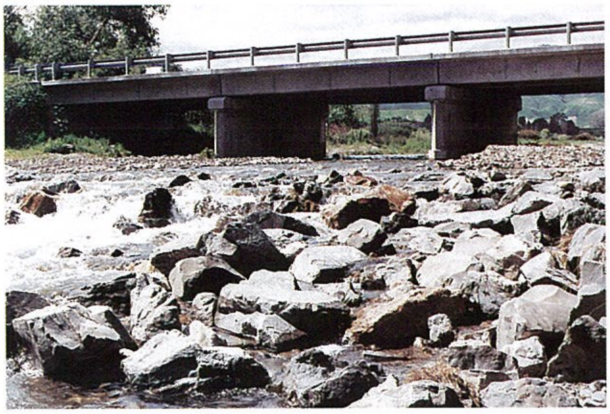

Figure 10.10: Riprap weir below the Waikanae River Bridge

- Weirs – placed immediately downstream of the crossing;
- Paving the entire crossing using materials such as concrete blocks, riprap, gabions or mattresses. This is generally only economical for relatively small streams;
- Regulation – modifying or preventing gravel extraction, river works, dam construction.

10.6.7 River Re-alignment

Re-alignment may be a means of improving the approach of the river to the crossing and of decreasing the risk or incidence of attack of the piers, abutments or embankments. This would normally be carried out in conjunction with appropriate river training and bank protection works.

Where significant works are proposed it is important that the consequences be thoroughly evaluated at the bridge as well as upstream and downstream. For example, channel shortening can result in degradation of the bed at the crossing and the structure may be put at risk from undermining. Away from the bridge, the potential impacts on property owners and river users should be investigated.

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