Bridge Scour Field Guide

Catchments & Creeks

Version 1, 2020

Bridge Scour Field Guide

Version 1, July 2020

Prepared by: Grant Witheridge, Catchments and Creeks Pty Ltd

Photos and diagrams by: Catchments and Creeks Pty Ltd

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Key words: bridge design, bridge scour control, rock sizing, rock placement, debris control for bridges, fish passage under bridges, revegetation under bridges.

Cover image: Flood damage to Brookbent Road bridge over Oxley Creek, Willawong, Queensland, May 1996.

Disclaimer

Significant effort has been taken to ensure that this document is representative of current best practice bridge design and waterway control; however, the author cannot and does not claim that the document is without error, or that the recommendations presented within this document will not be subject to future amendment.

To be effective, bridge scour control measures must be investigated, planned, and designed in a manner appropriate for the expected site conditions, including those site conditions relating to the waterway morphology, site soils and bed rock, vegetation, catchment hydraulics, and bridge maintenance.

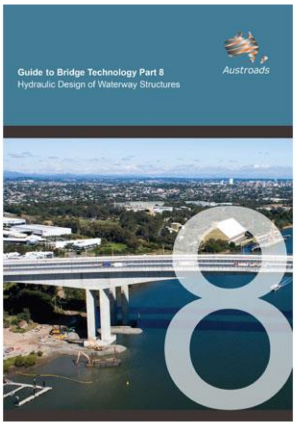
No warranty or guarantee, express, implied, or statutory is made as to the accuracy, reliability, suitability, or results of the methods or recommendations.

The author shall have no liability or responsibility to the user or any other person or entity with respect to any liability, loss, or damage caused, or alleged to be caused, directly or indirectly, by the adoption and use of any part of the document, including, but not limited to, any interruption of service, loss of business or anticipatory profits, or consequential damages resulting from the use of the document.

Specifically, adoption of the recommendations and procedures presented within this field guide will not guarantee:

(i) compliance with any statutory obligations
(ii) minimisation of damage to bridge structures
(iii) avoidance of environmental harm.

Reference documents:



Guide to Bridge Technology Part 8
Hydraulic Design of Waterway Structures
Austroads

Austroads, 2018

Guide to Bridge Technology Part 8

Hydraulic Design of Waterway Structures

(Section 5 – Bridge scour)

Austroads Ltd., Sydney, 2018

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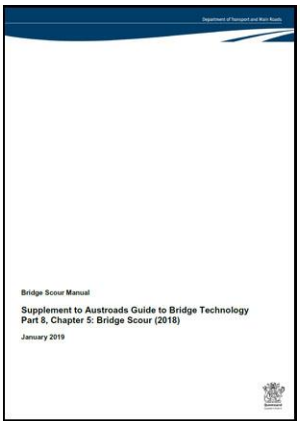


Bridge Scour Manual
Supplement to Austroads Guide to Bridge Technology Part 8, Chapter 5: Bridge Scour (2018)
January 2019

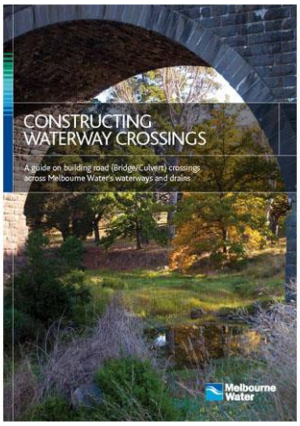
Qld Transport and Main Roads, 2019

Bridge Scour Manual

Supplement to Austroads Guide to Bridge Technology, Part 8, Chapter 5: Bridge Scout (2018)

The State of Queensland (Department of Transport and Main Roads), January 2019, Brisbane Queensland.

69 page colour PDF



CONSTRUCTING WATERWAY CROSSINGS
A guide on building road (Bridge/Culvert) crossings across Melbourne Water's waterways and drains
Melbourne Water

Melbourne Water, 2011

Constructing Waterway Crossings

A guide on building road (Bridge/Culvert) crossings across Melbourne Water's waterways and drains

Melbourne Water Corporation, East Melbourne, Victoria, May 2011

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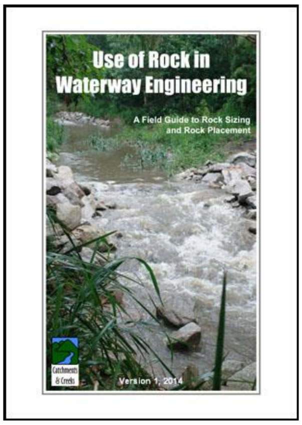

Use of Rock in Waterway Engineering
A Field Guide to Rock Sizing and Rock Placement
Catchments & Creeks
Version 1, 2014

Catchments & Creeks, 2020

Use of Rock in Waterway Engineering

Catchments & Creeks Pty Ltd, 2020, Brisbane Queensland.

75 page colour PDF

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Purpose of field guide

The purpose of this field guide is to:

- provide a general overview of scour control around waterway bridges
- introduce readers to the Austroads' 2018 and the Queensland Main Roads' 2019 guidelines on bridge scour control
- provide general information on the management soil scour around low-risk, minor bridges that are likely to be found in private property and along minor council roads.

This is not a design manual, and it is not a replacement for the Austroads guidelines on bridge scour or the various state and regional guidelines.

The photos presented within this document are intended to represent the current topic being discussed. These photos are presented for the purpose of depicting either a preferred or discouraged outcome (as the case may be). In some cases the photo may not represent current best practice, but is simply the best photo available to the author at the time.

The caption and/or associated discussion should not imply that the actual site shown within the photograph represents either good or bad engineering practice. The site conditions and history of each site are not known, and thus the actual conditions of the site may not align perfectly with the current discussion. This means that there may be a completely valid reason why the designer chose the design presented within the photo.

About the author

Grant Witheridge is a civil engineer with both Bachelor and Masters degrees from the University of NSW (UNSW). He has 40 years experience in the fields of hydraulics, stormwater management, creek engineering, and erosion & sediment control, during which time he has worked for a variety of federal, state and local governments, and private organisations.

Grant commenced his career at the UNSW Water Research Laboratory constructing and operating physical models of river floodplains. He later worked for Brisbane City Council on creek engineering and stormwater management issues. He currently works through his own company Catchments & Creeks Pty Ltd.

Grant is the principal editor of the 2007, 2013 and 2016 editions of the Queensland Urban Drainage Manual, as well as Brisbane City Council's *Natural Channel Design* and *Creek Erosion* guidelines, the 2002 engineering guidelines on the Fish Passage Requirements for Waterway Crossings, and the IECA (2008) Best Practice Erosion and Sediment Control documents.

Introduction

In aeronautical engineering, if your design does not fly, you're sacked; in mechanical engineering, if your design does not move, you're sacked; in civil engineering, if your design either flies or moves, you're sacked. And it is here, in these simple words that we find the real issue—the problems that occur when you build something that shouldn't move over a waterway that is certainly capable of moving.

This is where the world of structural engineering meets the world of fluvial geomorphology. Understanding the behaviour of major waterways goes beyond the application of simple mathematical equations, it requires the input of an experienced river geomorphologist.

Soil scour around the foundations of a bridge can be a result of the impacts the bridge is having on the waterway, or just a outcome of the natural movement of the waterway that would have occurred with or without the bridge being in place.

As with almost every problem we face, there are four types of solutions that we can explore when looking for ways to manage the problem of bridge scour:

- remove yourself from the problem
- remove the problem from yourself
- change the outcome of the problem
- change your response to the problem.

With respect to bridge scour, the **first response** can be achieved by altering the alignment of the road or driveway to minimise the number of waterway crossings, while also avoiding highly unstable sections of the waterway.

The **second response** may be achieved through the use of hard engineering measures that aim to prevent the erosion problems from occurring, but this is a rare outcome. The alternative is to design the bridge so that it spans the waterway in a manner that prevents any channel erosion from impacting on the bridge.

The **third response** can be achieved by accepting that some degree of soil scour will occur during flood events, but taking steps to ensure that the soil scour either:

- occurs at locations that do not adversely affect the structural integrity of the bridge (this outcome overlaps the second response), or
- occurs to such a limited degree (i.e. depth and width) that it will not adversely affect the structural integrity of the bridge.

If erosion were to occur without causing harm to the bridge, then there may still be an adverse impact on the aesthetics of the bridge and/or waterway, and thus there could still be a need for post-flood repairs (depending on the community's response).

The aim of this third approach is to accept some degree of scour during severe floods, but to:

- design the scour control measures such that affordable repairs can occur after each flood (this is a strategy that is adopted in some clay-based waterways), or
- design the bridge's foundations such that they can retain their required structural integrity even if significant flood scour were to occur (this is the strategy that usually needs to be adopted in most alluvial waterways (i.e. sand-based and gravel-based waterways).

The benefits of this approach is that it allows the usage of soft engineering scour control measures, such as rock and vegetation. The disadvantage of this method is the likely increased frequency and cost of post-flood maintenance. However, it is noted that the use of soft engineering measures does not mean that flood damage will always occur; and that the use of hard engineering measures does not mean that flood damage will never occur.

The **final response** can also be achieved by accepting that soil scour will occur around the bridge, but then using a cost:benefit analysis to determine what level of risk you are willing to accept. This does not mean that you leave the bridge to simply fail during the each flood event. What it means is you implement a measured (i.e. cost-effective) approach to scour control.

It also means:

- bridge designers have a bit more flexibility to implement soft engineering scour control measures that may have a higher risk of failure, but integrate better with the needs of the waterway, including the needs of fauna associated with the waterway corridor; and
- bridge designers can pay greater attention to the waterway's past history of flood damage and the frequency of flood damage to similar bridges in the region; and
- the cost of the scour control measures can be appropriate for the value and importance of the bridge—this can be particularly relevant for low-risk private bridges.

It is this final approach that is likely to be of most relevance to privately owned bridges, such as bridges on driveways and on rural tracks. Unfortunately for local governments and state authorities, this approach may not gain community acceptance. For some members of the community, any damage to public infrastructure is looked upon as an example of poor engineering design and/or inadequate bridge maintenance.

The benefit of considering at least one outcome within each of these four types of solutions listed above is that it can prompt the bridge design team to explore a bit of lateral thinking that may guide them to a better final outcome—better for the bridge, better for the waterway, better for the community, and of course better for the bridge owner.

Layout of this field guide


Photo supplied by Brisbane City Council

Bridge scour (Qld)

Introduction to bridge scour

- Sections 1 contains an overview of the different types of bridge scour and the factors affecting bridge scour.
- Section 2 contains an overview of general design considerations, including:
  - the likely interaction between bridges and different types of waterways
  - fauna considerations with regards to managing bridge scour.


Guide to Bridge Technology Part 8
Hydraulic Design of Waterway Structures

Austroads

Austroads, 2018

Scour control on major bridges

- Section 3 contains an overview of the 2018 Austroads guidelines for bridge scour prediction and control.
- Section 4 contains an overview of the 2019 Queensland Main Roads guidelines for bridge scour prediction and control.
- Section 4 has been presented as an example of how individual states can develop local guidelines that supplement the national Austroads guidelines.


Photo supplied by Catchments & Creeks Pty Ltd

Minor bridge (USA)

Scour control on minor bridges

- Section 5 contains an overview of rock sizing and placement on minor bridges.
- This section has been provided as a guide to scour control on minor bridges, such as those found on private property.
- An alternative equation is presented for the sizing of rock placed adjacent low-risk, minor bridges—this equation is not considered appropriate for the sizing of rock on major bridges.


Photo supplied by Catchments & Creeks Pty Ltd

Fractured rock

Scour control measures

- Section 6 provides an overview of rock placement around waterway bridges.
- Section 7 provides an overview of rock riprap characteristics, including Manning's roughness of rock, and rock grading.
- Section 8 provides an overview of other types of scour control measures.
- Section 9 discusses pavement scour.
- Section 10 presents several case studies of bridge flood damage and scour control.

Types of bridge crossings

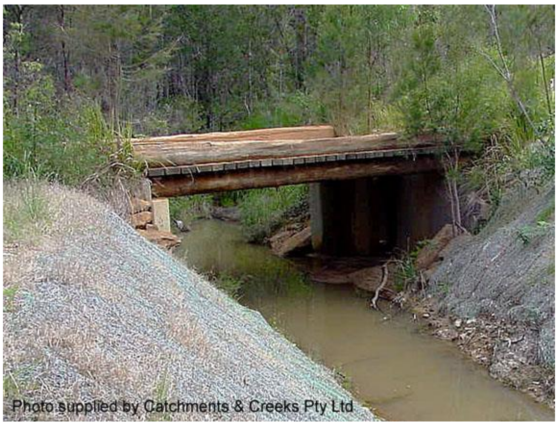


Photo supplied by Catchments & Creeks Pty Ltd

Minor bridge crossing (NSW)

Low-risk minor bridges

- A low-risk minor bridge crossing may be defined as a bridge crossing where:
  - flow velocities within the drain or waterway are unlikely to cause erosion
  - the cost of repairing any channel erosion is minor, and
  - the bridge does not represent critical infrastructure (e.g. a bypass exists).
- Typically these are single-lane bridges spanning low-velocity stormwater drains or minor waterways.


Photo supplied by Catchments & Creeks Pty Ltd

Minor bridge crossing (Tas)

High-risk minor bridges

- A high-risk minor bridge crossing may be defined as a bridge crossing where:
  - flow velocities within the drain or waterway are likely to cause erosion
  - the cost of repairing any channel erosion is considered significant, or
  - the bridge is considered critical infrastructure, even if a bypass exists.
- Typically these are single-lane bridges spanning high-velocity stormwater drains or minor waterways (creeks).


Photo supplied by Catchments & Creeks Pty Ltd

Footbridge (SA)

Footbridges

- Design procedures for scour control around footbridges should follow the same rules as for road bridges.
- This means footbridges should be assessed as either ‘minor’ or ‘major’ structures.
- Also, the design procedure should reflect the design guidelines adopted by the authority responsible for approving the footbridge, as well as the authority responsible managing the waterway.

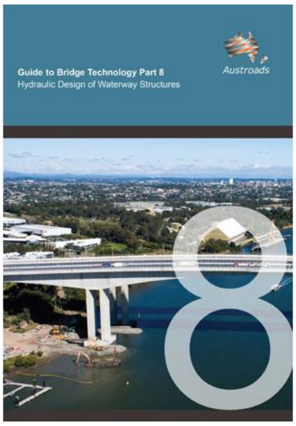

Photo supplied by Catchments & Creeks Pty Ltd

Major bridge crossing (SA)

Major bridges

- A major bridge crossing may be defined as:
  - a bridge that is not a minor bridge; or
  - a bridge that represents critical public infrastructure, even if a bypass exists; or
  - a bridge that is a part of a State-controlled transport corridor.

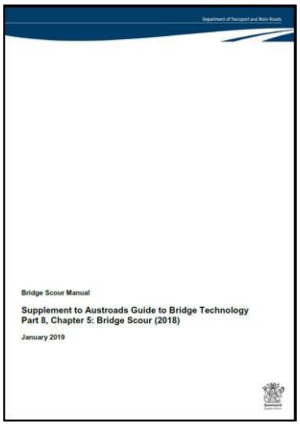
Related design guidelines



Austroads, 2018

Major road or rail bridges

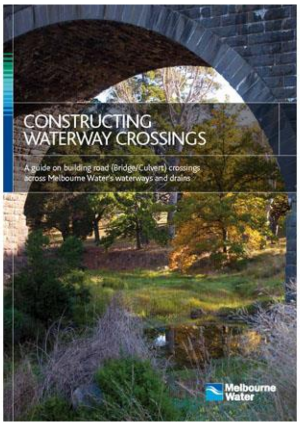
- Irrespective of the ownership of the waterway crossing, it is the designer's responsibility to be aware of best practice engineering design recommendations.
- In the <u>absence</u> of a local design code (i.e. a design code supported by the relevant approving authority), best practice bridge scour design is presented within the latest Austroads guidelines.
- The application of this guideline is not limited to road bridges.



Qld Transport and Main Roads, 2019

State-owned bridges

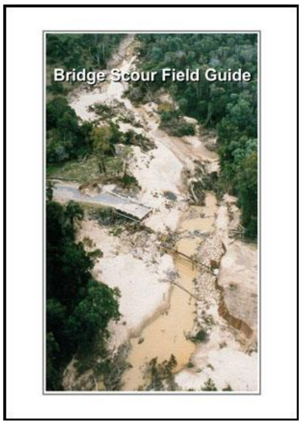
- Each state may have a local design manual/guideline for:
  - State-owned roads bridges
  - State-owned or managed rail bridges
- In some case these local state guidelines may be written as a supplement to the latest Austroads guidelines, in other cases the guidelines will act as a stand-alone document.



Melbourne Water, 2011

Bridges over waterways owned or managed by a local authority

- For minor bridge crossings that are located within private property, the relevant design guideline depends on:
  - the owner or responsible authority acting for the waterway
  - whether or not the structure requires design approval from the local government (refer to the local government's Planning Scheme).



Catchments & Creeks, 2020

Privately owned bridges

- Subject to the requirements of the local government and/or the waterway authority, this field guide provides general design information on the management soil scour around privately-owned minor bridges.
- The use of this field guide requires appropriate experience and training.
- This field guide has not been developed as a general public guide.

1. Types of Bridge Scour

Types of bridge scour


Photo supplied by Brisbane City Council

Johnson Road, Forestdale, Qld

Surface scour

- Sometimes referred to as ‘contraction scour’, this form of erosion results from the direct removal of surface material by flowing water.
- This term is used to describe scour that originates from this smooth, orderly flow that is largely absent of large-scale turbulence.
- Soil scour that is the direct result of turbulent flows generated by the bridge structure is commonly referred to as ‘local scour’.


Photo supplied by Catchments & Creeks Pty Ltd

Old Toowoomba Rd, Ipswich, Qld

Structure-induced scour (local scour)

- Rough turbulent flow can originate from obstructions associated with the bridge, such as abutments and piers, or from channel irregularities upstream of the bridge.
- Soil scour is commonly found around the base of bridge piers, which is caused by changes in flow velocity and turbulence as floodwaters pass around the pier.


Photo supplied by Catchments & Creeks Pty Ltd

Johnson Road, Forestdale, Qld

Debris-induced scour

- Debris wrapped around bridge piers can cause a local increase in flow velocity and turbulence resulting in bed scour.
- Trapped debris rafts can also increase the average flow velocity under a bridge by reducing the effective flow area.


Photo supplied by Catchments & Creeks Pty Ltd

Burdekin River, Queensland

Deep bed-substrate migration

- Waterways can be either ‘fixed bed’ or ‘moving bed’ systems.
- Fixed bed waterways are rock-based or clay-based systems that have little or no loose bed sediment.
- Moving bed waterways have a deep substrate layer, and are typically sand or gravel-based waterways.
- This deep substrate typically moves (migrates) during major floods, which may result in short-term or long-term changes in bed level.

Types of bridge scour

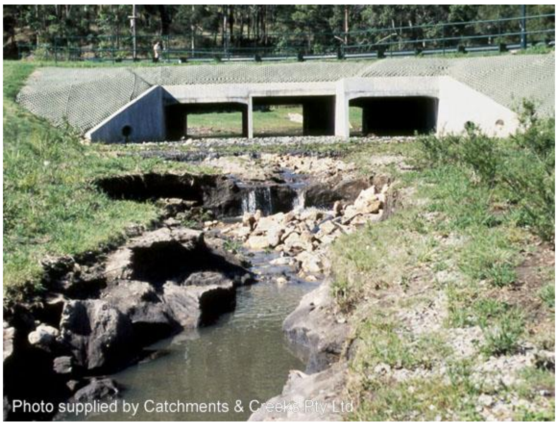


Photo supplied by Catchments & Creeks Pty Ltd

Small head-cut migrating towards a road

Head-cut bed erosion

- A 'head-cut' is an unstable sudden drop in the waterway bed that usually:
  - migrates up the waterway during flood events; and
  - often acts like a mini waterfall during periods of low flow.
- This form of waterway scour is normally initiated by downstream actions/events, which cause the head-cut to migrate upstream to the bridge.

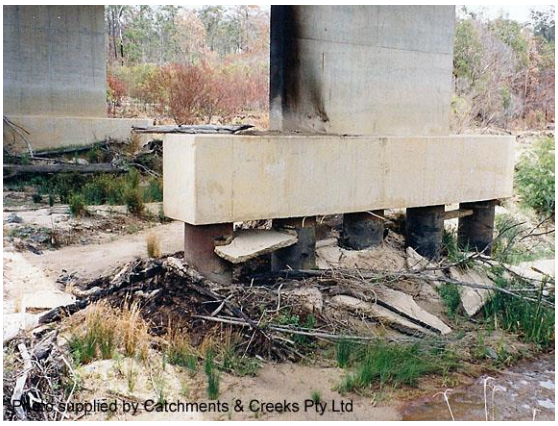


Photo supplied by Catchments & Creeks Pty Ltd

Logan Motorway, Oxley Creek, Qld

Waterway migration

- Waterway migration is where the low-flow channel moves laterally across the bed of a wide channel, or the whole channel moves laterally across a floodplain.
- Bridge piers, abutments and foundations can be exposed as a result of channel migration.
- Historical aerial photography can often be used to identify past phases of channel migration.


Photo supplied by Catchments & Creeks Pty Ltd

Princes Highway, Murray Bridge, SA

Long-term lowering of bed levels

- Bridge piers, abutments and foundations can be exposed as a result of long-term changes to waterway bed levels.
- Long-term changes in bed levels can be the result of:
  - head-cut erosion
  - changes in annual river flow (e.g. climate change or changes in dam operation)
  - changes in sediment flow along the waterway.


Photo supplied by Brisbane City Council

Brookbent Road, Willawong, Qld

Scour due to overtopping floods

- Overtopping flows can cause damage to the approach roads as well as the bridge.
- The head-cut scour visible to the left of this timber bridge is an example of erosion caused by overtopping flows.
- At this site, head-cut erosion attacked the approach roads each side of the bridge, but the erosion occurring on the right-hand side broke through the roadway first, which is why that side of the road was washed away.

Examples of bridge crossings over meandering waterways

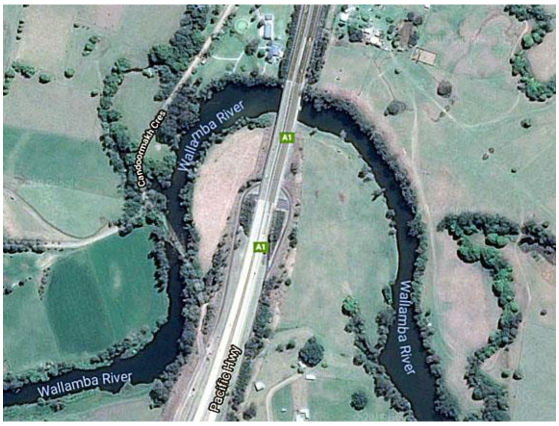
Pacific Highway, Ballina, NSW

Pacific Highway, Coldstream River

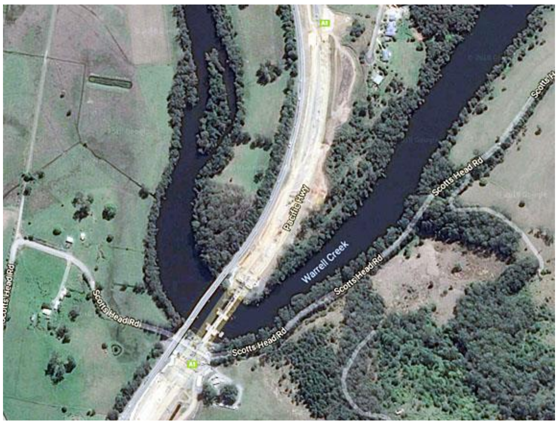
Pacific Highway, Collombatti Creek

Pacific Highway, Myall River

Pacific Highway, Serpentine Channel



Pacific Highway, Wallamba River



Pacific Highway, Warrell Creek

Pacific Highway, Blackadder Gully

Factors affecting soil erosion around bridges


Photo supplied by Catchments & Creeks Pty Ltd

Overtopping flood flows (Qld)

The type of water flow

- Factors that can influence the degree of soil erosion include:
  - flow velocity
  - depth of flow
  - degree of turbulence
  - degree of entrained sediment (clean water or dirty water)
- The strength of vegetation can be influenced by the recent frequency of major flows, which inturn can influence adjacent soil erosion.

Types of waterways

Impact of waterway type on scour control

- Flood-induced channel erosion varies with the type of waterway.
- Different types of waterways react differently to flood events.
- The design of scour protection measures must reflect the type of bed material—for example, the placement of rock within a sand-based waterway is different from its placement within a clay-based waterway.

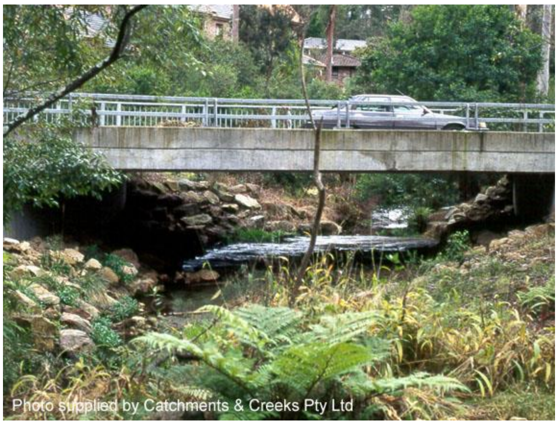
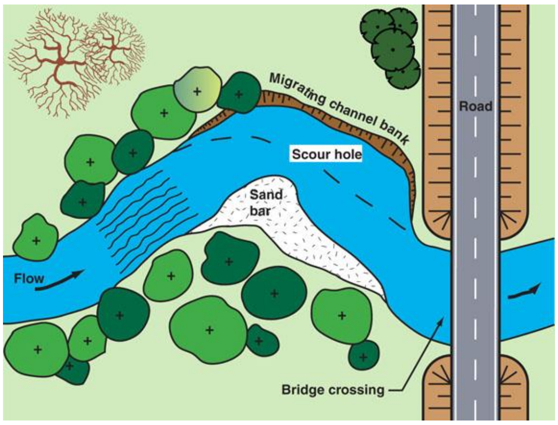


Photo supplied by Catchments & Creeks Pty Ltd

Urban creek, Sydney, NSW

The size of the waterway

- Small waterways, such as creeks and constructed channels (drains), are less likely to experience significant channel migration.
- Large waterways, such as rivers, are more likely to have a deep layer of loose substrate (bed sediment) that migrates downstream during flood events.



Bridge built across a migrating channel

Impacts of waterway alignment on scour control

- Scour control measures will be influence by the location of the bridge with respect to the waterway alignment.
- Different degrees of scour control are required for bridges located on a:
  - straight channels
  - meandering channels
  - channel bends.

Factors affecting soil erosion around bridges


Photo supplied by Catchments & Creeks Pty Ltd

Bowen River, Queensland

The type and depth of bed substrate

- Assessing the deep the loose substrate (sand or gravel beds) can be critical in determining the potential depth of bed scour during severe floods.
- The depth of the bed substrate may be determined by reviewing bore hole data.
- It is noted that the maximum depth of bed scour may not be limited to just the depth of this loose bed material.


Photo supplied by Catchments & Creeks Pty Ltd

Good vegetation cover (Qld)

The degree of vegetation cover

- There are two issues here:
  - the degree of vegetation cover over the channel upstream and downstream of the bridge
  - the health and coverage of vegetation under the bridge deck.
- The stability of this vegetation is also dependent on the stability of the bed and bank material in which the plants are growing, and on the size of the waterway.


Photo supplied by Catchments & Creeks Pty Ltd

Debris raft trapped on a bridge pier

Consideration of debris blockage

- The effects of debris blockage on flow velocities and the potential scour risk must be considered.
- Debris deflection systems can be used to:
  - capture and hold debris upstream of the bridge, thus moving any associated bed scour upstream of the bridge, and
  - reduce lateral forces placed on the bridge piers by large debris rafts.


Photo supplied by Catchments & Creeks Pty Ltd

Airport Link, Schulz Canal, Brisbane

Location of bridge piers relative to waterway banks

- Ideally, bridge piers should not be located near waterway banks because this inturn results in an increase in potential damage to the bank.
- The existence of a waterway bank near a bridge pier can influence local flow velocities and turbulence, and thus the resulting flood scour.

Predicting potential river migration

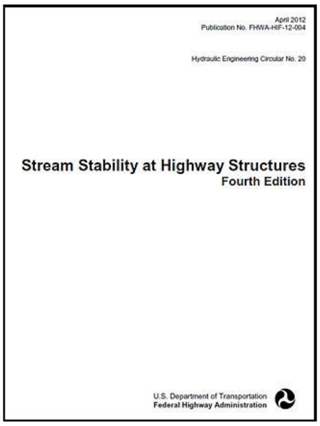

Photo supplied by Catchments & Creeks Pty Ltd

Braided waterway, Queensland

Reference documents

Austroads presents the following publications as useful guides in river morphology:

- *Fluvial Geomorphology in Australia*, Warner, 1988 (a collection of specialist papers providing background into the geomorphology of rivers and related phenomena in Australia).


April 2012
Publication No. FHWA-HIF-12-004

Hydraulic Engineering Circular No. 20

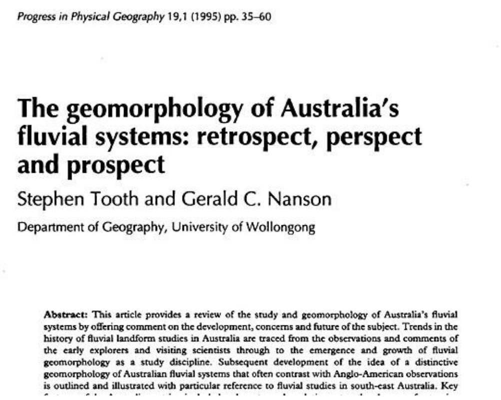
Stream Stability at Highway Structures
Fourth Edition

U.S. Department of Transportation
Federal Highway Administration

Lagasse et al. 2012

Stream Stability at Highway Structures

- *Stream Stability at Highway Structures*, Fourth Edition, P.F. Lagasse, L.W. Zevenbergen, W.J. Spitz, L.A. Arneson, 2012, US Department of Transport, Federal Highway Administration, Publication FHWA-HIF-12-004.


Progress in Physical Geography 19,1 (1995) pp. 35–60

The geomorphology of Australia's fluvial systems: retrospect, perspect and prospect

Stephen Tooth and Gerald C. Nanson

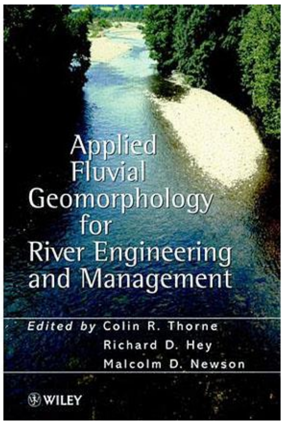
Department of Geography, University of Wollongong

Abstract: This article provides a review of the study and geomorphology of Australia's fluvial systems by offering comment on the development, concerns and future of the subject. Trends in the history of fluvial landform studies in Australia are traced from the observations and comments of the early explorers and visiting scientists through to the emergence and growth of fluvial geomorphology as a study discipline. Subsequent development of the idea of a distinctive geomorphology of Australian fluvial systems that often contrast with Anglo-American observations is outlined and illustrated with particular reference to fluvial studies in south-east Australia. Key

Tooth and Nanson, 1995

The geomorphology of Australia's fluvial systems: retrospect, perspect and prospect

- *The geomorphology of Australia's fluvial systems: retrospect, perspect and prospect*, Stephen Tooth and gerald C. Nanson, 1995, Progress in Physical Geography 19.1 pp. 35–60 (Edward Arnold, 1995).


Applied Fluvial Geomorphology for River Engineering and Management

Edited by Colin R. Thorne
Richard D. Hey
Malcolm D. Newson

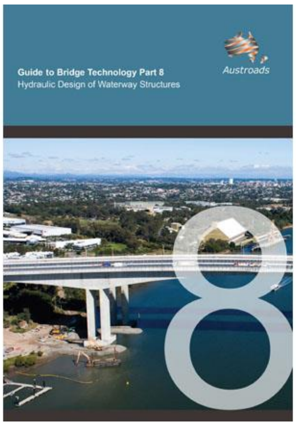
WILEY

Thorne, Hey and Newson, 1997

Applied Fluvial Geomorphology for River Engineering and Management

- *Applied Fluvial Geomorphology for River Engineering and Management*, C.R. Thorne, R.D. Hey and M.D. Newson, 1997, Wiley.

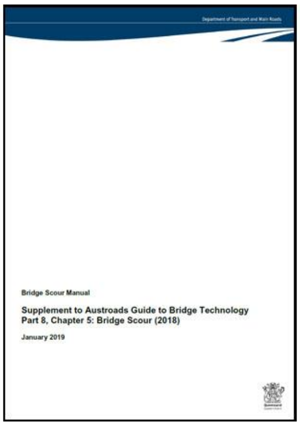
Predicting the depth of scour



Austroads, 2018

Austroads' Guide to Bridge Technology, Part 8

- Austroads (2018) provides guidance on methods for predicting scour depths adjacent to bridges.
- Refer to section 3 of this field guide for an overview of the 2018 Austroads guidelines.


Department of Transport and Main Roads

Bridge Scour Manual

Supplement to Austroads Guide to Bridge Technology Part 8, Chapter 5: Bridge Scour (2018)

January 2019

Qld Transport and Main Roads, 2019

Queenslands' Bridge Scour Manual

- The Queensland Department of Transport and Main Roads' *Bridge Scour Manual* provides commentary on the Austroads (2018) guidelines, as well as making further recommendations on the of prediction scour depths.
- Bridge designers should refer to their local state guidelines.
- Refer to section 4 for an overview of the Queensland Main Roads' guidelines.

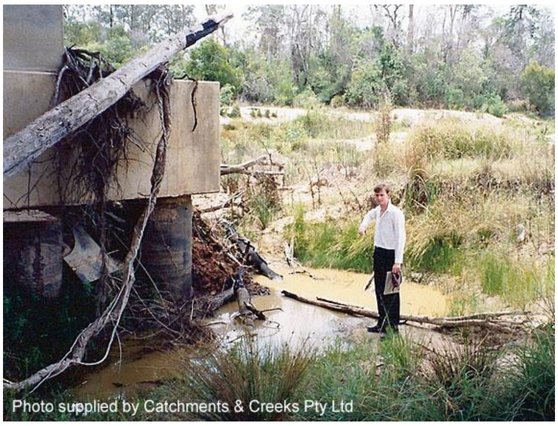
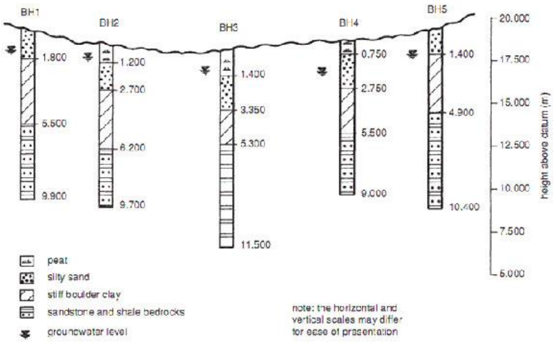


Photo supplied by Catchments & Creeks Pty Ltd

Bridge inspection (Qld)

River morphology

- Predicting the maximum possible depth of bed scour at a bridge site can a very simple or very complex exercise.
- In simple cases the maximum depth of scour can be limited by the existence of bed rock.
- In complex cases the investigation may involve a study of the waterway's stream power and geological history.
- Obtaining advice from a river morphologist is highly recommended.



note: the horizontal and vertical scales may differ for ease of presentation

Bore hole data

Scour predictions based on bore hole information

- The depth of the bed substrate may be determined by reviewing bore hole data.
- Bore hole data may also provide information of past river migration and flood damage—this usually requires input from fluvial geomorphology experts.

2. General Design Considerations

Types of waterways

Major waterway (Bremer River, Qld)

Major waterways

- Major waterways are most commonly referred to as 'rivers'.
- In some regions of Australia, as well as within the upper regions of most rivers, these waterways can be so narrow that their behaviour is more closely aligned with the behaviour of minor waterways.
- In major waterways, bank vegetation can play a major role in providing post-flood bank stability, but during a flood, it is the floodwater that usually dominates over the vegetation.

Minor urban waterway (Brisbane, Qld)

Minor waterways

- Within this field guide, the term 'minor waterway' is used to describe narrow-bed waterways where vegetation type and density is a dominant factor in determining the size and stability of the channel.
- 'Springs', 'brooks' and 'creeks' are the waterways most likely to be referred to as minor waterways.
- These waterways normally have a low (1, 2, 3, etc.) 'stream order' classification.

Dolo Creek, Broken Hill, NSW

Arid and semi-arid waterways

- Arid and semi-arid waterways are often treated as a separate waterway category due to the reduced influence of vegetation on the channel form and stability.
- In arid regions it can be difficult to distinguish between a 'waterway' and a 'drainage line'.
- These waterways can, however, share many characteristics with coastal waterways, including the wide flat channel bed found in most sand and gravel-based waterways.

Well-vegetated drainage line (Qld)

Drainage lines

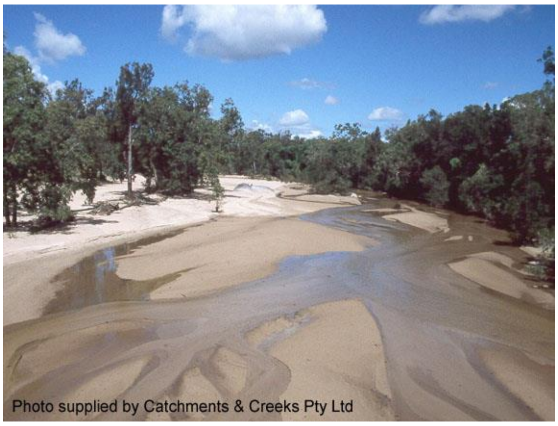
- A 'drainage line' is a stormwater drainage pathway (or overland flow path) that carries concentrated flow (not sheet flow).
- These drains are likely to flow only while rain is falling, and for short periods (hours) after rainfall has stopped.
- Drainage lines are generally **not** considered to be 'waterways'.
- The classification of waterways is usually a matter for state governments, while the mapping of drainage lines is more commonly done by local governments.

Types of waterways (the following is just one of many classification systems)

Clay-based waterway (Qld)

Clay-based waterways

- The bed and banks of clay-based waterways are primarily formed from clayey soils that are not covered by loose (natural) sediments.
- These are 'fixed bed' waterways, that typically have minimal natural sediment flow or bed movement—this allows mature woody vegetation to establish close to, or even on, the channel bed.
- Typically these waterways have a U-shaped or V-shaped channel profile.



Sand-based waterway (Qld)

Sand-based waterways

- Deep, loose sand dominates the make-up of the bed of sand-based waterways.
- The depth of the sand can exceed the depth of the root systems of much of the bed and lower bank vegetation.
- These are alluvial waterways that experience significant bed movement (sand flow) during both minor and major stream flows.
- Bed vegetation (if any) typically consists of quick-response, short-lived, non-woody species.

Gravel-based waterway (Tas)

Gravel-based waterways

- Bed material is made-up mostly of well-rounded gravels, cobbles or boulders.
- These are alluvial waterways that often feature pools and riffles, which can completely reform during floods.
- The movement of the bed material during major floods means the channel bed is usually flat (similar to sand-based rivers).
- Woody vegetation can struggle to form on the channel bed if the bed movement is significant—which may not be the case in the upper reaches of the waterway.

Rock-based waterway (Tas)

Rock-based waterways

- The bed material of rock-based waterways is made-up of exposed rock outcrops often separated by sections of clay, sand or gravel-based channels.
- These are fixed-bed, 'spilling' waterways usually containing waterfalls or riffles followed by deep pools within which energy dissipation occurs.
- These waterways are sometimes referred to as 'rocky-spilling' or 'steep pool-fall' waterways.

Bridges over clay-based waterways

Sand-based waterway (Qld)

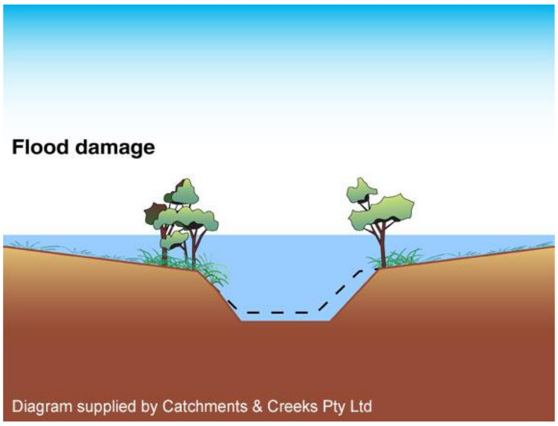
Clay-based waterways

- Clay-based waterways contain cohesive clayey soils across the bed and banks.
- These are fixed bed waterways, that in their undisturbed state would normally experience only minor sediment flow (in comparison to sand-based waterways).
- Due to the relative stability of the bed and banks, mature woody vegetation can often establish well down the banks, and even on the channel bed in ephemeral waterways.

Flood damage to bridge abutment

Likely types of bridge scour

- All forms are scour are possible in clay-based waterways.



Flood response

Typical response to major floods

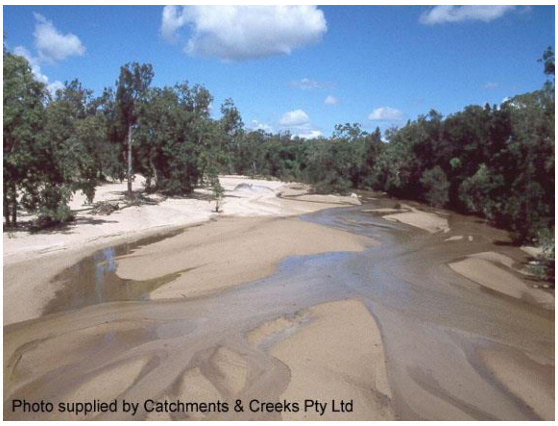
- Away from the bridge, soil scour occurs across the bed and banks, and the channel typically erodes in a manner that maintains the original shape of the channel (i.e. the channel gets both deeper and wider).
- Under a bridge, expect deep bed scour, especially if the bridge forms a constriction across the channel or floodplain.
- Abutment foundations can be exposed by the loss or movement of the channel bank.

Scour protection measures (NSW)

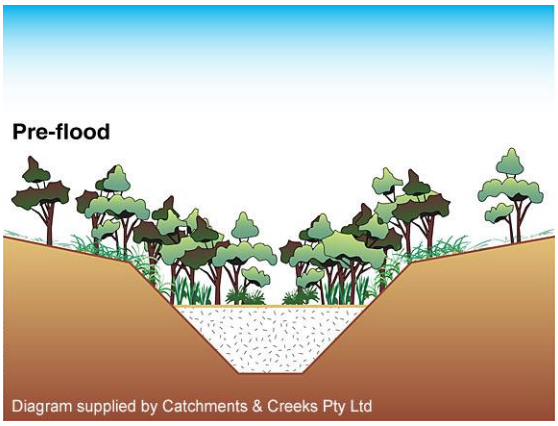
Typical scour control measures

- Rock stabilisation of the bed and banks.
- Scour control measures normally applied if flow velocities exceed 1 m/s.
- Even though it is highly desirable to establish vegetation over all scour control measures, it can be difficult to maintain this vegetation in a healthy state given the fact that the bridge deck shades the vegetation from direct sunlight and rainfall.

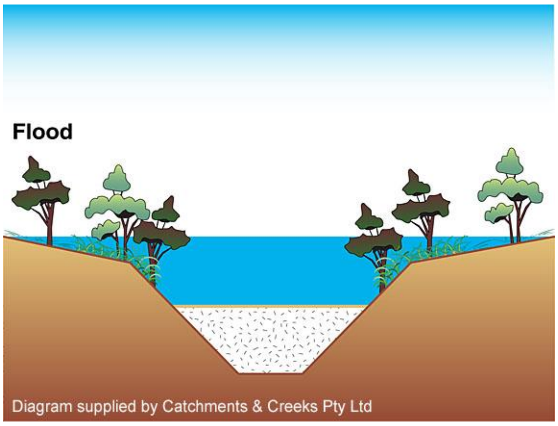
Bridges over sand-based waterways



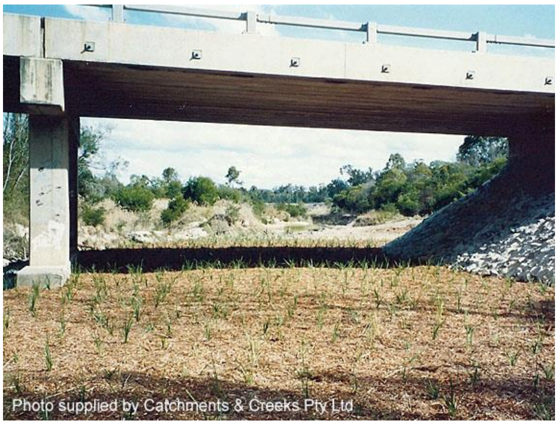
Sand-based waterway (Qld)



Pre-flood channel condition



Post flood channel condition



Scour protection measures (Qld)

Sand-based waterways

- Sand-based waterways contain deep, loose sand across the channel bed.
- These are alluvial waterways that experience significant bed movement during a wide range of flood events.
- There is normally a clearly defined change in plant species from those growing on the bed (if any) to those growing on the banks.
- These waterways should not be confused with urban clay-based waterways that contain large quantities of introduced sediment (urban runoff).

Likely types of bridge scour

- Along with ‘contraction scour’ and ‘local scour’, bridge designers should expect significant ‘natural’ channel erosion associated with the deep movement of the sandy bed.
- During rare, severe floods, well-established trees located close to the channel banks can be displaced if they have established in old sand deposits—the loss of these trees can significantly add to the debris loading on downstream bridges.

Typical response to major floods

- During major floods, the sand contained in the channel bed can liquefy and move in mass.
- Away from the bridge the pre-flood channel will likely erode to form a wide, flat-bed channel.
- Under a bridge, expect deep movement of bed material during the peak of the flood, even though no evidence of this deep scour may be obvious after the flood as passed.

Typical scour control measures

- The use of rock on the channel bed can be questionable if the depth of sand exceeds 1 m.
- In such cases, the rock can sink into the sandy bed as the sand liquefies during flood events.
- Rock stabilisation can be applied to the clayey soil banks and abutments.
- Hard engineering scour control measures are applied to the abutments if flow velocities are expected to exceed 1 m/s.

Bridges over gravel-based waterways


Photo supplied by Catchments & Creeks Pty Ltd

Dry-bed, gravel-based waterway (SA)

Gravel-based waterways

- In gravel-based waterways, the bed material is made up of well-rounded gravels, cobbles and/or boulders.
- These are alluvial waterways that usually contain pools and riffles.
- The channel bed of both sand and gravel-based waterways is usually 'flat', as compared to the U-shaped bed of clay-based waterways.
- The growth of trees near the bed can depend on how often the bed gravels move.

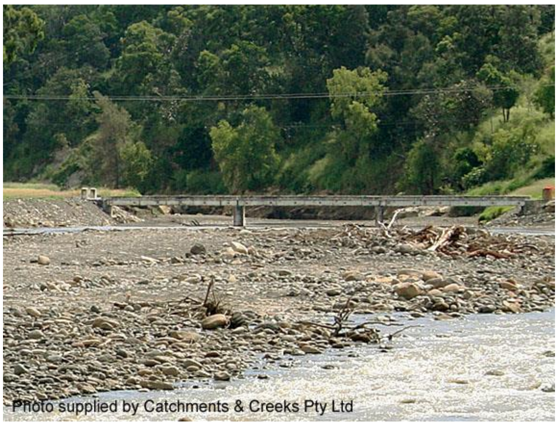


Photo supplied by Catchments & Creeks Pty Ltd

Bridge over a gravel-based waterway (Qld)

Likely types of bridge scour

- Along with 'contraction scour' and 'local scour', bridge designers should expect significant 'natural' channel erosion associated with the movement of bed material during major floods.
- There is likely to be only shallow movement of the surface gravel during the more regular floods.

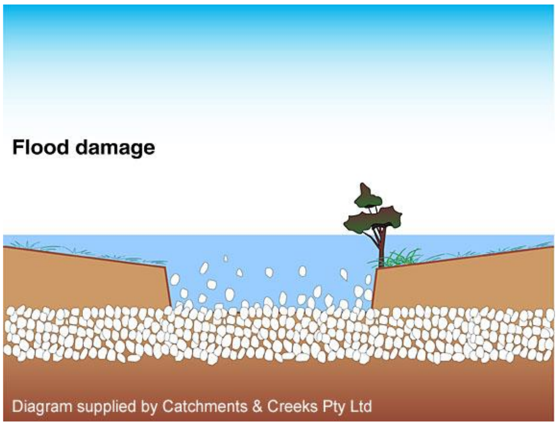


Diagram supplied by Catchments & Creeks Pty Ltd

Flood response

Typical response to major floods

- Away from the bridge the channel typically erodes to form a wide, flat-bed channel.
- Under a bridge, deep bed scour is possible during the peak of the flood, especially if the bridge forms a constriction across the channel or floodplain.
- During rare severe floods, the mass of gravels suspended in the floodwater can cause significant damage to all structures, including the bridge.


Photo supplied by Catchments & Creeks Pty Ltd

Large gravel-based waterway (Qld)

Typical scour control measures

- The use of rock stabilisation of a gravel bed can be questionable in some circumstances—seek expert advice.
- Rock stabilisation can be applied to clayey soil banks and abutments.
- Hard engineering scour control measures are applied to the abutments if flow velocities are expected to exceed 1 m/s.

Cobble or boulder-based waterways

Cobble-based waterway (Tas)

Cobble-based waterways

- Similar to gravel-based waterways, the bed material is made-up of well-rounded cobbles or boulders.
- These are relatively stable alluvial waterways that usually contain relatively stable pools and riffles.
- The channel bed is usually 'flat', as compared to the U-shaped bed of clay-based waterways.
- Woody vegetation may establish in parts of the channel bed.

Boulder-based waterway (Qld)

Likely types of bridge scour

- Expect the surface movement of the cobbles during major floods.
- Deep movement of the cobbles could occur during rare, severe floods.

Cobble-based waterway (Qld)

Typical response to major floods

- These waterways can appear relatively stable for decades, then experience major bed movement during a rare, severe flood event.
- The flood event that initiates bed movement could be in excess of the bridge's serviceability limit state (10–100 year ARI, SLS flood).

Boulder-based waterway (Tas)

Typical scour control measures

- The use of rock stabilisation of a cobble or boulder bed can be of questionable value.
- Rock stabilisation can be applied to clayey soil banks and abutments.
- Hard engineering scour control measures are applied to the abutments if flow velocities are expected to exceed 1 m/s.

Bridges over rock-based waterways


Photo supplied by Catchments & Creeks Pty Ltd

Rock-based waterway (Tas)

Rock-based waterways

- Only isolated reaches of rock-based waterways may contain a solid rock bed.
- These rocky sections are usually separated by lengths of clay, sand or gravel-based channels.
- These are fixed-bed 'spilling' waterways usually containing waterfalls.
- In some cases the rock can be completely covered by soil, which can be stripped from the rock during severe floods.

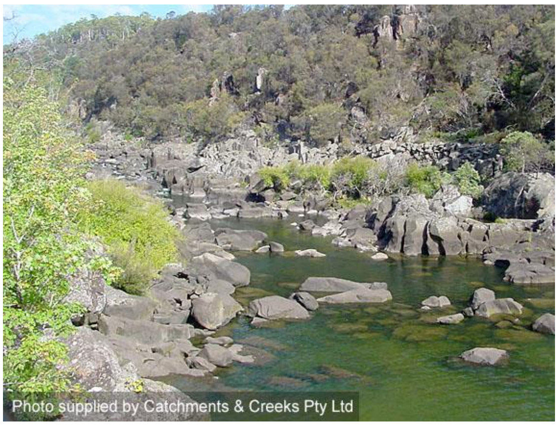


Photo supplied by Catchments & Creeks Pty Ltd

Rocky gorge (Tas)

Likely types of bridge scour

- Bed scour can be unlikely.
- Clayey banks and abutments can be subject to a full range of erosion types.


Photo supplied by Catchments & Creeks Pty Ltd

Flood-induced loss of soil (Qld)

Typical response to major floods

- If loose bedding material has collected on the rocky bed over years, then this material can move in mass during major floods causing the bed rock to be exposed.
- The waterway shown here is Gowrie Creek downstream of Toowoomba, stripped of soil and vegetation following the severe flood of 2011.


Photo supplied by Catchments & Creeks Pty Ltd

Exposed bed rock (Qld)

Typical scour control measures

- Scour control measures are typically not required.
- Seek expert advice if unique channel conditions exist.

Bridges over arid and semi-arid waterways

Central NSW

Arid and semi-arid waterways

- Arid and semi-arid waterways are often treated as a separate waterway category due to the reduced influence of vegetation on the channel form and stability.
- Similar to coastal waterways, arid waterways can be grouped into clay-based, sand-based, gravel-based, and rock-based waterways.

King's Canyon, NT

Likely types of bridge scour

- As per a clay-based, sand-based, or gravel-based coastal waterway.

Black Hill Creek, Silverton, NSW

Typical response to major floods

- Highly variable.
- Assess each bridge crossing on site by site basis.
- Floodwaters often have low flow velocities; however, significant increases in the local flow velocity can occur around bridge structures.
- Floodplain bridges should be treated the same as bridges spanning the main channel.

Todd River, Alice Springs, NT

Typical scour control measures

- Suitable rock can be scarce in some locations.
- Cellular-confinement systems can allow the use of locally available small rock.
- Gabions and rock mattresses have proven successful in some arid regions; however, frequent flows can cause flood-entrained sediments to damage the galvanising and plastic coating of the gabions—local experience can be a good guide.

Bridges over constructed stormwater drains

Constructed drains and stormwater channels

- These are storm drains typically constructed in locations where a natural creek did not previously exist.
- Constructed storm drain are generally <u>not</u> considered to be 'waterways'; however, Natural Channel Design principles can be used to form constructed channel that closely resemble natural waterways.

Constructed stormwater channel (Qld)

Likely types of bridge scour

- The risk of soil scour will vary from site to site.
- All forms are scour are possible; however, in some low-gradient channels, flow velocities can be very low and soil scour may not occur even during flood events.

Constructed stormwater channel (Qld)

Typical response to major floods

- Away from the bridge, the risk of soil scour will again vary from site to site.
- Under a bridge, localised bed scour may occur if vegetation cover is reduced in comparison to the rest of the drain.
- Scour damage to the bridge abutments is just as likely as scour damage to the channel bed.

Gabion-lined storm drain (NSW)

Typical scour control measures

- Rock stabilisation of the bed and banks heavily integrated with vegetation cover.

Reconstructed waterway channel (Qld)

General debris and hydraulic considerations

Vegetation damage, Brisbane River, 2011

Flood damage to in-bank vegetation

- Flood damage to waterway vegetation is important to the management of bridge scour control for the following reasons:
  - the loss of vegetation and/or changes in channel roughness can alter flow patterns and velocities upstream and downstream of a bridge
  - the degree of vegetation damage directly impacts the volume of flood debris.

100% debris blockage of a road culvert

Debris collection on bridge structures

- The potential for debris collection depends on the following factors:
  - debris availability within a catchment
  - debris mobility, potentially caused by the current flood or by previous landslides or wind storms
  - debris transportability relating to the ability of the waterway to transport debris to a bridge
  - structure interaction, including the existence of central piers.

Scour hole formed by flood debris (Qld)

The impact of debris collection on local flow velocities

- Debris collection can alter the local flow velocities and cause scour holes to form in critical locations, such as at the base of abutments.

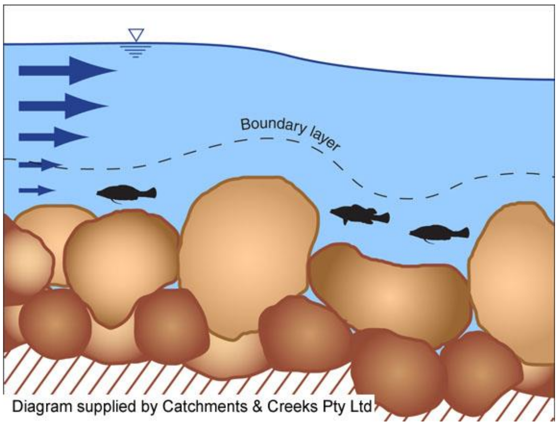
Torrens River, Adelaide, SA

Use of debris control systems

- Debris control systems can be used to reduce debris capture and debris loads on bridges and bridge piers.

Fish passage considerations

Fish passage, Adelaide, SA



Variation in velocity with depth

Adverse under-deck planting conditions

Poor light conditions under a bridge

Fish habitats and fish passage

- Consideration must be given to the fish passage requirements of the waterway and how this may alter the design of any scour control measures.
- Some state have mapped the waterways that require consideration of fish passage issues.
- It is noted that the terrestrial passage requirements at a bridge may conflict with the ideal fish passage needs of the waterway.

The benefits of channel roughness

- Flow velocities are never uniform across the depth and width of flowing water.
- The fish passage requirements of a waterway are likely to be closely related to the boundary layer conditions of the waterway.
- The thickness of the boundary layer at any location under a bridge is directly related to the degree of surface roughness, and it is this roughness that can be altered through the placement of bridge scour control measures.

The importance of establishing vegetation under bridge decks

- Fish passage not only occurs within the main waterway channel, but can also occur along the upper banks and across overbank areas during flood events.
- Appropriate vegetation can aid fish passage in the following locations:
  - channel bed (ephemeral streams)
  - channel banks (moderated flows)
  - overbank areas (minor floods)
  - bridge abutments (major floods)

Difficulties in establishing vegetation under bridge decks

- The bank and overbank areas under a bridge deck can be hostile areas for vegetation growth.
- The problems experienced include:
  - shading from sunlight
  - lack of natural rainfall resulting in dry ground conditions even through the area can be close to a flowing stream
  - high flow velocities during flood events.

Fauna-friendly design features


Photo supplied by Catchments & Creeks Pty Ltd

Bridge with no instream piers (Qld)

Avoid instream piers (fish)

- With respect to fish passage, the aim should be to minimise the number of bridge piers located within the channel.
- If bridge piers must be located within the main channel, then avoid placing these piers too close to the channel banks.
- It is noted that for public safety reasons, bridge piers should also not be located near the centre of the channel if the waterway is likely to carry supercritical flow during flood events.


Photo supplied by Catchments & Creeks Pty Ltd

Bridge with minimal constriction (NSW)

Minimal constriction of the channel (fish)

- Bridge abutments should be located well away from the tops of channel banks.
- Any form of flow constriction at a bridge crossing will technically alter the fish passage conditions at that crossing, even if velocities under the bridge are considered within acceptable ranges.
- The full impact of flow constrictions on fish passage will ultimately depend on the total number of culvert and bridge crossings over the waterway—if few crossings exist, then the issue reduces in importance.


Photo supplied by Catchments & Creeks Pty Ltd

Incorporation of vegetation (NSW)

Naturalised bank features (fish)

- Natural bank features, including roughness, vegetation and habitat features, can facilitate both aquatic and terrestrial passage.
- Maintaining stiff grasses along the water's edge aids fish passage during low flows, while upper bank vegetation can assist fish passage during flood events.
- Designs should minimise the use and extent of any scour control measures that cannot be integrated with native vegetation.


Photo supplied by Catchments & Creeks Pty Ltd

Plants under a wide bridge deck (Qld)

Water needs of plants under a bridge deck

- In order for plants to survive long-term under a wide bridge deck, the plants will need sufficient light and water.
- Successful revegetation under bridges may require stormwater runoff from the deck or adjacent land to be channelled under the bridge deck.
- The process of supplying water to under-deck plants can be integrated with the treatment and filtration of road runoff.

Fauna-friendly design features

Twin bridge crossing (Qld)

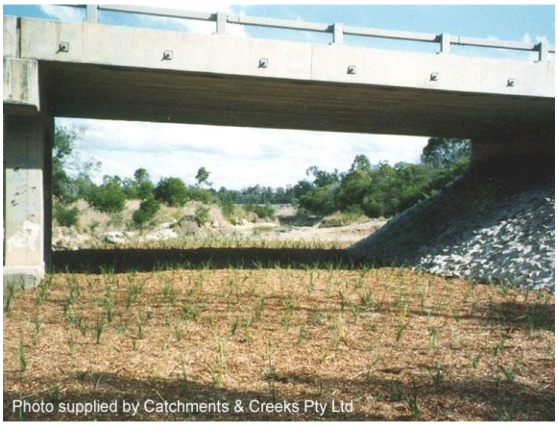
Twin bridge crossings (fish)

- Divided road crossings improve light penetration thus assisting both fish passage and bank revegetation.

Riffle downstream of bridge (NSW)

Pool-riffle systems (fish)

- Pool-riffle systems should only be established in waterways that naturally contain such pool-riffle systems.
- If channel works are required, then try to mimic the natural pool-riffle spacing.
- Caution; a riffle formed under a bridge will likely be washed away during floods.
- Instead, try to position riffles just downstream of the bridge after flow expansion has occurred.



Overbank terrestrial pathway (Qld)

Terrestrial passage considerations

- Most Australian native terrestrial fauna require a ‘dry’ pathway along waterways.
- A dry path can be formed by locating abutments away from the top of bank.
- Textured abutments can be designed to encourage the movement of smaller terrestrial wildlife (lizard runs).

Arch bridge crossing (NSW)

Arched structures (terrestrial)

- On arched structures it is important to ensure ‘dry’ terrestrial pathways are formed on both sides the low-flow channel, and that these pathways provide appropriate continuity with the adjacent overbank areas.

Fish-friendly scour control measures


Photo supplied by Catchments & Creeks Pty Ltd

Gravel-based waterway (Qld)

Replacement of natural bed material

- After the construction of a bridge, the natural bed material should be returned to the channel bed wherever possible.
- The replacement of the natural substrate is important for:
  - fish passage
  - maintaining the natural boundary layer flow conditions along the bed
  - maintaining the natural migration of bed material down the waterway during floods (alluvial waterways only).


Photo supplied by Catchments & Creeks Pty Ltd

Natural bank vegetation (NSW)

Stiff grasses

- Wherever possible, the bank vegetation should mimic the natural bank vegetation, which usually requires integrating vegetation into any scour control measures.
- Reinstating edge plants along the bank and the water's edge is critical for fish passage and general fish habitat.
- Stiff grasses, such as Lomandra, can be very important along the lower bank and water's edge.


Photo supplied by Catchments & Creeks Pty Ltd

Vegetated rock stabilisation (NSW)

Vegetated rock stabilisation

- Vegetated rock surfaces are always more stable than non-vegetated rock.
- Wherever practical, rock stabilisation measures should be actively vegetated to ensure appropriate plants are established rather than weed species.
- The voids between the rocks should be filled with soil and pocket-planted at the time of rock placement.


Photo supplied by Catchments & Creeks Pty Ltd

Vegetated rock mattresses (NSW)

Vegetated rock mattresses and gabions

- Non-vegetated gabion and rock mattress surfaces are 'hydraulically' smooth, and consequently produce boundary layers that are too thin for larger fish.
- To aid fish passage, these surfaces should be suitably vegetated to ensure appropriate plants and surface roughness conditions are established.
- When placed near waterways, all wire basket products **must** be vegetated due to the limited working life of the wire baskets.

Potentially non fish-friendly scour protection measures


Photo supplied by Catchments & Creeks Pty Ltd

Non-vegetated rock stabilisation

Non-vegetated rock stabilisation

- In some circumstances, plain, non-vegetated, rock-lined surfaces can also represent a barrier to fish passage.
- Such surfaces may not be able to produce desirable boundary layer conditions, or desirable shading of the water's edge.
- In permanent streams, open voids below the water line can provide useful fish habitat; however, above the water line it is preferable for vegetation to be established within the rock voids.


Photo supplied by Catchments & Creeks Pty Ltd

Non-vegetated rock mattresses (NSW)

Non-vegetated rock mattresses

- When placed in an aquatic environment, the wire baskets used to form gabions and rock mattresses can be damaged by the natural movement of bed sediments (sand) and woody debris.
- The wire baskets only have a limited life span prior to rusting, even if the wire is galvanised and plastic-coated.
- Appropriate vegetation cover is **essential** for the long-term durability of gabion structures in aquatic environments.


Photo supplied by Catchments & Creeks Pty Ltd

Concrete abutments (Qld)

Concrete and grouted stone pitching

- Concrete, shotcrete, and grouted stone pitching are commonly used as a surface material on bridge abutments.
- These 'hydraulically' smooth surfaces do not provide the necessary boundary layer conditions required for fish passage.
- Grouted stone pitching is also not very durable and the inevitable cracking of the grout will ultimately result in the failure of the scour protection (see below).


Photo supplied by Catchments & Creeks Pty Ltd

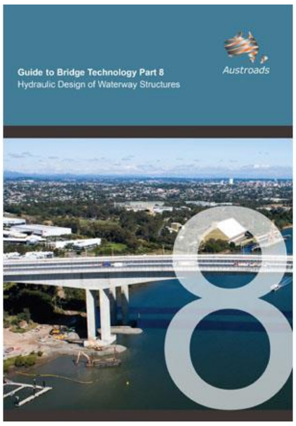
Grouted stone pitched abutment (Qld)


Photo supplied by Catchments & Creeks Pty Ltd

Same bridge post flood (2011)

3. Overview of the 2018 Austroads Guidelines

Introduction



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Guide to Bridge Technology Part 8

Hydraulic Design of Waterway Structures

Austroads Ltd., Sydney, 2018

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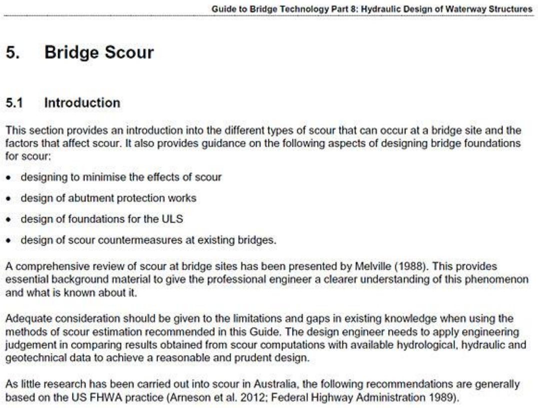


Guide to Bridge Technology Part 8: Hydraulic Design of Waterway Structures

5. Bridge Scour

5.1 Introduction

This section provides an introduction into the different types of scour that can occur at a bridge site and the factors that affect scour. It also provides guidance on the following aspects of designing bridge foundations for scour:

- designing to minimise the effects of scour
- design of abutment protection works
- design of foundations for the ULS
- design of scour countermeasures at existing bridges.

A comprehensive review of scour at bridge sites has been presented by Melville (1988). This provides essential background material to give the professional engineer a clearer understanding of this phenomenon and what is known about it.

Adequate consideration should be given to the limitations and gaps in existing knowledge when using the methods of scour estimation recommended in this Guide. The design engineer needs to apply engineering judgement in comparing results obtained from scour computations with available hydrological, hydraulic and geotechnical data to achieve a reasonable and prudent design.

As little research has been carried out into scour in Australia, the following recommendations are generally based on the US FHWA practice (Arneson et al. 2012; Federal Highway Administration 1989).

Chapter 5 – Bridge Scour

Chapter 5

- Discussion on waterway scour around bridge structures is presented in Part 8, Chapter 5.
- For a comprehensive review of bridge scour, readers are directed to the publication of Melville (1988)—this and other publications are also referenced within Queensland Main Roads guidelines (section 4 of this field guide).

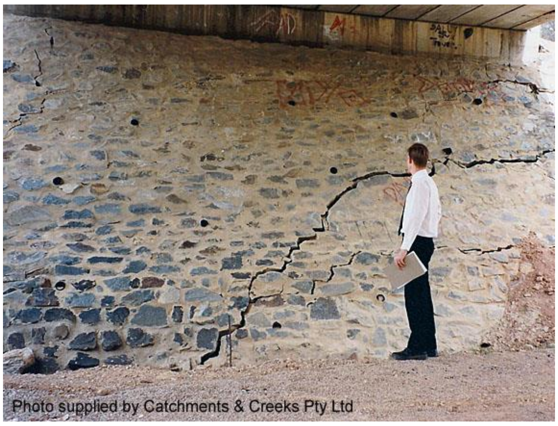


Photo supplied by Catchments & Creeks Pty Ltd

Abutment damage (Qld)

Rate of scour

- The rate of scour around a bridge typically varies with the type of waterway.
- In sand and gravel-based waterways, maximum scour can be achieved in a matter of hours.
- In clay-based (cohesive soil and cemented soils), similar maximum scour depths can be achieved, but this maximum scour depth may require flood flows to occur over a few days.


Photo supplied by Catchments & Creeks Pty Ltd

Flood debris (Qld)

Factors affecting bridge scour (S5.2.3)

- Slope and alignment of the waterway
- Type of bed material and the degree of sediment transport
- Type of vegetation cover
- Long-term changes in the waterway
- The degree of flow constriction through the bridge
- Alignment of the bridge and training walls
- Debris collection on the bridge
- Shape and size of bridge piers

Types of bridge scour (sections 5.2.2 to 5.2.8)

Meandering waterway, Queensland

Scour due to river morphology

- Bed and bank erosion is a natural process within most waterways.
- In addition to in-channel erosion, waterways can slowly migrate across the floodplain.
- Old meander patterns can often be seen in aerial photography.

Wawirra Creek, South Australia

Clear-water scour (section 5.2.4)

- Clear-water scour occurs when there is generally no movement of bed material along the waterway except at the bridge.
- The contraction of the flow at the bridge, and the vortices created by piers, cause the bed material to move.
- Clear-water scour typically reaches its maximum scour depth over a longer period of time than live-bed scour.
- Note; the term ‘clear-water scour’ does not mean the floodwater is ‘clear’.

Burnett River, Gayndah, Qld

Live-bed scour

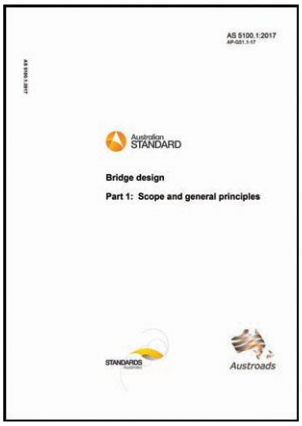
- Live-bed contraction scour occurs when there is general movement (migration) of bed material along the waterway as well as at the bridge.
- In live-bed scour, the movement of bed material upstream of the bridge can be vary from that observed downstream of the bridge causing either the aggradation or degradation of bed material at the bridge.
- Live-bed scour can be cyclic in nature.

Local scour near a bridge pier (Qld)

Local scour (section 5.2.8)

- Local scour is the result of changes in flow velocity and turbulence as water passes around specific components of a bridge, such as bridge piers, footings and abutments.

Design conditions (section 5.3.1)


AS 5100.1:2017
AP-G51.1-17

Australian STANDARD

Bridge design

Part 1: Scope and general principles

Austroads

Australian Standard, AS 5100.1

Australian Standard AS 5100.1

- AS 5100.1 requires that account be taken of the corresponding scour at the relevant floods.
- The design of bridge piers should not rely on the adopted scour protection for its structural stability.
- Bridge abutments shall be adequately protected to prevent scour that could affect the stability of the bridge for floods up to the SLS (serviceability limit state, 10–100 year ARI) flood.


Photo supplied by Catchments & Creeks Pty Ltd

Overtopping flood event, Brisbane, 2011

Worst case flood event

- The hydraulic analysis should identify the highest velocity condition and the 'worst case' flood.
- The worst case flow condition may not occur at the highest probable flood level; however, it should be noted that the highest probably flood is likely to include the worst case flow condition at some stage during the rise and/or fall of the flood.
- Bridge foundations checked for the 2000 year ARI flood event.


Photo supplied by Catchments & Creeks Pty Ltd

Flood debris, Brisbane, 2013

Impact of flood debris.

- Flood debris can place impact loads on the bridge, as well as alter flow conditions under the bridge.
- If debris collection on the bridge deck and hand/guard rails is likely to become a major problem, then designers should consider utilising the approach roads as bypass weirs, thus protecting the bridge.

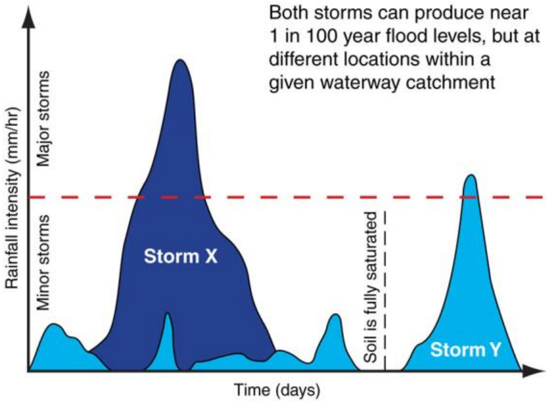

Photo supplied by Catchments & Creeks Pty Ltd

Floodwater passing over approach road

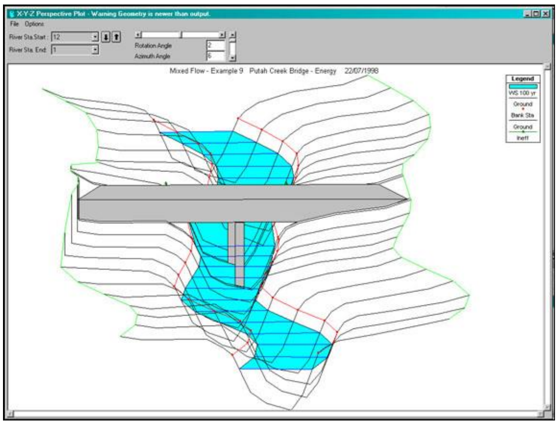
Allowable flow velocity

- Austroads recommends (section 5.3.1) that flow velocities through (over) bridge approaches should be kept below 2.5 m/s or lower (i.e. flows overtopping an approach road).
- The maximum allowable velocity for flows passing under the bridge will depend on the type of waterway.

Scour control design procedure for new bridges (section 5.3.2)



Storm hydrographs


X-Y-Z Perspective Plot - Warning Geometry is newer than output.

River Sta Start : 12

River Sta. End: 1

Rotation Angle 2

Azimuth Angle 6

Mixed Flow - Example 9 Putah Creek Bridge - Energy 22/07/1998

1D HecRas numerical model


Photo supplied by Catchments & Creeks Pty Ltd

Bridge construction (NSW)


Photo supplied by Catchments & Creeks Pty Ltd

Scour control measures (Qld)

Design procedure (new bridges)

1. Determine the relevant flood event(s).
   - If there is an overtopping event that causes greater hydraulic stresses to the bridge than the hydraulic design event, then that flood should be used for computing scour and designing the foundations.
2. Develop hydraulic parameters necessary to estimate scour for the flood flows in Step 1 by applying a 1D or 2D hydraulic model.
   - The full range of hydraulic conditions that could impact the bridge need to be assessed.
3. Estimate total scour for the hydraulic conditions identified from Steps 1 and 2.
   - The resulting scour prediction should be considered in the design of the bridge foundations.
4. Plot the total scour depths obtained in Step 3 on a cross-section of the stream channel and floodplain at the bridge site.
5. Evaluate the results obtained in Steps 3 and 4 to determine if they are reasonable.
   - This should be based on the judgment of a multi-disciplinary team comprised of hydraulic, geotechnical, and structural engineers.
   - There are many factors that could affect the magnitude of the overall scour estimate, including but not limited to: storm duration, erodibility of channel materials, flow conditions or debris.
6. Evaluate the proposed bridge size, configuration, and foundation elements on the basis of the scour analysis performed in Steps 3 through 5.
   - Modify the design as necessary taking into account various measures to minimise scour such as increasing bridge length, adjusting the location of the bridge, changing the configurations of substructure elements and providing guide banks.
7. Perform the bridge foundation analysis on the basis that all streambed material in the scour prism above the total scour line (Step 4) has been removed and is not available for bearing or lateral support.

Design procedure for abutment protection (section 5.3.4)


Photo supplied by Brisbane City Council

Flood damage to approach roads (Qld)

Design flood

- The recommended design approach is to:
  - design the abutment protection to accommodate the waterway design flood (10 yr to 100 yr ARI depending on bridge type) without damage, and
  - assume the abutment is fully scoured under the ultimate limit states flood event (ULS) when assessing the structural integrity of the abutments (typically the 2000 year ARI event).


Photo supplied by Brisbane City Council

Sand-based waterway, Brisbane, Qld

Design Approach 1

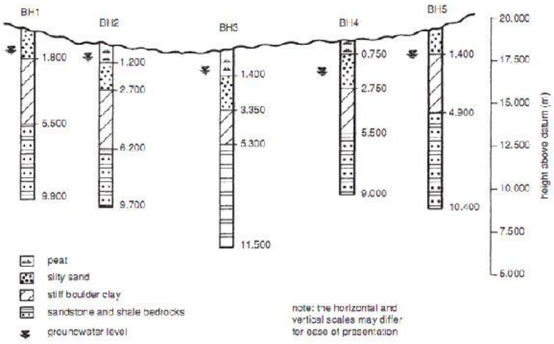
- Utilise scour protection measures, such as rock and/or guide banks, to keep scour from developing at the base of the abutments.
- This approach is typically cost effective, but relies on the availability of suitable rock.
- **Warning:** rock, no matter what size, can be unstable and unreliable when placed on a deep sand substrate (i.e. sand-based waterways that have a sand depth greater than the rock size).


Photo supplied by Catchments & Creeks Pty Ltd

Flood damage to bridge abutment (Qld)

Design Approach 2

- Design the abutments on the basis that they behave as freestanding piers.
- This approach is based on the idea that a failed embankment can be more easily repaired than a failed abutment.
- The approach roads may 'fail', but the bridge remains structurally sound.

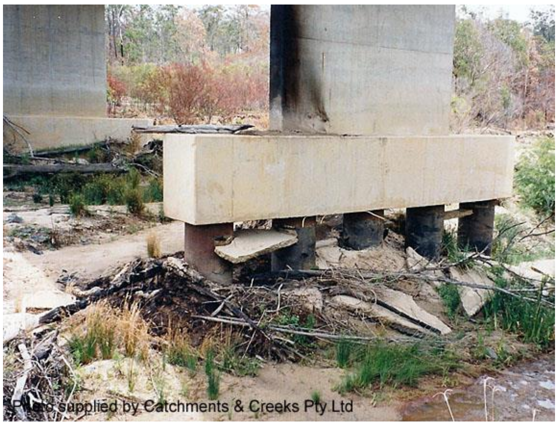


Bore hole data at a bridge site

Design Approach 3

- The third approach is based around the development of scour depth prediction for the site.
- Typically these scour depth predictions are based on empirical methods.
- In some cases the scour depth can be limited by:
  - the existence of sound bed rock, or
  - the existence of geological indicators within the soil horizon that identifies previous maximum scour depths.

Bridge foundation design (sections 5.3.5 to 5.3.7)



Exposed pier foundations (Qld)

Depth of footings

- Bridge foundations located within the floodplain should be placed at the same elevation as those in the waterway channel.
- This allows for any possible migration of the stream channel.
- Abutment foundations should be placed below the elevation of the thalweg (channel invert) below the bridge opening.

Bridge footing (SA)

Spread footing on soil

- The top of the footing should be placed below the design scour line.
- If there is any risk of waterway scour undermining spread footings, then deep foundations in the form of piles should be used.
- The top of a pile cap should be placed at a depth equal to the contraction scour depth—this will minimise obstruction to flood flows and resulting local scour.

Bridge piles (Qld)

Spread footing on sound bedrock

- The bottom of the footing should be placed directly on the cleaned rock surface.
- Avoid blasting, which may damage the rock structure.
- If lateral restraint is required, it should be provided with steel dowels drilled and grouted into the rock.

Vegetation cleared from under a bridge

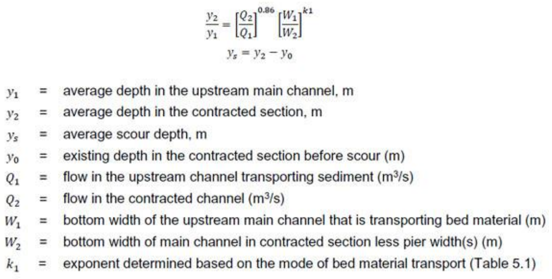
Construction induced waterway scour

- The removal of vegetation under and around the bridge can alter flow patterns, which may affect the depth and extent of scour.
- An existing bridge may have been stable for many years because of the well-established channel vegetation, which can all be disturbed when a replacement bridge is constructed, even if the new bridge has a larger flow area.

Estimating waterway scour around bridges (section 5.4)

Live-bed contraction scour

- The modified version of Laursen's 1960 equation (Arneson et al. 2012) for live-bed scour at a long contraction can be used to estimate the depth of scour in a contracted section.



$$\frac{y_2}{y_1} = \left[\frac{Q_2}{Q_1}\right]^{0.86}\left[\frac{W_1}{W_2}\right]^{k1}$$

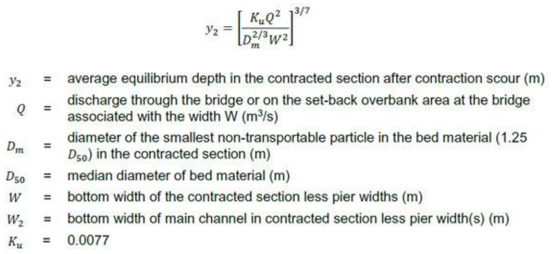
$$y_s = y_2 - y_0$$

y_1 = average depth in the upstream main channel, m
y_2 = average depth in the contracted section, m
y_s = average scour depth, m
y_0 = existing depth in the contracted section before scour (m)
Q_1 = flow in the upstream channel transporting sediment (m³/s)
Q_2 = flow in the contracted channel (m³/s)
W_1 = bottom width of the upstream main channel that is transporting bed material (m)
W_2 = bottom width of main channel in contracted section less pier width(s) (m)
k_1 = exponent determined based on the mode of bed material transport (Table 5.1)

Laursen's equation (1960)

Clear-water contraction scour

- The recommended clear-water contraction scour equation is based on a development suggested by Laursen (Arneson et al. 2012).
- Equation 35 is a rearranged version of Laursen's equation (equation 33).
- Mean rock size (d_{50}) equal to 0.2 mm is a reasonable lower limit that can be applied to this equation—a smaller value will likely over-estimate clear-water contraction scour.



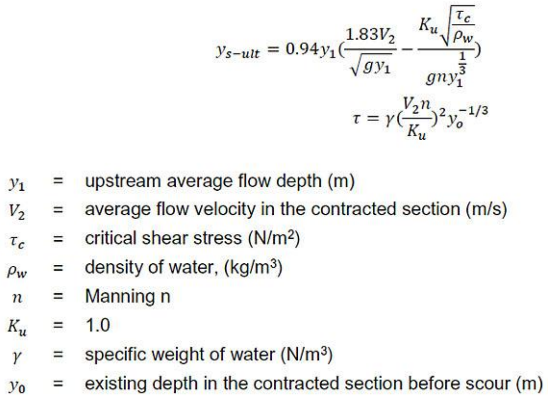
$$y_2 = \left[\frac{K_u Q^2}{D_m^{2/3} W^2}\right]^{3/7}$$

y_2 = average equilibrium depth in the contracted section after contraction scour (m)
Q = discharge through the bridge or on the set-back overbank area at the bridge associated with the width W (m³/s)
D_m = diameter of the smallest non-transportable particle in the bed material (1.25 D_{50}) in the contracted section (m)
D_{50} = median diameter of bed material (m)
W = bottom width of the contracted section less pier widths (m)
W_2 = bottom width of main channel in contracted section less pier width(s) (m)
K_u = 0.0077

Austroads' equation 35

Contraction scour in cohesive materials

- Briaud et al. (2011) outlines an equation to compute ultimate scour for cohesive materials, based on laboratory data (equation 36).
- This computes the centreline scour downstream of the bridge entrance (scour in the vicinity of the entrance is 35% greater) and assumes that upstream flow depth is equal to the flow depth at the constriction (equation 37).



$$y_{s-ult} = 0.94 y_1 \left(\frac{1.83 V_2}{\sqrt{g y_1}} - \frac{K_u \sqrt{\frac{\tau_c}{\rho_w}}}{g n y_1^{\frac{1}{3}}}\right)$$

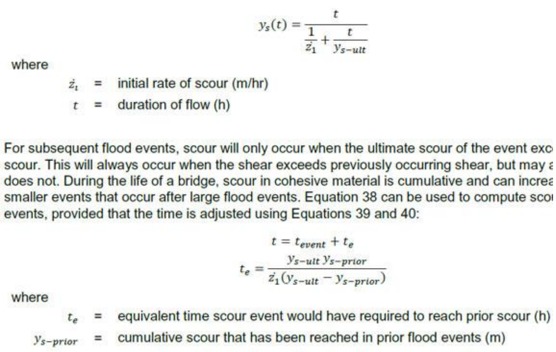
$$\tau = \gamma \left(\frac{V_2 n}{K_u}\right)^2 y_o^{-1/3}$$

y_1 = upstream average flow depth (m)
V_2 = average flow velocity in the contracted section (m/s)
τ_c = critical shear stress (N/m²)
ρ_w = density of water, (kg/m³)
n = Manning n
K_u = 1.0
γ = specific weight of water (N/m³)
y_0 = existing depth in the contracted section before scour (m)

Austroads' equations 36 & 37

Time rate of scour

- The time rate of scour is an important consideration in cohesive soils.
- The actual scour that occurs during the first flood event during the life of the bridge depends on the initial scour rate, ultimate scour for the flow and its duration.
- For subsequent flood events, scour will only occur when the ultimate scour of the event exceeds previous scour.
- Scour in cohesive material is cumulative and can increase even during smaller events that occur after large flood events.



$$y_s(t) = \frac{t}{\frac{1}{\dot{z}_1} + \frac{t}{y_{s-ult}}}$$

where

$\dot{z}_i$ = initial rate of scour (m/hr)
t = duration of flow (h)

For subsequent flood events, scour will only occur when the ultimate scour of the event exc scour. This will always occur when the shear exceeds previously occurring shear, but may a does not. During the life of a bridge, scour in cohesive material is cumulative and can increa smaller events that occur after large flood events. Equation 38 can be used to compute sco events, provided that the time is adjusted using Equations 39 and 40:

$$t = t_{event} + t_e$$

$$t_e = \frac{y_{s-ult}\, y_{s-prior}}{\dot{z}_1 (y_{s-ult} - y_{s-prior})}$$

where

t_e = equivalent time scour event would have required to reach prior scour (h)
$y_{s-prior}$ = cumulative scour that has been reached in prior flood events (m)

Austroads' equations 38 to 40

Scour at abutments and piers (sections 5.4.9 to 5.4.11)

Scour at abutments (section 5.4.9)

- Methods of estimating abutment scour include:
    - Froehlich's live-bed scour equation
    - HIRE equation in FHWA's HDS 6 (Arneson et al. (2012)
    - NCHRP Project 24-20 (Ettema, Nakato, & Muste 2010).
- Froehlich's live-bed scour equation is detailed in Arneson et al. (2012).

$$\frac{y_s}{y_a} = 2.27\, K_1\, K_2\, (\frac{L'}{y_a})^{0.43}\, Fr^{0.61} + 1$$

K_1 = coefficient for abutment shape

K_2 = coefficient for angle of embankment to flow: $(\theta/90)^{0.13}$
θ < 90 ° if embankment points downstream
θ > 90 ° if embankment points downstream

L' = length of active flow obstructed by the embankment (m)
A_e = flow area of the approach cross-section obstructed by the embankment (m^2)
Fr = Froude Number of approach flow upstream of the abutment = $V_e/(gy_a)^{1/2}$
V_e = velocity at approach cross-section obstructed by the embankment Q_e/A_e (m/s)
Q_e = flow obstructed by the abutment and approach embankment (m^3/s)
Y_a = average depth of flow on the floodplain (A_e/L) (m)
L = length of embankment projected normal to the flow (m)
y_s = scour depth (m)

Froehlich's equation

Local scour at piers (section 5.4.10)

- The HEC-18 pier scour equations (based on the Colorado State University (CSU) equation) are recommended for both live-bed and clear-water pier scour (equation 42 and equation 43).

$$\frac{y_s}{y_a} = 2.0\, K_1\, K_2\, K_3\, (\frac{a}{y_1})^{0.65}\, Fr_1^{0.43}$$

$$\frac{y_s}{a} = 2.0\, K_1\, K_2\, K_3\, (\frac{y_1}{a})^{0.35}\, Fr_1^{0.43}$$

as a rule of thumb, the maximum scour depth for round nose piers flow is:
$y_s \leq 2.4$ times the pier width (a) for $Fr \leq 0.8$
$y_s \leq 3.0$ times the pier width (a) for $Fr > 0.8$

y_s = scour depth (m)
y_1 = flow depth directly upstream of pier
K_1 = correction factor for pier nose shape
K_2 = correction factor for angle of attack of flow
K_3 = correction factor for bed condition
A = pier width (m)
L = length of pier (m)
Fr_1 = Froude Number directly upstream of the pier = $V_1/(gy_1)^{1/2}$
V_1 = mean velocity of flow directly upstream of the pier (m/s)
g = acceleration of gravity, 9.81 (m/s^2)

Austroads' equations 42 & 43

Footings and pile caps (section 5.4.10)

- Where the footing or pile cap extends above the stream bed, a second computation should be made using the width of the footing (or pile cap) for the value of a and the depth and average velocity in the flow zone obstructed by the footing for the y_1 and V_1 respectively in the scour equation.
- The average velocity of flow at the exposed footing (V_f) should be determined using equation 44 (Jones 1989).

$$\frac{V_f}{V_1} = \frac{\ln(10.93\, \frac{y_f}{k_s} + 1)}{\ln(10.93\, \frac{y_1}{k_s} + 1)}$$

V_f = average velocity in the flow zone below the top of the footing (m/s)
V_1 = mean velocity of approach flow upstream of the pier (m/s)
y_f = distance from the bed to the top of the footing
k_s = the grain roughness of the bed = D_{84} (m) of the bed material
y_1 = depth of flow upstream of the pier (m)

Jones' equation, 1989

Pressure flow scour (section 5.4.11)

- The pressure scour depth y_s is determined by using the horizontal contraction scour equations to calculate the height, $y_s + h_c$, required to convey flow through the bridge opening at the critical velocity.
- This height is equivalent to y_2 (the average depth in the contracted section) in the clear-water contraction scour (equation 35) and the live-bed contraction scour (equation 33).
- Combining this relation with the definitions of t and h_b (equation 45):

$$y_s = y_2 + t - h_b$$

$$\frac{t}{h_b} = 0.5\left(\frac{h_b h_t}{h_u^2}\right)^{0.2}\left(1 - \frac{h_w}{h_t}\right)^{-0.1}$$

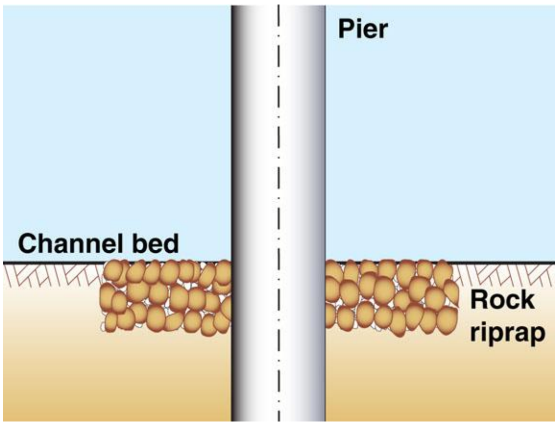
h_b = vertical size of the bridge opening prior to scour (m)
h_u = upstream channel flow depth (m)
h_t = distance from the water surface to the lower face of the bridge girders, equals $h_u - h_b$ (m)
h_w = weir flow height, $h_w = h_t - T$ for $h_t > T$, $h_w = 0$ for $h_t \leq T$

Austroads' equations 45 & 46

Scour control measures (section 5.5)

Bridge pier construction (NSW)

Bridge pier construction (NSW)



Rock placement around a bridge pier

$$d_{50} = \frac{0.692(V_{des})^2}{(S_g - 1)2g}$$

d_{50} = particle size for which 50% is finer by weight, (m)
V_{des} = design velocity for local conditions at the pier, (m/s)
S_g = specific gravity of riprap (usually taken as 2.65)
g = acceleration due to gravity, (9.81 m/s2)

Modified Isbash equation (eqn. 47)

Rock protection of bridge piers

- Rock riprap is not considered a permanent countermeasure for scour at piers on existing bridges, and should not be used to protect piers at new bridges.
- The size of rock required to protect a bridge pier is determined from the velocity (V*) obtained by multiplying the velocity of flow approaching the pier (V) by a coefficient (K_p) for pier shape.
- K_p can be taken as 1.5 for a round-nose pier, and 1.7 for a rectangular pier.

Determination of flow velocity (V)

- The velocity of flow (V) approaching the pier is estimated by taking the average velocity under the bridge multiplied by:
  - 0.9 for a pier near the bank in a straight uniform reach of the stream
  - 1.7 for a pier in the main current of flow around a bend.
- For piers located on the floodplain the velocity on the floodplain should be used.

$$V^* = V \cdot K_p$$

Rock protection details

- The class and thickness of rock is determined from Austroads Table 5.11 for the velocity given by $V \times K_p$.
- The rock riprap should extend horizontally at least twice the pier width, measured from the pier face.
- The top of the riprap mat should be placed at the same elevation as the stream bed.
- Filter cloth or a gravel filter may or may not be required under the rock.

Rock sizing

- The required size of stone for riprap at bridge piers is determined by the rearranged Isbash equation (equation 47), as recommended by Lagasse et al. (2009).

$$V_{des} = V^* = V.K_p$$

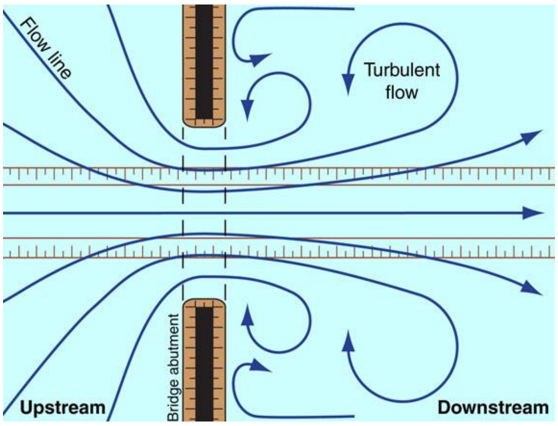
- This equation is effectively the same as the rock sizing equation presented in section 5 of this field guide; however, it does not provide a correction for the use of 'rounded' rock, or for variations in flow turbulence.

Austroads’ standard rock classes (tables 5.11 & 5.12)

Velocity	Class	Grading	Size	Weight
(m/s)			(m)	(kg)
< 2	Special*	Depends on soil (bed/bank) condition*		
2.0–2.6	Facing	d_{10}	0.15	2.5
		d_{50}	0.30	35
		d_{100}	0.40	100
2.6–2.9	Light	d_{10}	0.20	10
		d_{50}	0.40	100
		d_{100}	0.55	250
2.9–3.9	1/4 tonne	d_{10}	0.30	35
		d_{50}	0.55	250
		d_{100}	0.75	500
3.9–4.5	1/2 tonne	d_{10}	0.40	100
		d_{50}	0.70	450
		d_{100}	0.90	1000
4.5–5.1	1 tonne	d_{10}	0.55	250
		d_{50}	0.90	1000
		d_{100}	1.15	2000
5.1–5.7	2 tonne	d_{10}	0.75	500
		d_{50}	1.15	2000
		d_{100}	1.45	4000
5.7–6.4	4 tonne	d_{10}	0.90	1000
		d_{50}	1.45	4000
		d_{100}	1.80	8000
> 6.4	Special	Site specific design (rock may not be appropriate)*		

* Text not included in the Austroads guidelines.

Rock protection of bridge abutments (section 5.5.4)



Flow contraction at a bridge

Design velocity

- The class of rock protection required to protect an abutment (without a guide bank) is determined as the average velocity (V) under the bridge multiplied by a factor of 1.33, to allow for the turbulently mixing flow action at bridge abutments.

  $$V^* = 1.33 \times V$$

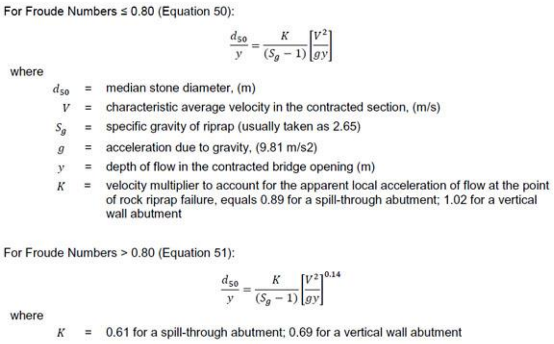
- This is similar to the coefficient 'K' used in equation 1 presented in section 5 of this field guide.


Photo supplied by Catchments & Creeks Pty Ltd

Rock riprap with open voids

Grading of rock

- The grading of rock riprap affects its resistance to erosion.
- The rock should be reasonably well graded throughout the riprap layer thickness.
- 'Well-graded' means a good range of rock sizes.
- The breadth or thickness of a single stone should be not less than one-third its length as an approximate guide for good stone shape.


For Froude Numbers ≤ 0.80 (Equation 50):

$$\frac{d_{50}}{y} = \frac{K}{(S_g - 1)}\left[\frac{V^2}{gy}\right]$$

where

d_{50} = median stone diameter, (m)
V = characteristic average velocity in the contracted section, (m/s)
S_g = specific gravity of riprap (usually taken as 2.65)
g = acceleration due to gravity, (9.81 m/s2)
y = depth of flow in the contracted bridge opening (m)
K = velocity multiplier to account for the apparent local acceleration of flow at the point of rock riprap failure, equals 0.89 for a spill-through abutment; 1.02 for a vertical wall abutment

For Froude Numbers > 0.80 (Equation 51):

$$\frac{d_{50}}{y} = \frac{K}{(S_g - 1)}\left[\frac{V^2}{gy}\right]^{0.14}$$

where

K = 0.61 for a spill-through abutment; 0.69 for a vertical wall abutment

Austroads' equations 50 and 51

Rock sizing at abutments

- It is recommended that equations 50 & 51 are used to determine the size of rock riprap for protecting abutments from scour for spill-through and vertical wall abutments (Lagasse et al. 2009).


Photo supplied by Catchments & Creeks Pty Ltd

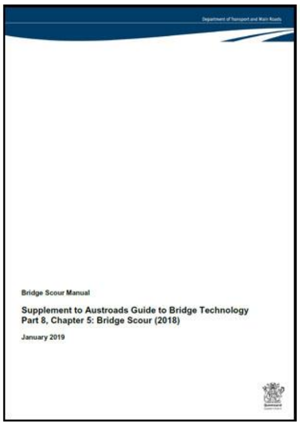
Gabion-protected bridge abutment

Rock gabions and mattresses

- Galvanised or polyvinyl chloride coated wire is used to resist corrosion, and either welded or twisted into a lattice.
- Angular rock is preferred to fill the containers due to the higher degree of natural interlocking of the stone fill.
- It should be noted that gabions and mattresses have durability concerns due to the durability of the steel wire mesh.
- The maximum life for gabion is 50 years as claimed by the manufacturers.

4. Overview of the 2019 Queensland Main Roads Guidelines

Introduction



Department of Transport and Main Roads

Bridge Scour Manual

Supplement to Austroads Guide to Bridge Technology
Part 8, Chapter 5: Bridge Scour (2018)

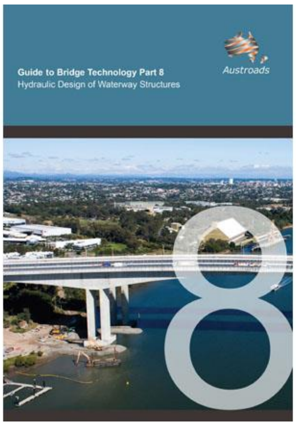
January 2019

Qld Transport and Main Roads, 2019

Bridge Scour Manual – Supplement to Austroads Guide to Bridge Technology, Part 8, Chapter 5: Bridge Scour (2018)

The State of Queensland (Department of Transport and Main Roads), January 2019, Brisbane Queensland.

- This edition of the Bridge Scour Manual is cross-reference to the *Guide to Bridge Technology Part 8: Hydraulic Design of Waterway Structures, Chapter 5: Bridge Scour*.

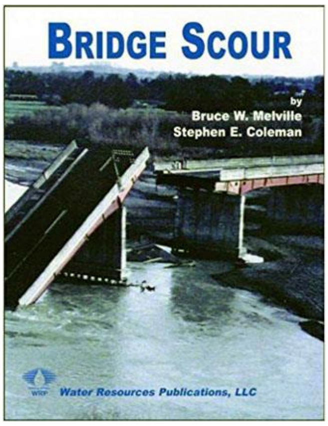


Guide to Bridge Technology Part 8
Hydraulic Design of Waterway Structures

Austroads, 2018

Addressing differences with Austroads

- Where a section of the Austroads Guide is accepted with amendments, the amendments can take one of two forms:
  - **Addition(s):** where the Bridge Scour Manual provides additional guidance specific to departmental policies and practices.
  - **Difference(s):** where this Manual provides guidance specific to departmental policies and practices, to be used instead of Austroads.



BRIDGE SCOUR

by
Bruce W. Melville
Stephen E. Coleman

Water Resources Publications, LLC

Melville and Coleman, 2000

Additional references

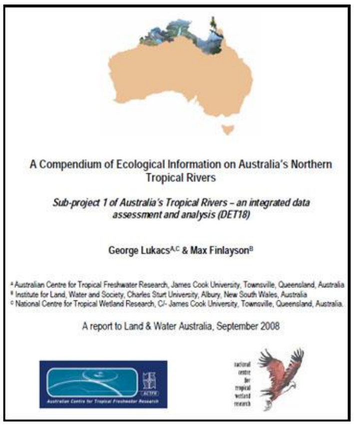
- Melville, B. W. and Coleman, S. E. (2000), Bridge Scour, Water Resources Publications, LLC, Colorado, U.S.A.
- Kirby, A.M., Roca M., Kitchen A., Escarameia, M.and Chesterton, O.J. (2015), Manual on Scour at bridges and Other Hydraulic Structures, 2nd Edition, CIRIA, London, U.K.

Flood damage to bridge abutment

Total scour depth

- Total scour depth at a bridge is the sum of:
  - natural / general scour
  - contraction scour
  - local scour at piers and abutments.
- All factors contributing to scour are subject to a significant degree of uncertainty.

Types of scour (section 5.2.6)



A Compendium of Ecological Information on Australia's Northern Tropical Rivers

Sub-project 1 of Australia's Tropical Rivers – an integrated data assessment and analysis (DET18)

George Lukacs[A,C] & Max Finlayson[B]

[A] Australian Centre for Tropical Freshwater Research, James Cook University, Townsville, Queensland, Australia
[B] Institute for Land, Water and Society, Charles Sturt University, Albury, New South Wales, Australia
[C] National Centre for Tropical Wetland Research, C/- James Cook University, Townsville, Queensland, Australia.

A report to Land & Water Australia, September 2008

Lukacs and Finlayson (2008)

Reference

River typologies in Northern Australia are documented in Saynor et al. (2008).

- Saynor, M.J., Erskine, W., and Lowry, J. (2008), Report: Geomorphology. In Lukacs G.P. and Finlayson C.M. (eds). *A compendium of Ecological Information on Northern tropical rivers. Sub-project 1 of Australia's Tropical Rivers – An integrated data assessment in Analysis (DET18).* A report to Land and Water, Australia. National Centre for Tropical Wetland Research, Townsville.

Photo supplied by Catchments & Creeks Pty Ltd

Braided waterway, Queensland

Braded channels

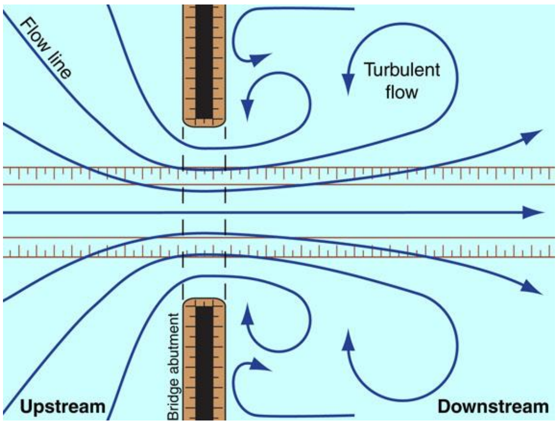
- Braided channels are unstable and unpredictably prone to aggradation, degradation or lateral movement.
- Deepest scour in these channels can occur at the confluence of two or more major channels, downstream of a bar or island in the channel.

Photo supplied by Catchments & Creeks Pty Ltd

Meandering waterway, Queensland

Channel migration

- It can occur naturally or be caused by anthropogenic activity and is associated with aggradation / degradation processes.
- Migration of the stream or lowering of the deep-water channel (thalweg) changes local bed elevation and flow direction and can increase the risk of scour at bridge piers and abutments.

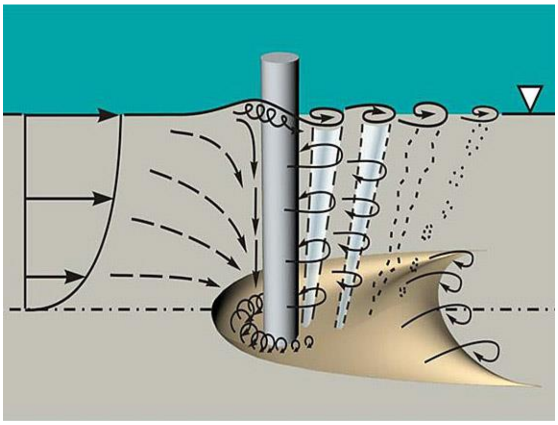


Flow contraction at a bridge

Contraction scour

- Note that contraction scour does not account for localised scour at the foundations or long-term changes in the stream bed elevation.

Local scour (section 5.2.8)



Pier scour flow patterns

Scour at bridge piers

- The flow field and maximum scour depths around bridge piers are dependent on three main variables:
    - effective pier width (including pier geometry and position in relation to flow)
    - flow depth, and
    - erodibility of the bed material.
- Flow fields around piers vary depending on the effective width of the pier in relation to the water depth.

Floodwater passing around a tree

Scour patterns around floodplain trees

The following text is **not** contained within the Queensland Bridge Scour Manual.

- Scour patterns around bridge piers closely mimics the scour patters found when floodwaters pass around an isolated tree located in a floodway.

Photo supplied by Catchments & Creeks Pty Ltd

Scour pattern similar to a 'narrow' pier

Flow conditions around piers

- Three categories of pier flow field, which produce significantly different pier scour morphologies are identified:
    - narrow piers ($y/a > 1.4$) for which scour typically is deepest at the pier face
    - transitional piers ($0.2 < y/a < 1.4$)
    - wide piers ($y/a < 0.2$) for which scour typically is deepest at the pier flank.
- Where 'a' is the pier width, and 'y' is the flow depth.

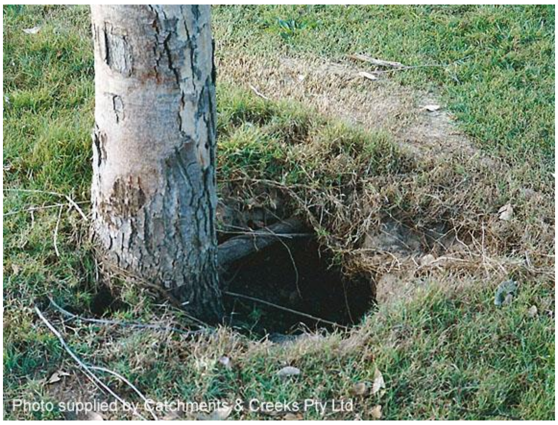


Photo supplied by Catchments & Creeks Pty Ltd

Scour pattern similar to a 'wide' pier

Bed scour at the base of 'wide' piers

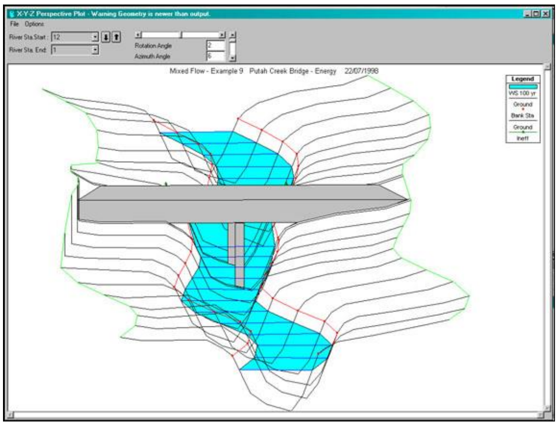
- For a given flow depth, greater pier width increases flow blockage and therefore causes more of the approach flow to be swept laterally along the pier face than around the pier's flanks.
- Increased blockage modifies the lateral distribution of approach flow over a longer distance upstream of a pier.

Bridge scour design and evaluation (section 5.3)

Cooper Creek, Innamincka, SA

Serviceability Limit States (SLS) and Ultimate Limit States (ULS)

- SLS = 1% AEP
- ULS = 0.05% AEP or overtopping event if less than 0.05% AEP, whichever is critical in terms of flood forces.
- If the overtopping event is greater than SLS or 1% AEP, but smaller than the 0.05% AEP event, a risk assessment to determine if the scour protection should be designed to withstand the overtopping event (instead of the SLS) must be conducted.



River Sta Start: 12
River Sta End: 1
Rotation Angle 2
Azimuth Angle 6

1D HecRas numerical model

Numerical modelling (new bridges)

- Two-dimensional (2D) models should be used on all but the simplest bridge crossings as a matter of course.
- While two-dimensional models cannot replicate pressurised flow conditions, but they better replicate flow contraction and expansion patterns occurring at bridges.

Photo supplied by Catchments & Creeks Pty Ltd

Bridge pier (Qld)

Pier design (new bridges)

- Design of bridge piers shall not rely on pier scour protection.
- They shall be designed considering estimated maximum scour depths at piers to ensure the structural integrity of the bridge under the action of scour.
- Scour protection should <u>not</u> be installed around new bridge piers

Photo supplied by Catchments & Creeks Pty Ltd

Bridge abutment (Qld)

Abutment design (new bridges)

- Abutments and road approaches shall be adequately protected to prevent scour for floods up to the SLS event.
- However, any scour protection designed for SLS conditions, shall not be relied upon at the ULS event (as per Clause 11.1, AS 5100.1:2017).
- Excluding spread footings founded on solid rock, minimum scour depth for ULS design shall be 2 m measured from the bottom of the headstock.

Abutment design (new bridges)


Photo supplied by Brisbane City Council

Brookbent Road, Oxley Ck, 1996

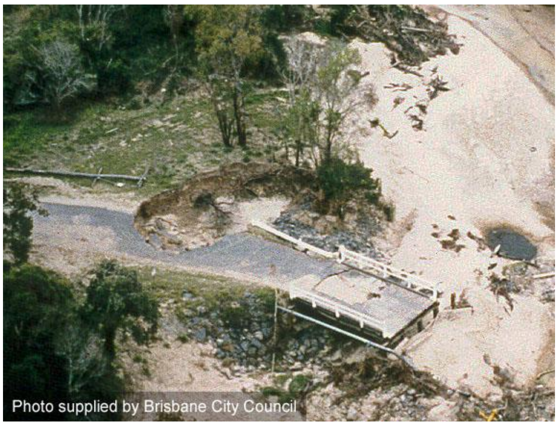


Photo supplied by Brisbane City Council

Flood damage to approach road


Photo supplied by Catchments & Creeks Pty Ltd

Timber bridge post May 1996 flood


Photo supplied by Catchments & Creeks Pty Ltd

Original bridge prior to 1996 flood

Abutment design

- The bridge shall be designed for worst ultimate flood forces up to 0.05% AEP event without relying on abutment protection.
- If the bridge is closed to traffic under ULS conditions, the accompanying traffic loads on the bridge can be excluded (as per Clause 23.3, AS 5100.2:2017).
- In addition to the scour analysis conducted by the hydraulic engineer, a geotechnical engineer shall be consulted when determining the maximum design scour depths at the bottom of the abutment headstock to use for bridge design.
- The work in both disciplines shall be conducted under the direction of an experienced RPEQ engineer in each field.
- The limiting depth of abutment scour when the geotechnical stability of the bridge embankment is reached, shall also be considered when calculating abutment scour depths (see Figure 5.4.9(b).
- The geotechnical engineer designing the abutments should be consulted regarding this limit.
- Scour protection at piers and abutments shall be designed based on the maximum average cross sectional velocity for floods up to the ULS event, and shall consider situations such as:
  - overtopping bridge and bridge embankment
  - effects of local catchments and along road drainage, and
  - scour analysis based on actual particle size of bed material and bed shear stress (in sand, scours to more than 5 m are common).
- In some situations, maximum localised velocities at abutments and piers might provide more accurate information on velocities required for design.
- Engineering judgement shall always be exercised to endorse large velocities potentially created by two-dimensional model instabilities.
- On site observations and evidence of previous scour often help to validate calculated velocities.
- Potential scour at approach embankments should also be considered when designing overtopping bridges.

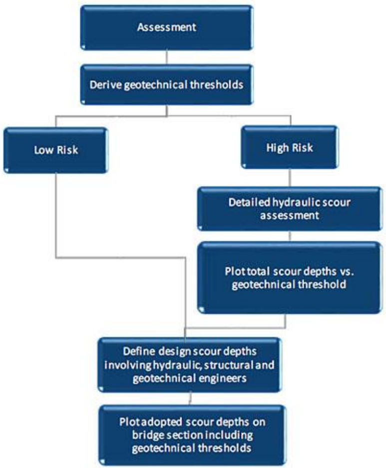
Methods of estimating scour (section 5.4)

Photo supplied by Catchments & Creeks Pty Ltd

Flood damage (Qld)

Initial scour risk assessment

- Identify evidence of previous scour (utilise aerial photography).
- Identify other parameters that might influence the scour:
  - is the bridge near a bend or confluence
  - are there steep stream slope
  - are flow velocities expected to be high.
- Seek input from a river geomorphologist.



Assessment methodology

- Low risk bridge: a bridge located outside the floodplain or a bridge founded on erosion resistant material.
- Otherwise; conduct a detailed scour assessment, including an assessment of the potential total scour depth.
- Pier and abutment foundations to be drawn on a borehole log profile, and included as part of the bridge drawings supplied for review and approval.

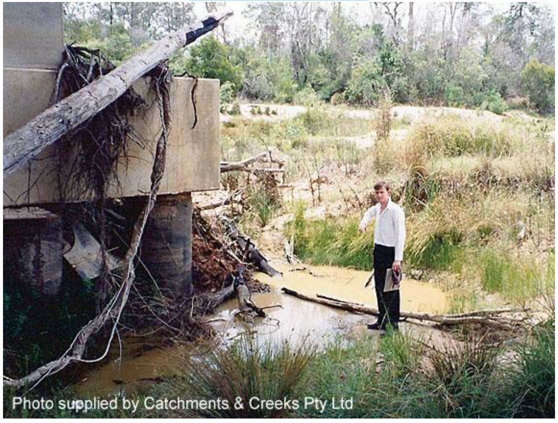


Photo supplied by Catchments & Creeks Pty Ltd

Degraded waterway channel (Qld)

Natural channel degradation

Kirby et al. (2015) recommend four methods to estimate degradation in channels:

1. Collection of historical and field data.
2. Regime equations to determine channel dimensions based on bankfull flow.
3. Threshold methods that determine channel threshold conditions in terms of velocity, shear stress or stream power.
4. 1D or 2D morphological models to predict long term changes in channel geometry.

$$Y_{ms} = 0.47\left(\frac{Q}{f}\right)^{1/3}$$

Where:

Q is the bankfull discharge (m^3/s)

f is the Lacey silt factor, denoted as $f = 1.76 d_m^{0.5}$

d_m is the mean diameter of the bed material in millimetres

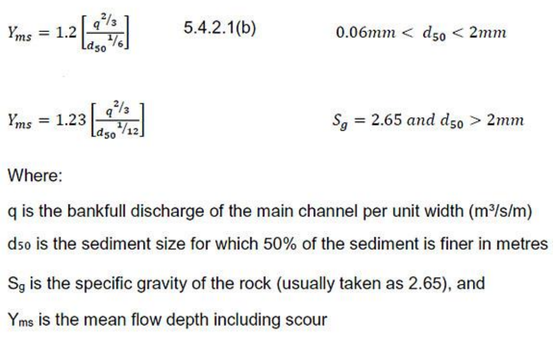
Y_{ms} is the mean flow depth at regime in metres (measured from the water surface to the channel bed)

DTMR equation 5.4.2.1(a)

Regime equations: Lacey (1930)

- Regime equations predict the mean flow depth; that being measured from the water surface to the channel bed.
- Where the variation of water surface level with flow rate is known, degradation levels at a bridge site in an uncontracted alluvial river can be calculated with the regime formula of Lacey (1930).
- This method was derived for uncontracted sandy alluvial channels; and might give excessive scour depths for more resistant materials.

Regime equations and natural channel scour (sections 5.4.2 & 5.4.3)



$Y_{ms} = 1.2\left[\frac{q^{2/3}}{d_{50}{}^{1/6}}\right]$ 5.4.2.1(b) $0.06mm < d_{50} < 2mm$

$Y_{ms} = 1.23\left[\frac{q^{2/3}}{d_{50}{}^{1/12}}\right]$ $S_g = 2.65 \; and \; d_{50} > 2mm$

Where:

q is the bankfull discharge of the main channel per unit width ($m^3/s/m$)

d_{50} is the sediment size for which 50% of the sediment is finer in metres

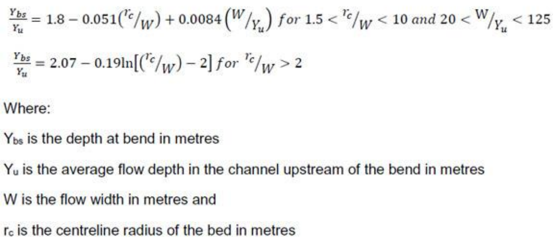
S_g is the specific gravity of the rock (usually taken as 2.65), and

Y_{ms} is the mean flow depth including scour

DTMR equations 5.4.2.1(b) & (c)

Regime equations : Blench (1969)

- Blench (1969) provides another regime formula to determine scour depths for sand streams.
- This method was derived for hydraulically smooth channels of steady discharge, very small steady sediment transport rate and suspended load.
- Equation 5.4.2.1(b) applies to most sand bed irrigation canal systems.
- Equation 5.4.2.1(c) was derived for large gravel rivers.



$\frac{Y_{bs}}{Y_u} = 1.8 - 0.051\left({}^{r_c}/_{W}\right) + 0.0084\left({}^{W}/_{Y_u}\right) \; for \; 1.5 < {}^{r_c}/_{W} < 10 \; and \; 20 < {}^{W}/_{Y_u} < 125$

$\frac{Y_{bs}}{Y_u} = 2.07 - 0.19\ln\left[\left({}^{r_c}/_{W}\right) - 2\right] \; for \; {}^{r_c}/_{W} > 2$

Where:

Y_{bs} is the depth at bend in metres

Y_u is the average flow depth in the channel upstream of the bend in metres

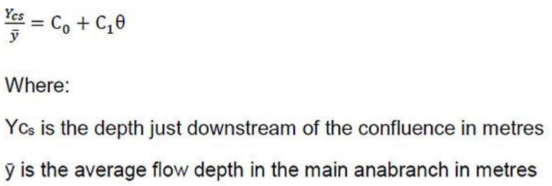
W is the flow width in metres and

r_c is the centreline radius of the bed in metres

DTMR equations 5.4.2.2(a) & (b)

Bend scour

- Flow depth on the outside of a bend is usually greater than the average depth in a straight channel.
- Melville and Coleman (2000) recommends the equations provided by Maynord (1996) and Thorne (1988).
- These equations were obtained for in-bank flows.
- Maynord provides recommended safety factors, and the adoption of r_c/W=1.5 for r_c/W < 1.5, and W/Y_u = 20 for W/Y_u < 20.



$\frac{Y_{cs}}{\bar{y}} = C_0 + C_1\theta$

Where:

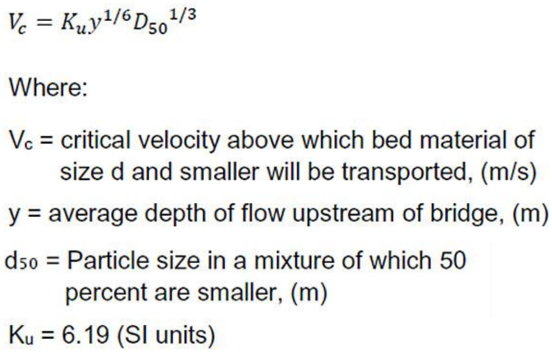
Y_{cs} is the depth just downstream of the confluence in metres

$\bar{y}$ is the average flow depth in the main anabranch in metres

DTMR equation 5.4.2.3

Confluence scour

- When two rivers meet at a confluence a deep scour hole and a depositional point bar can form.
- Ashmore and Parker (1983) and Klaasen and Vermeer (1988) provide an equation to calculate confluence scour.
- C_0 is 1.29 and C_1 is 0.037 for rivers with fine sands, 2.24 and 0.031 for rivers with coarse sands and gravels and 1.01 and 0.03 in cohesive material and θ is the angle between anabranches in degrees



$V_c = K_u y^{1/6} D_{50}{}^{1/3}$

Where:

V_c = critical velocity above which bed material of size d and smaller will be transported, (m/s)

y = average depth of flow upstream of bridge, (m)

d_{50} = Particle size in a mixture of which 50 percent are smaller, (m)

K_u = 6.19 (SI units)

DTMR equation 5.4.3(a)

Live-bed contraction scour (section 5.4.3)

- If the critical velocity of the bed material is larger than the mean velocity ($V_c > V$), then clear-water contraction scour will exist.
- If the critical velocity is less than the mean velocity ($V_c < V$), then live-bed contraction scour will exist.
- Equation 5.4.3(a) can be used to calculate the critical velocity.

Scour at abutments (section 5.4.9)


Photo supplied by Catchments & Creeks Pty Ltd

Abutments close to channel banks (Qld)

$$Y_{max} = \alpha_A \cdot Y_C \quad (live - bed) \quad or \quad Y_{max} = \alpha_B \cdot Y_C \quad (clear - water)$$

$$Y_s = Y_{max} - Y_0$$

Where:

Y_{max} = Maximum flow depth resulting from abutment scour, (m)

Y_c = Flow depths including live-bed or clear-water contraction scour, (m)

α_A = Amplification factor for live-bed conditions

α_B = Amplification factor for clear-water conditions

Y_s = Abutment scour depth, (m)

Y_0 = Flow depth prior to scour, (m)

DTMR equations 5.4.9(a) & (b)

$$Y_c = Y_1 \left(\frac{q_{2c}}{q_1}\right)^{6/7}$$

Y_c = Flow depth including live-bed contraction scour, (m)

Y_1 = Upstream flow depth, (m)

q_1 = Upstream unit discharge, (m^2/s)

q_{2c} = Unit discharge in the constricted opening accounting for non-uniform flow distribution, (m^2/s)

DTMR equation 5.4.9(c)

$$Y_c = Y_1 \left(\frac{q_{2f}}{K_u D_{50}^{1/3}}\right)^{6/7}$$

Where:

Y_c = Flow depth including clear-water contraction scour, (m)

q_{2f} = Unit discharge in the constricted opening accounting for non-uniform flow distribution, (m^2/s)

K_u = 6.19 (SI)

d_{50} = Particle size with 50% finer, (m)

DTMR equation 5.4.9(d)

NCHRP approach

- NCHRP (2010) developed abutment scour equations.
- Flow conditions include:
  - abutment close to channel
  - abutment set back from the channel
  - abutment acting like a pier post flood.
- The abutment scour computed using the NCHRP approach is total scour at the abutment; and should not be added to contraction scour because it already includes contraction scour.

Advantages of the NCHRP approach

- The advantages of using the NCHRP abutment scour equations include:
  - not using the effective embankment length (L) which is difficult to determine in many situations
  - the equations are more physically representative of the abutment scour process, and
  - the equations predict total scour at the abutment rather than the abutment scour component that is then added to contraction scour.

Constricted floodplains

- If the projected length of the embankment, L, is 75 percent or greater than the width of the floodplain (B_f) the contraction scour calculation is performed using a live-bed scour calculation.
- The contraction scour equation is a simplified version of the live-bed contraction scour equation (equation 33, in Austroads 2018).
- The value of Y_c is then used in equation 5.4.9(a) to compute the total flow depth at the abutment.

Less constricted floodplains

- If the projected length of the embankment, L, is less than 75 percent of the width of the floodplain (B_f), the contraction scour calculation is performed using the clear-water scour equation (equation 35, in Austroads, 2017).
- The standard clear-water contraction scour equation also uses the unit discharge (q), which can be estimated either by dividing the discharge by width or by the product of velocity and depth.

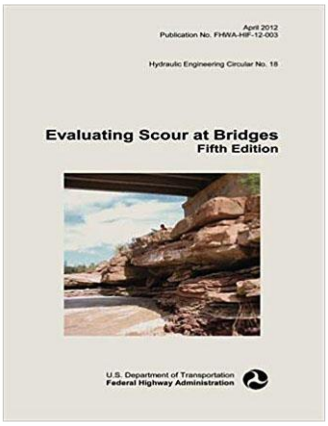
Local scour at piers (section 5.4.10)

$$Y_s = K_{yB} K_I K_d K_s K_\theta K_G K_t$$

DTMR equation 5.4.10.1

Melville and Coleman (2000)

- Y_s denotes the local scour depth
- The K’s are empirical factors:
  - size ratio for piers (K_{yB}) or
  - abutments (K_{yL})
  - flow intensity (K_I)
  - sediment size (K_d)
  - pier or abutment shape (K_s)
  - pier or abutment alignment (K_θ)
  - channel geometry (K_G) and
  - time (K_t)



April 2012
Publication No. FHWA-HIF-12-003

Hydraulic Engineering Circular No. 18

Evaluating Scour at Bridges
Fifth Edition

U.S. Department of Transportation
Federal Highway Administration

Arneson et al. (2012)

Florida DoT Pier Scour Method (2011)

- The Florida Department of Transport approach is published in their *Bridge Scour Manual* (FDOT, 2011).
- Supporting spreadsheets (available from the FDOT website) were also developed for a wide range of pier scour applications.
- The FDOT methodology is presented in detail in section 7.3 of Arneson et al. (2012).

$$K_w = 2.58 \left(\frac{y}{a}\right)^{0.34} Fr_1^{\;0.65} \qquad for \frac{V}{Vc} < 1$$

$$K_w = 1.0 \left(\frac{y}{a}\right)^{0.13} Fr_1^{\;0.25} \qquad for \frac{V}{Vc} \geq 1$$

DTMR equations 5.4.10.2(a)&(b)

Scour at wide piers (section 5.4.10.2)

- Transportation Research Board (1994) suggests the following equations for a K_w factor to be used to correct equations 42 or 43 for wide piers in shallow flow where:
  - the ratio of depth of flow to pier width (y/a) is less than 0.8 ($y/a < 0.8$)
  - the ratio of pier width (a) to the median diameter of the bed material (d_{50}) is greater than 50 ($a/d_{50} > 50$)
  - the flow is subcritical (Froude No. < 1)
  - K_w is the correction factor to equations 42 or 43 for wide piers in shallow flow.

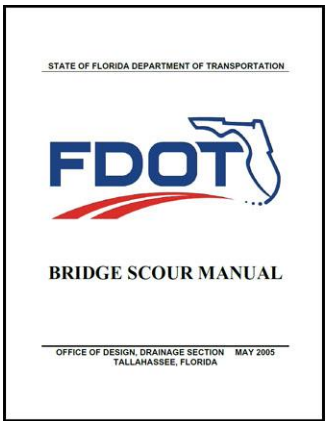
Photo supplied by Catchments & Creeks Pty Ltd

Murray Bridge, Murray River, SA

Complex pier foundations (section 5.4.10.3)

- The total scour depth for complex pier configurations is determined by:
  - separating the pier components exposed to flow
  - determining the scour depth for each component and adding the results.
- This method is called *‘Superposition of the Scour Components’*.
- Section 7.5 of Arneson et al. (2012) for further details on this methodology.
- Also Jones and Sheppard (2000).

Complex pier foundations and piers in cohesive bed waterways



STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION

FDOT

BRIDGE SCOUR MANUAL

OFFICE OF DESIGN, DRAINAGE SECTION MAY 2005
TALLAHASSEE, FLORIDA

Florida DOT (2011)

Complex pier foundations (section 5.4.10.3)

- The FDOT methodology can also be used to calculate scour at complex piers, it has a similar approach of decomposing the pier into three layers, but considers the effective width of the pier instead of considering the cumulative effect of each component.
- Moreno et al. (2016) propose equations for complex piers aligned with the flow
- Yang et al. (2018) propose equations that consider the effect of skewness on clear-water scour.

Pier scour in cohesive material

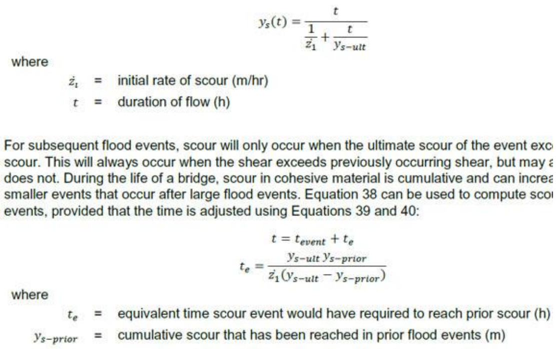
- Briaud et al. (2011) developed equation 5.4.10.3 to calculate pier scour in cohesive materials, which incorporates the critical velocity for initiation of erosion.
- Where Y_s, K_1, K_2, a, and V_1 are defined as in equation 43 of Austroads (2018) and V_c is the critical velocity for the onset of erosion of the cohesive material in m/s.
- This velocity can be determined through material testing or using an erosion rate of 0.1 mm/hr from Figure 5.4.10.3(b) for various types of materials.

$$Y_s = 2.2 K_1 K_2 a^{0.65} \left(\frac{2.6V_1 - V_c}{\sqrt{g}}\right)^{0.7}$$

DTMR equation 5.4.10.3

Pier scour in cohesive material

- In cohesive soils, maximum pier scour may not be reached during a flood or even over the life of the bridge.
- Equations 38 to 40 from Austroads (2018) can be used to calculate incremental scour for a time series of flows expected for the life of the bridge (including extreme design events).
- However, the initial rate of scour and the ultimate scour must be determined for each flow condition in the subject time series of flows.



$$y_s(t) = \frac{t}{\frac{1}{\dot{z}_1} + \frac{t}{y_{s-ult}}}$$

where

$\dot{z}_1$ = initial rate of scour (m/hr)
t = duration of flow (h)

For subsequent flood events, scour will only occur when the ultimate scour of the event exc scour. This will always occur when the shear exceeds previously occurring shear, but may a does not. During the life of a bridge, scour in cohesive material is cumulative and can increa smaller events that occur after large flood events. Equation 38 can be used to compute scor events, provided that the time is adjusted using Equations 39 and 40:

$$t = t_{event} + t_e$$

$$t_e = \frac{y_{s-ult}\, y_{s-prior}}{\dot{z}_1 (y_{s-ult} - y_{s-prior})}$$

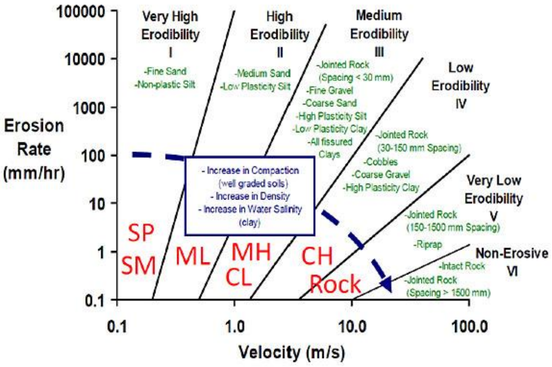
where

t_e = equivalent time scour event would have required to reach prior scour (h)
$y_{s-prior}$ = cumulative scour that has been reached in prior flood events (m)

Austroads' equations 38 to 40

Pier scour in cohesive material

- Ultimate scour is determined using equation 5.4.10.3 while the initial rate of scour can be determined from either material testing, from Figure 5.23 of Austroads, 2018 (from shear stress) or from Figure 5.4.10.3(b) (from velocity).



DTMR Figure 5.4.10.3(b)

Piers in cohesive bed waterways and pressure flow scour

$$\tau_{pier} = \frac{\gamma}{y_1^{0.333}}\left(\frac{nKV_1}{K_u}\right)^2$$

Where:

τ_{pier} = shear stress at the pier, (N/m²)

γ = Unit weight of water, (N/m³)

n = Manning's n of channel bed ($m^{1/3}/s$)

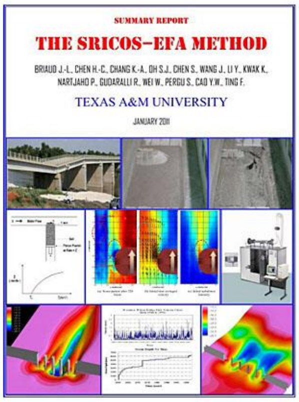
y_1 = Depth of flow at pier (m)

V_1 = Approach flow Velocity

K = Velocity coefficient, 1.5 for circular piers and 1.7 for square piers

K_u = 1.0, (SI)

DTMR equation 5.4.10.4



SUMMARY REPORT

THE SRICOS–EFA METHOD

BRIAUD J.-L., CHEN H.-C., CHANG K.-A., OH S.J., CHEN S., WANG J., LI Y., KWAK K., NARTJAHO P., GUDARALLI R., WEI W., PERGU S., CAO Y.W., TING F.

TEXAS A&M UNIVERSITY

JANUARY 2011

Briaud et al. (2011)

$$Q_{ue} = Q_1\left(\frac{h_{ue}}{h_u}\right)^{8/7}$$

Where:

Q_{ue} = Effective channel discharge

Q_1 = Upstream channel discharge

h_u = Upstream channel flow depth

DTMR equation 5.4.11(a)

$$\frac{Y_s}{Y_1} = min\left[0.105\left(\frac{V_a}{V_c}\right)^{2.95}, 0.5\right]$$

Where:

Y_s is the ultimate scour depth (m)

Y_1 is the non-overtopping upstream depth (up to stagnation stream line) (m)

V_a is the initial (prior to scour velocity through bridge opening (m/s)

V_c is the critical velocity associated with incipient sediment motion (m/s)

DTMR equation 5.4.11(b)

Maximum shear stress at a pier

- Briaud (2011) and HEC-23 (Lagasse et al. 2009) provide equations for estimating maximum shear stress at a pier.

Numerical analysis

- The Hydraulic Toolbox software developed by the American Federal Highway Administration (FHWA, 2017) calculates the ultimate pier scour and the scour depth after a flow event of a given duration in cohesive materials based on equation 5.4.10.3 developed by Briaud et al. (2011) and documented in section 7.12 of Arneson et al. (2012).
- For most bridge pier applications, these two scour depths (ultimate and design flow event) are the only values required.

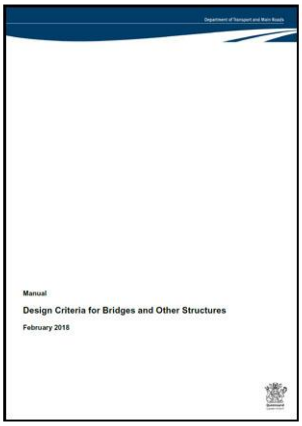
Pressure flow scour (section 5.4.11)

- When flow overtops the bridge or approach roadway, the value of Q_2 (flow in the contracted channel) in the live-bed equation (Austroad equation 33) or Q (discharge through the bridge) in the clear-water equation (eqn 35) should include only the flow through the bridge opening.
- For overtopping flows in live-bed conditions, Q_{ue} is used instead of Q_1 in equation 33 and can be calculated from the total channel discharge at the approach Q_1, from equation 5.4.11(a).

Alternative methods

- Alternative methods to calculate pressure flow scour are presented in Lyn (2008) and Melville (2014).
- Lyn (2008) found that equation 45 exhibits unsatisfactory behaviour, he proposed equation 5.4.11(b) for clear-water conditions in bridges without piers.
- Melville (2014) presents an equation that can be used to calculate maximum likely pressure flow scour depths for design purposes.

Scour countermeasures (section 5.5)


Department of Transport and Main Roads

Manual

Design Criteria for Bridges and Other Structures

February 2018

Qld Transport and Main Roads, 2018

Queensland Main Roads

- Austroads (2018) should be read in conjunction with:
  - MRTS03 *Technical Specification* (TMR 2018)
  - *Design Criteria for Bridges and Other Structures* (TMR 2018)
  - Transport and Main Road's abutment protection Standard Drawings (2232 - 2237, 2238 and 2241).


Photo supplied by Catchments & Creeks Pty Ltd

Bridge construction (Qld)

New bridges

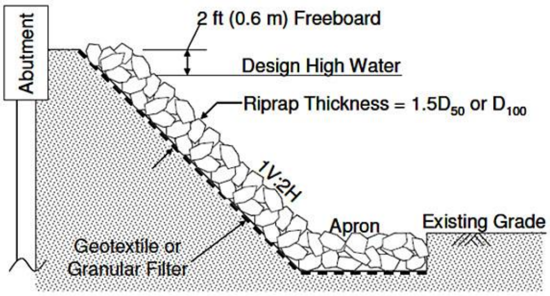
- New bridges shall be designed by taking into account estimated maximum scour depth at piers to ensure the structural integrity of the bridge under the action of scour.
- Bridge piers for new bridges, shall not be relied on a pier scour protection.
- Pier scour protection is not recommended for new bridges.
- Abutments shall be adequately protected to prevent scour for floods up to the SLS event.

HEC-23 (Lagasse et al. 2009)	$\frac{d_{50}}{y} = \frac{0.692(V_{des}^2)\cdot y}{(S_s - 1)2g}$ 5.5.4(b)
Transport and Main Roads 2019**	$\frac{d_{50}}{y} = \frac{0.23K_pK_v}{(S_s - 1)}Fr^2$ 5.5.4(e)

DTMR equations 5.5.4(b)&(e)

Rock riprap at bridge piers

- Based on Queensland experience, either the HEC-23 (preferred method in Austroads 2018) or the Transport and Main Roads (2019) equations are recommended.
- However, it should be noted that the Transport and Main Roads (2019) equation does not represent a mandatory Transport and Main Roads policy.



DTMR Figure 5.5.4(e)(b)

Rock riprap at abutments – Thickness

- The minimum riprap layer thickness (t) recommended for the different rock classes is listed in Table 5.11 (Austroads, 2018).
- This equates to at least two layers of the selected rock class or 1.7 to 2 d_{50}.
- This thickness might be increased by 50% if placed under water to provide for the uncertainties associated with this type of placement.

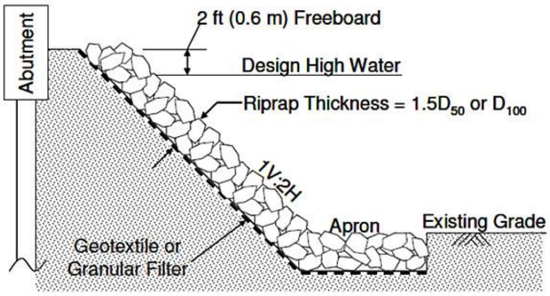
Rock riprap at abutments (section 5.5.4)


Photo supplied by Catchments & Creeks Pty Ltd

Rock riprap

Rock grading

- HEC-23 (Lagasse et al. 2009) presents an alternative gradation to that recommended in (Austroads, 2018).
- This gradation reproduced in Table 5.5.4(b) (in SI units) recommends ten different classes instead of seven.
- This criterion is based on a nominal or target d_{50} and a uniformity ratio d_{85}/d_{15} that results in well-graded riprap.
- The target uniformity ratio d_{85}/d_{15} is 2.0 with an allowable range from 1.5 to 2.5.



DTMR Figure 5.5.4(e)(b)

Elevation of rock protection

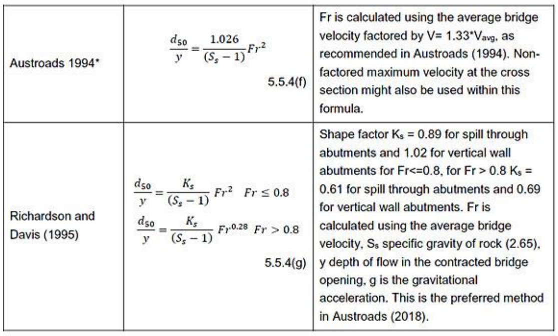
- Spill-through abutment slopes should be protected with the selected rock riprap size to a minimum elevation of 0.6 m above the water elevation expected for ULS conditions.
- If the bridge is overtopped during ULS (Ultimate Limit States) conditions, the entire abutment should be protected.


Photo supplied by Catchments & Creeks Pty Ltd

Flood damage upstream of bridge (Qld)

Extent of rock protection

- The apron should wrap around the abutment to at least the tangent point with the roadway embankment slopes, however additional protection might be required beyond this point for overtopping bridges.
- Lagasse et al. (2009) recommend extending the length of the downstream embankment protection by 2 flow depths or 7.5 m, whichever is larger, to protect the roadway embankment.



Austroads 1994*	$\frac{d_{50}}{y}=\frac{1.026}{(S_s-1)}Fr^2$ 5.5.4(f)	Fr is calculated using the average bridge velocity factored by V= 1.33*V_{avg}, as recommended in Austroads (1994). Non-factored maximum velocity at the cross section might also be used within this formula.
Richardson and Davis (1995)	$\frac{d_{50}}{y}=\frac{K_s}{(S_s-1)}Fr^2 \quad Fr \le 0.8$ $\frac{d_{50}}{y}=\frac{K_s}{(S_s-1)}Fr^{0.28} \quad Fr > 0.8$ 5.5.4(g)	Shape factor K_s = 0.89 for spill through abutments and 1.02 for vertical wall abutments for Fr<=0.8, for Fr > 0.8 K_s = 0.61 for spill through abutments and 0.69 for vertical wall abutments. Fr is calculated using the average bridge velocity, S_s specific gravity of rock (2.65), y depth of flow in the contracted bridge opening, g is the gravitational acceleration. This is the preferred method in Austroads (2018).

DTMR equations 5.5.4(f)&(g)

Sizing rock riprap for abutments

- Based on Queensland experience, either the Austroads (1994) or the Richardson and Davis (1995) methods are recommended.
- When the velocities at the abutment can be accurately identified (i.e. based on two-dimensional model results), the highest value of the maximum velocities observed at the cross section and the factored average cross section velocities might also be used within the below methods.

5. Rock Sizing and Placement on Minor Bridge Crossings

Minor bridge crossing

Single lane timber bridge (NSW)

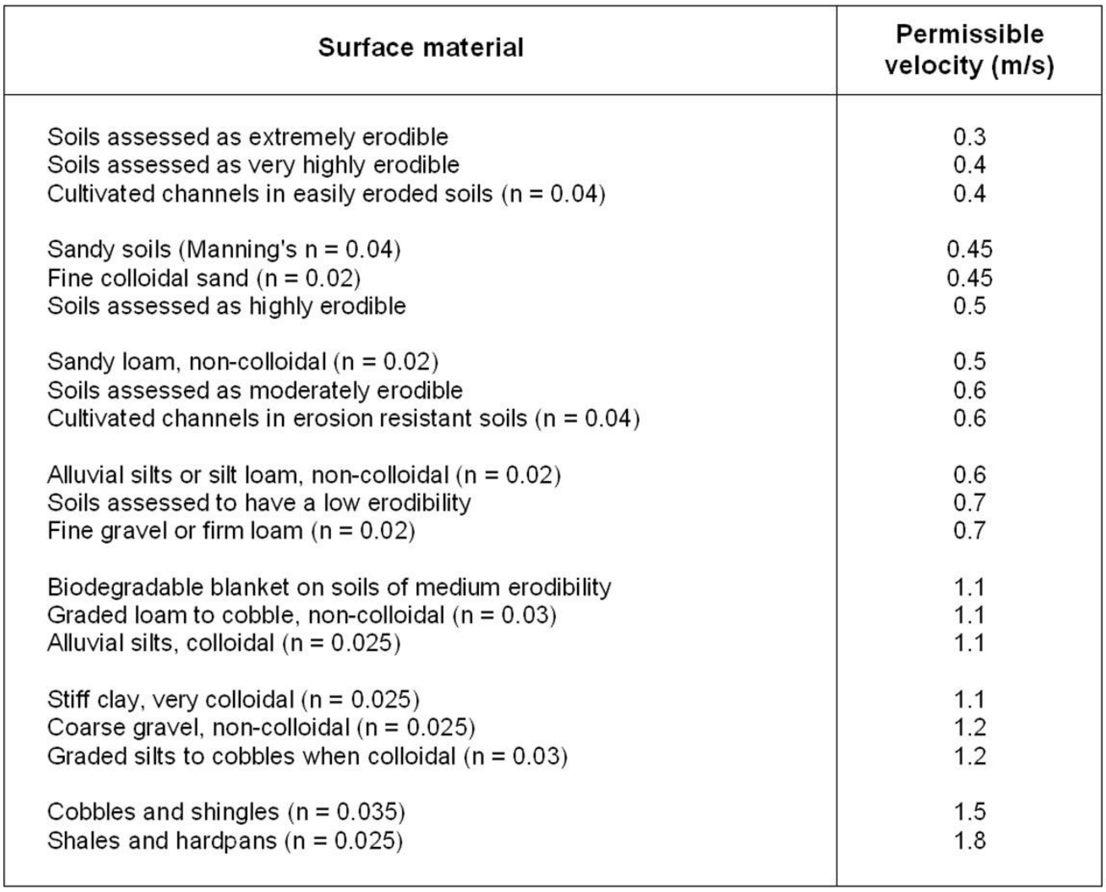
Lomandra (Qld)

Introduction

- Within this document, a minor bridge crossing is defined as a crossing where:
  - flow velocities within the drain or waterway are unlikely to cause erosion
  - the cost of repairing any associated channel erosion is minor and affordable
  - the bridge does not represent critical infrastructure (e.g. a bypass exists).
- **Warning:** a government authority may have an alternative definition of what constitutes a minor bridge crossing.

Permissible velocity limits

- Permissible flow velocities for exposed earth are presented in Table 1.
- The following velocity limits apply to healthy, open canopy, 100% coverage growth.
  - grassed banks = 2.0 m/s
  - thick shrub and tree cover = 2.5 m/s
  - Lomandra (or equivalent) = 3.0 m/s



Surface material	Permissible velocity (m/s)
Soils assessed as extremely erodible	0.3
Soils assessed as very highly erodible	0.4
Cultivated channels in easily eroded soils (n = 0.04)	0.4
Sandy soils (Manning's n = 0.04)	0.45
Fine colloidal sand (n = 0.02)	0.45
Soils assessed as highly erodible	0.5
Sandy loam, non-colloidal (n = 0.02)	0.5
Soils assessed as moderately erodible	0.6
Cultivated channels in erosion resistant soils (n = 0.04)	0.6
Alluvial silts or silt loam, non-colloidal (n = 0.02)	0.6
Soils assessed to have a low erodibility	0.7
Fine gravel or firm loam (n = 0.02)	0.7
Biodegradable blanket on soils of medium erodibility	1.1
Graded loam to cobble, non-colloidal (n = 0.03)	1.1
Alluvial silts, colloidal (n = 0.025)	1.1
Stiff clay, very colloidal (n = 0.025)	1.1
Coarse gravel, non-colloidal (n = 0.025)	1.2
Graded silts to cobbles when colloidal (n = 0.03)	1.2
Cobbles and shingles (n = 0.035)	1.5
Shales and hardpans (n = 0.025)	1.8

Table 1 – Permissible flow velocities for non-vegetated surfaces

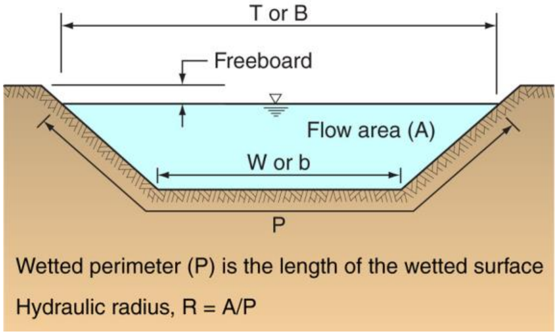
Determination of the water velocity (minor bridges only)


Photo supplied by Catchments & Creeks Pty Ltd

Bankfull flow conditions (Qld)

Introduction

- Velocity estimation procedures can vary from simple Manning's calculations to complex two-dimensional numerical modelling.
- The methodology used to estimate the flow velocity must be commensurate with the erosion risk and the importance of the bridge structure.
- It is noted that maximum channel velocities may not occur at the flood peak, but instead during bankfull conditions.



Channel cross-section

Manning's equation

- A formula used to predict the 'average' flow velocity in an open channel.
- **$V = (1/n).R^{2/3}.S^{1/2}$** (Metric SI units)
  - V = mean velocity of flow [m/s]
  - R = hydraulic radius [m]
  - S = channel slope [m/m]
  - n = Manning's roughness coefficient of the channel/conduit [dimensionless]
- Note; the coefficient '1' is assumed to have the units of [$m^{1/3}/s$], thus allowing Manning's n to remain dimensionless.


Photo supplied by Catchments & Creeks Pty Ltd

High velocity flow (Qld)

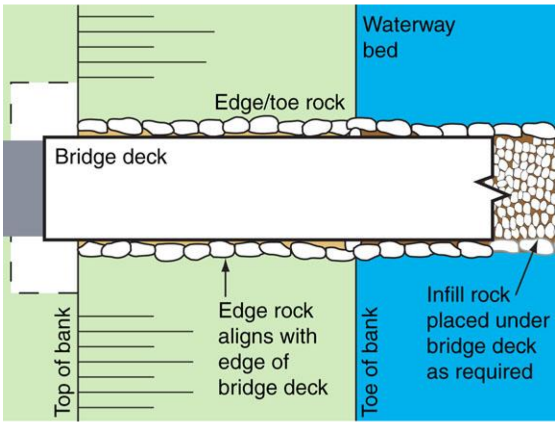

Photo supplied by Catchments & Creeks Pty Ltd

Flow jetting downstream of a culvert

Determination of a design velocity from the estimated average channel velocity

- The nominated design flow velocity at any location along the waterway should be representative of the expected flow velocity immediately adjacent to the surface requiring protection.
- Within the flow **contraction** region immediately upstream of a bridge, assume the flow velocity immediately adjacent a vegetated bank is 0.67 times the average channel velocity.
- Within the same flow contraction region adopt a bed velocity equal to the average channel velocity.
- Within the flow **expansion** region downstream of a bridge, adopt a bed and bank velocity equal to the average channel velocity.
- The adopted flow velocity under a bridge should account for the likely impact of debris blockages.
- For the design of scour protection of bridge abutments, adopt a flow velocity 1.33 times the average flow velocity (this accounts for likely flow turbulence).

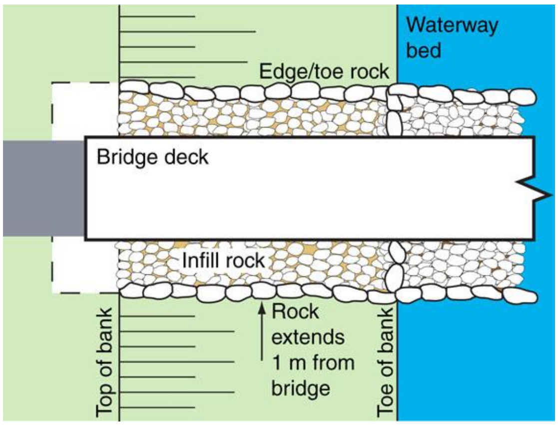
Extent of scour protection upstream and downstream of minor bridges



Low velocity channel

Peak flow velocity < 1 m/s

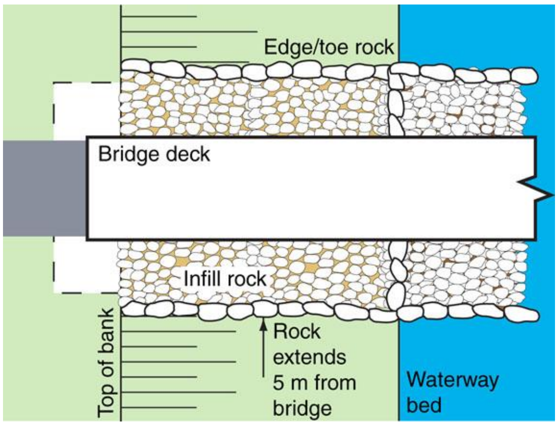
- If the bridge crosses a low velocity drain or waterway where soil scour is only likely to occur at locations where:
  - – the soil is exposed (i.e. not vegetated)
  - – the maximum flow velocity (flood velocity) exceeds the permissible flow velocity for the exposed soil; then . . .
- . . . scour protection is generally limited to those locations where soil is exposed to stream flows, such as under the bridge deck.



Bridge with a debris blockage risk

Low velocity channels at risk of partial debris blockage

- If the bridge crosses a low velocity drain or waterway and debris blockages could cause a local scour risk, then scour protection measures may need to extend beyond the limits of the bridge deck.
- Scour protection should extend (upstream and downstream) at least 1 m from the edge of the bridge deck.



Medium velocity channel

Peak flow velocity of 1 m/s to 2 m/s

- As flow velocities increase, the risk of local scour resulting from turbulence or debris blockages also increases.
- As a default setting, Melbourne Water (as an example) requires rock placement to be extended 5 m upstream and downstream of a bridge.
- Alternatively, numerical modelling can be used to investigate velocity profiles upstream and downstream of the bridge.

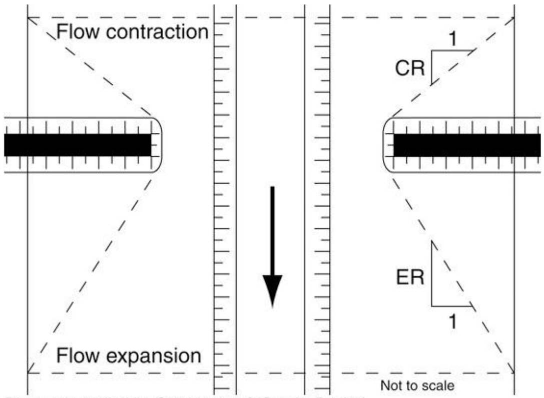


Diagram supplied by Catchments & Creeks Pty Ltd

Minor bridge with embankments

Minor bridges that partially constrict a channel

- Flow expansion and contraction can be predicted through the use of two-dimensional numerical modelling.
- If the importance of the site cannot justify such modelling, then the HecRas *User Manual* provides a means of predicting the expansion and contraction of flows adjacent to bridge structures.
- The suggested flow constriction and expansion limits are presented in the images shown left and over the page.

Extent of rock protection in medium to high velocity channels

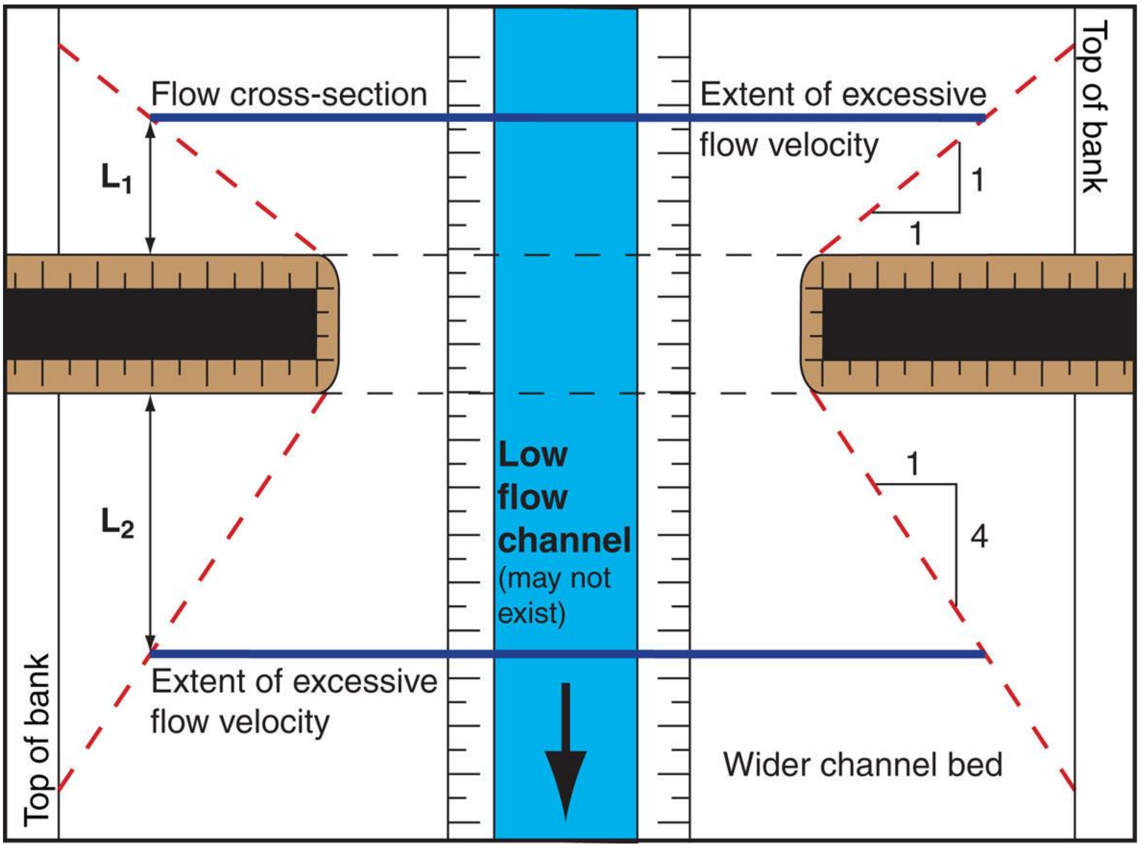


Figure 1 – Determination of velocity upstream and downstream of a bridge constriction

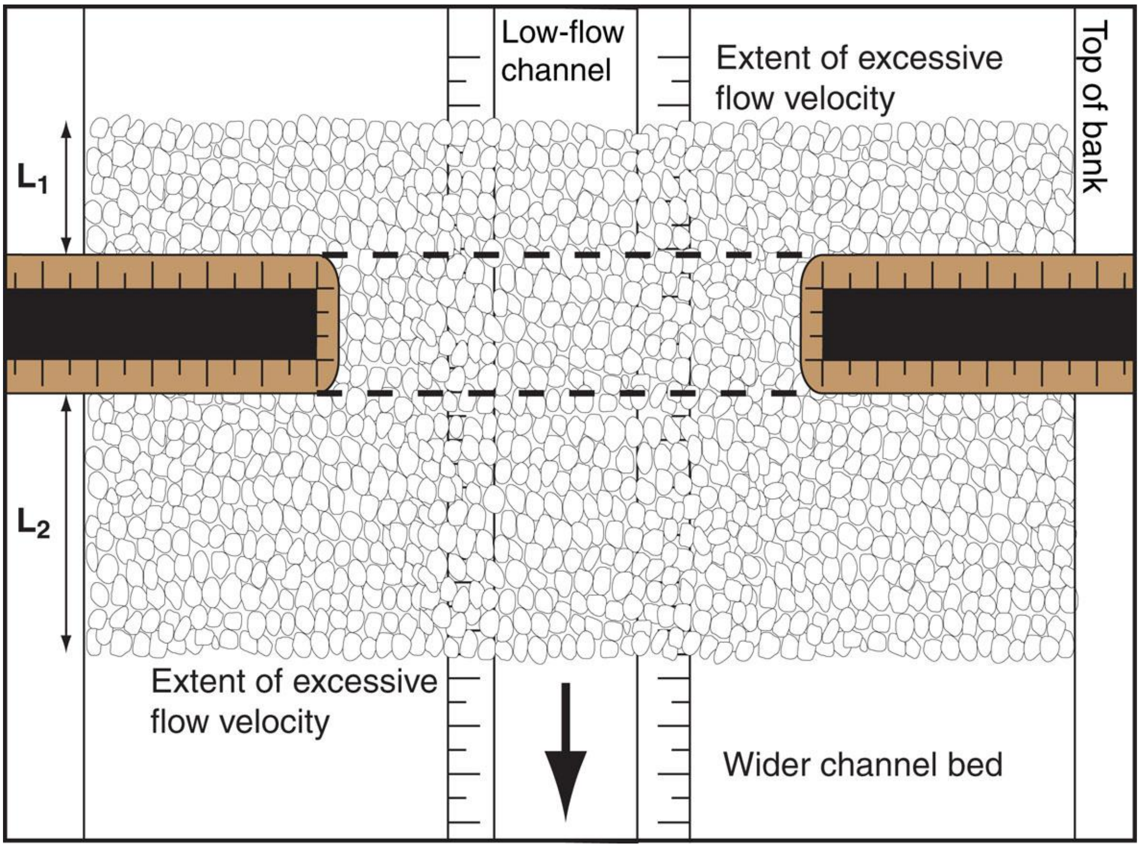


Figure 2 – Extent of rock placement upstream and downstream of a minor bridge

Rock placement under the bridge deck (minor bridges only)

Large toe rock (NSW)

Small toe rock (Qld)

Toe rock

- Toe rock is placed along the toe of the waterway bank, or along the edge of the permanent low-flow channel.
- Individual toe rock should be recessed 2/3 of its diameter into the earth.
- Toe rock provides the following benefits:
  - protects the bank from undercutting in the event of minor bed erosion
  - provides a visible control 'edge' during maintenance weeding or de-silting of the channel bed.

Edge rock

- Edge rock is placed vertically up a waterway bank to 'book-end' the infill rock.
- Edge rock should be recessed into the bank such that the top of the rock is approximately level with the upper surface of the infill rock.
- Edge rock provides the following benefit:
  - a visible control 'edge' that is useful during maintenance weeding of the channel banks.

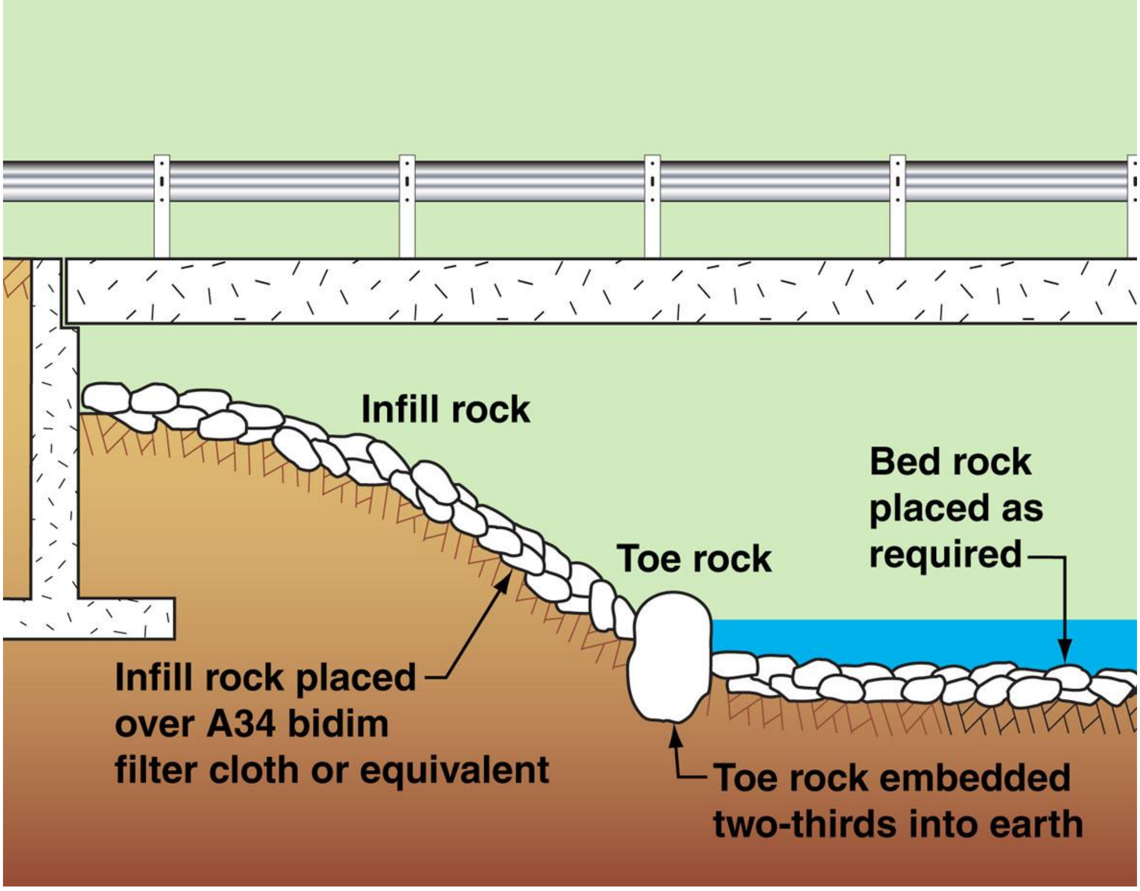


Figure 3 – Typical placement of rock under 'minor' bridge crossings

Sizing rock for placement under minor bridges

Infill rock (Qld)

Toe rock (NSW)

Sizing infill rock for minor bridges

- For a flow velocity less than 1 m/s, the recommended infill rock size is:
  - Minimum 100 mm (this is the d_{10} size, the size of which only 10% is smaller).
  - Mean rock size (d_{50}) of 200 mm
- For a flow velocity greater than 1 m/s:
  - Mean rock size (d_{50}) is based on Table 2 or equation 2 (over page)
- If the flow velocity is greater than 3 m/s, then seek expert advice.

Sizing toe and edge rock for minor bridges

- Unless otherwise specified, the recommended toe/edge rock size is:
  - 450 mm for flow velocity < 1 m/s
  - 600 mm for flow velocity 1 to 2 m/s
  - 750 mm for flow velocity > 2 m/s
  - site specific design for velocity > 3 m/s
- The toe rock should be recessed 2/3 its diameter into the channel bed.

Table 2 – Rock sizing selection table, d_{50} (mm)

Uniform flow conditions			Angular rock (K_1 = 1.0)			Specific gravity, s_r = 2.4		
Uniform velocity (m/s)	**Degree of expected flow turbulence, which is based on bed slope (%) ***							
	1.0	**2.0**	**3.0**	**4.0**	**5.0**	**6.0**	**8.0**	**10.0**
0.5	100	100	100	100	100	100	100	100
0.8	100	100	100	100	100	100	100	100
1.0	100	100	100	100	100	100	100	100
1.3	100	100	100	100	100	100	100	100
1.5	100	100	100	150	150	150	150	150
1.8	100	150	150	150	150	200	200	200
2.0	150	150	200	200	200	300	300	300
2.3	150	200	300	300	300	300	300	300
2.5	200	300	300	300	400	400	400	400
2.8	300	300	400	400	400	400	500	500
3.0	300	400	400	500	500	500	500	600
3.5	400	500	600	600	600	700	700	800
4.0	500	700	700	800	800	900	900	1000
5.0	800	1000	1100	1200				

* Flow turbulence generally increases with increasing bed slope; however, designers may use their experience and knowledge of the site to selected an alternative level of turbulence.

Sizing of rock placement within low-gradient waterways

Equation 1 can be used to size rock placed on the bed of waterway channels. The same equation can be used for rock placed on waterway banks with slopes equal to or less than 1:2 (V:H), but a 25% increase in rock size should be applied for bank slopes of 1:1.5.

A 36% increase in rock size is recommended for rounded rock (i.e. $K_1 = 1.36$).

Application of Equation 1	**Equation 1:**
• Simplified velocity-based equation suitable for uniform and non-uniform flow conditions [1] • Low channel gradients, $S_o < 5\%$	$d_{50} = \frac{K_1 . V^2}{2.g.K^2 (s_r - 1)}$ [1] K = 1.1 for low-turbulent deepwater flow K = 1.0 for low-turbulent shallow water flow K = 0.86 for highly turbulent flow (Table 3)

Note: Equation 1 is a modification of the equation originally presented by Isbash (1936).

The coefficient 'K' takes into account the degree of flow turbulence. Table 3 provides the recommended K-values for various uniform channel gradients (i.e. straight, uniform cross-sectional channels where a constant flow velocity is achieved). In non-uniform flow a K-value of 1.1 should be used for low-turbulent deepwater flow, 1.0 for low-turbulent shallow water flow, and 0.86 for highly turbulent and/or supercritical flow.

Table 3 – Suggested values of 'K' for uniform flow conditions

Bed slope (%)	**1.0**	**2.0**	**3.0**	**4.0**	**5.0**	**6.0**	**8.0**	**10.0**
K =	1.09	1.01	0.96	0.92	0.89	0.86	0.83	0.80
Flow conditions	Low turbulence ™ ™ ™ ™ ™ ™ ™ ™ ™ Highly turbulent (whitewater)							

Note: Tabulated results are applicable to uniform flow conditions, and Manning's n based on equation 8 (refer to section 7).

where:

d_{50} = nominal rock size (diameter) of which 50% of the rocks are smaller [m]

g = acceleration due to gravity [m/s^2]

K = equation constant based on flow conditions

= 1.1 for low-turbulent deepwater flow, 1.0 for low-turbulent shallow water flow, and 0.86 for highly turbulent and/or supercritical flow (also refer to Table 3)

K_1 = correction factor for rock shape

= 1.0 for angular (fractured) rock, 1.36 for rounded rock (i.e. smooth, spherical rock)

S_o = channel slope [m/m]

s_r = specific gravity of rock (e.g. sandstone 2.1–2.4; granite 2.5–3.1, typically 2.6; limestone 2.6; basalt 2.7–3.2)

V = depth-averaged flow velocity at location of rock [m/s]

Equation 1 reduces to the commonly used design equation (equation 2) for angular rock based on a rock specific gravity, $s_r = 2.6$

$$d_{50} = 0.04\, V^2 \qquad [2]$$

Filter layers placed under infill rock


Photo supplied by Catchments & Creeks Pty Ltd

Vegetated rock stabilisation (Qld)

Non use of a filter layer

- Armour rock that is intended to be vegetated by appropriately filling all voids with soil and pocket planting, will generally **not** require the placement of an underlying filter layer.
- However, a filter layer may be advisable if plant and soil loss is expected during severe flood events.


Photo supplied by Bruce Carey

Rock placement over filter cloth (Qld)

Filter cloth

- Non-vegetated armour rock must be placed over a layer of suitably graded filter rock, or geotextile filter cloth.
- The geotextile filter cloth must have sufficient strength (min. bidim A34), and must be suitably overlapped in order to withstand the placement of the rock (which normally results in movement of the fabric).
- Filter cloth must **not** be placed directly over a dispersive subsoil.


Photo supplied by Catchments & Creeks Pty Ltd

Small-rock filter layer (Qld)

Fine crushed rock filters

- Fine crushed rock filters should not be placed directly over a dispersive subsoil.


Photo supplied by Catchments & Creeks Pty Ltd

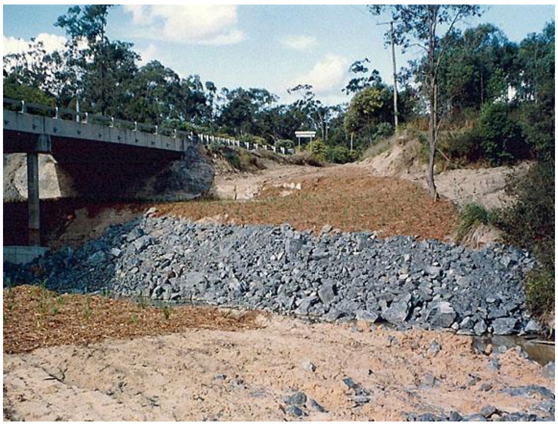
Larger rock filter layer (Qld)

Coarse rock filter layers

- Coarse rock filters should not be placed directly over a dispersive subsoil.
- In all cases, if the rock is to be placed over a dispersive (e.g. sodic) soil, then **prior** to placing the filter (cloth or rock), the dispersive soil **must** first be covered with a layer of non-dispersive soil, typically a minimum 200 mm thickness, but preferably 300 mm.

6. Rock Placement Upstream and Downstream of Bridge Crossings

Introduction



Rock placement upstream of a bridge

Bankfull flow conditions (Qld)

Bank erosion d/s of rock-stabilised bank

Vegetated rock placement (Qld)

Introduction

- This section looks at the sizing and placement of rock on waterway banks upstream and downstream of a bridge, that is:
  - the placement of rock in locations not affected by any hydraulic interference of bridge abutments and bridge piers
  - the use of rock to stabilise a waterway channel that needs to be partially realigned as part of the overall construction process.

Factors affects rock size

- The critical factors affecting rock size and rock selection include:
  - flow velocity
  - degree of flow turbulence
  - bank slope
  - rock shape (round or angular)
  - rock density
  - void condition (open or filled)
  - degree and type of vegetation cover.

Short-term stability of rock-lined banks

- Compared to most vegetated solutions, rock stabilisation provides the benefit of instantaneous scour protection.
- If however, the rock-lined channel has been designed to be fully vegetated, then in the short-term the non vegetated bank will have the a low Manning's roughness, which will result higher flow velocities.
- Because of the hydraulically-smooth nature of non-vegetated rock-lined surfaces, bank erosion often occurs downstream of newly placed rock.

Long-term stability of rock-lined banks

- Rock-protected waterway banks generally exhibit good long-term stability, especially if suitable deep-rooted vegetation is established over the rocks.
- In dynamic waterways (i.e. waterways subject to active channel expansion or migration) rock-lined banks can fail over the long-term.
- Large toe rock may be required if long-term bed lowering (bed erosion) is expected, especially on the outside of channel bends.

Attributes of rock stabilised waterway banks


Photo supplied by Catchments & Creeks Pty Ltd

Poor aesthetics without vegetation cover

Aesthetics

- Exposed rock can be unsightly.
- Weed invasion of rock-protected surfaces can also appear unsightly.
- Better long-term aesthetics are usually obtained when the rock-lined surface is fully vegetated with native plants.
- The use of broken concrete and building rubble for bank protection can be extremely unsightly, and is generally not recommended, especially in publicly accessible areas.


Photo supplied by Catchments & Creeks Pty Ltd

Lizard basking on exposed rock

Terrestrial habitats

- Non vegetated rock exposes migrating terrestrial wildlife to predators.
- Rock-lined surfaces can incorporate the occasional feature rock or rock outcrop that provides habitat diversity and habitat attributes such as:
  - sunbaking/roosting for reptiles
  - protection of wildlife from predators
  - protection of wildlife from floods and bushfire.
- However, open voids **above** the water line can encourage some forms of vermin.


Photo supplied by Catchments & Creeks Pty Ltd

Open voids below permanent waterline

Aquatic habitats

- Cavities between rocks that are placed **below** the permanent water level can provide desirable aquatic habitat and shelter, especially if rocks smaller than 200 mm are removed from the rock mix.
- The establishment of leafy vegetation along the water's edge can reduce water temperatures and greatly enhance aquatic habitat.


Photo supplied by Catchments & Creeks Pty Ltd

Bank stabilisation without revegetation

Riparian habitats

- Non-vegetated rock protection creates poor riparian values.
- Above the permanent water line, voids should be filled with soil and planted, but some exposed rock surfaces can be beneficial.
- Rock-lined waterway banks (vegetated or un-vegetated) can cause significant problems to burrowing fauna, such as platypus—expert advice should be sought on such matters.

Attributes of rock stabilised waterway banks


Photo supplied by Catchments & Creeks Pty Ltd

Vegetated rock stabilisation works

Establishment of vegetation over rocks

- The establishment of a vegetative cover over the rocks provides many benefits including:
  - increased stabilisation of the rocks
  - improved terrestrial habitat
  - improved aquatic habitat
  - improved fish passage conditions during periods of high flow
  - improved aesthetics.
- Vegetated rock-lined banks can be viewed as a form of 'soft engineering'.

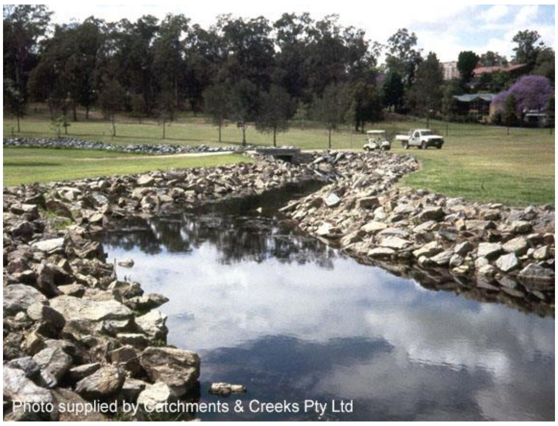


Photo supplied by Catchments & Creeks Pty Ltd

Rock-lined channel in a golf course

Impact on waterway hydraulics

- Non-vegetated rock stabilisation can significantly reduce the hydraulic resistance of the watercourse potentially resulting in increased channel velocities and bed scour, but with the possible benefit of reduced flood levels.
- The hydraulic roughness of rock-lined waterways depends on the degree of vegetation cover.
- In the long-term, some form of vegetation cover will occur unless controlled by regular maintenance.


Photo supplied by Catchments & Creeks Pty Ltd

Stacked boulder wall

Maximum bank slope

- Maximum batter slope is typically 1:2 (V:H) for non-vegetated, and 1:2.5 (V:H) if vegetated—the flatter slopes being desirable (but not essential) to provide safe conditions for planting operations.
- Steeper banks can be achieved with the use of slacked boulders, but the rocks must sit on a stable bed.
- Steep, high banks can represent a safety hazard to revegetation teams.

Photo supplied by Catchments & Creeks Pty Ltd

Rock placement over filter cloth

Backing material or filter layer

- Non-vegetated armour rock must be placed over a layer of suitably graded filter rock, or geotextile filter cloth.
- The geotextile filter cloth must have sufficient strength, and must be suitably overlapped, to withstand the placement of the rock (which normally results in movement of the fabric).
- Armour rock, that is intended to be vegetated by appropriately filling all voids with soil and pocket planting, will generally not require an underlying filter layer.

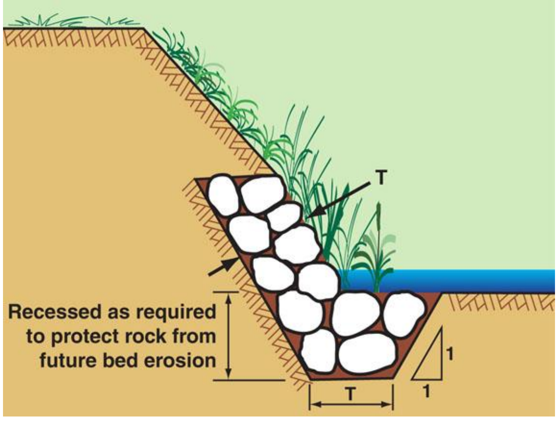
Toe stabilisation of waterway banks


Photo supplied by Catchments & Creeks Pty Ltd

Erosion along toe of bank

Toe erosion on channel banks

- Toe erosion is common on modified waterway banks if stream flows occur during the plant establishment phase.
- Rock protection along the toe of modified channel banks is usually necessary to provide short-term bank stabilisation during plant establishment.



Typical rock placement at toe of bank

Recessing rock below the toe of bank

- Extra rock may need to be placed **below** bed level to:
  - prevent slippage of the upper rock
  - increase toe stability during floods when short-term bed movement or bed lowing occurs during the flood peak
  - allow the bank to adjust to long-term variations in bed level.
- If the above conditions do not exist, then the rock can rest of the channel bed.


Photo supplied by Catchments & Creeks Pty Ltd

Large toe rock (NSW)

Toe stabilisation using large rock

- As an alternative to recessed mass rock (above), large toe rock can be placed along the toe of modified banks.
- Individual toe rock should be recessed 2/3 of its diameter into the earth.
- Toe rock provides the following benefits:
  - protects the bank from undercutting in the event of minor bed erosion
  - provides a visible control 'edge' during maintenance weeding or de-silting of the channel bed.

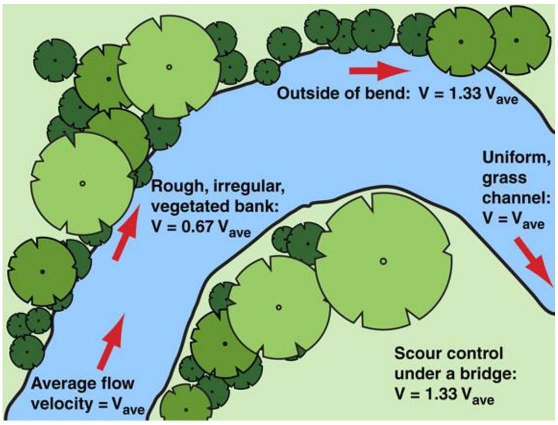

Photo supplied by Catchments & Creeks Pty Ltd

Coir 'geo-log' temporary toe protection

Alternative toe stabilisation measures

- Coir or jute 'geo logs' can be used as an alternative to rock stabilisation of the toe.
- These geo logs typically provide only temporary (less than 2-years) protection of the toe.
- These temporary protection measures are only successful if suitable vegetation is incorporated into, or around, the logs.
- It is important to ensure that bank erosion does not occur behind the logs during overtopping stream flows.

Design issues



Velocity multipliers for design purposes

Design velocity (V_{design}) adjacent banks

- In grass-lined channels with a uniform cross-section, adopt a design velocity equal to the calculated average flow velocity ($V_{design} = V_{average}$).
- In irregular, natural, woody/scrubby waterways, adopt a design velocity of two-thirds (67%) the average flow velocity.
- In all cases, on the outside of significant channel bends, adopt a design velocity adjacent to the outer bank of 133% of the average flow velocity ($1.33\ V_{average}$).


Photo supplied by Catchments & Creeks Pty Ltd

Partial vegetated bank stabilisation

Rock type and grading

- Crushed rock is generally more stable than natural rounded stone.
- A 36% increase (i.e. $K_1 = 1.36$) in rock size is recommended for rounded rock.
- All rock should be durable and resistant to weathering.
- Neither the breadth nor the thickness of a given rock less than one-third its length.
- In most situations the nominal rock size is usually between 200 mm to 600 mm.


Photo supplied by Catchments & Creeks Pty Ltd

Larger rocks forming toe protection

Thickness of rock protection

- The thickness of the armour layer should be sufficient to allow at least two overlapping layers of the nominal rock size.
- The thickness of rock protection must also be sufficient to accommodate the largest rock size.
- It is noted that additional thickness will **not** compensate for the use of undersized rock.


Photo supplied by Catchments & Creeks Pty Ltd

Rock stabilisation on channel bend

Elevation of rock placement on banks

- Rock placement often does not need to extent to the top of the bank—refer to diagram above.
- A simple guide to rock placement:
  - straight reaches: 1/3 to 1/2 bank height
  - channel bends: 2/3 lowest bank height on the outside of bends; and 1/3 the lowest bank height on inside of bends.
- In most cases, the upper bank area only needs to be stabilised with suitable vegetation.

Vegetated bank stabilisation works

Vegetated rock-lined creek bank (Qld)

Introduction

- Wherever practical, rock protected areas should be lightly covered with soil (to fill all voids) and pocket planted to encourage the preferred plant growth across the bank and along the water's edge.
- In areas where revegetation is not desired (e.g. when hydraulically efficient channels are required for flood control) then the establishment or retention of an effective canopy cover (i.e. shade trees) is generally the preferred means of controlling weed growth.

Voids filled with soil ready for planting

Infill soil

- Experience has shown that minimal soil is lost from the rock voids during flood events.
- The image presented left shows a recently planted bank that experienced a bankfull flow just weeks after planting—all plants were lost from the bank, but most of the soil remained.
- **Important:** In order to allow proper plant growth, the infill soil needs to be placed progressively as the layers of rock are added to the bank.

Planting along the water's edge

Planting along the water's edge

- Wherever practical, vegetation should extend to the water's edge to increase the value and linkage of aquatic and terrestrial habitats.
- Plants that branch over the water's edge can provide essential shading of the water to provide pockets of cool water for aquatic life.
- Edge plants also assist aquatic life to shelter from predators.

Planted rock covered with jute mesh

Use of erosion control mats

- During plant establishment it may be necessary to mulch around newly placed plants to control soil moisture loss.
- Covering such areas with a jute or coir mesh can help to reduce the loss of mulch by wind and minor flows.
- However, it is noted that the compete loss of the matting during high flows can cause damage to, or the total loss of, any recently established plants.

Examples of vegetated rock armouring

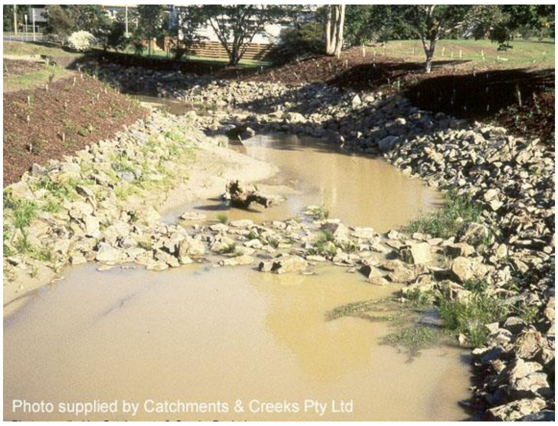


Photo supplied by Catchments & Creeks Pty Ltd

Sandy Creek, Enoggera, June 1997


Photo supplied by Catchments & Creeks Pty Ltd

Sandy Creek, Enoggera, October 2014


Photo supplied by Catchments & Creeks Pty Ltd

Sheep Station Gully, July 1999


Photo supplied by Catchments & Creeks Pty Ltd

Sheep Station Gully, September 2008


Photo supplied by Catchments & Creeks Pty Ltd

January 1995


Photo supplied by Catchments & Creeks Pty Ltd

Boss Creek, Inala, July 2004

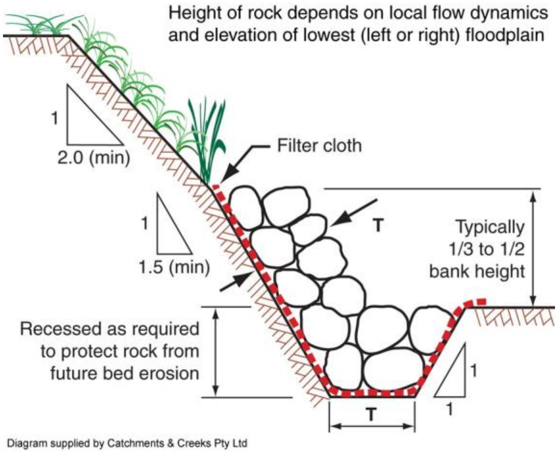

Photo supplied by Catchments & Creeks Pty Ltd

Kedron Brook, Ferny Hills, July 2011


Photo supplied by Catchments & Creeks Pty Ltd

Kedron Brook, Ferny Hills, September 2014

Rock placement on banks



Rock placement with open voids

Advantages:

Reduced quantity of rock.

Disadvantages:

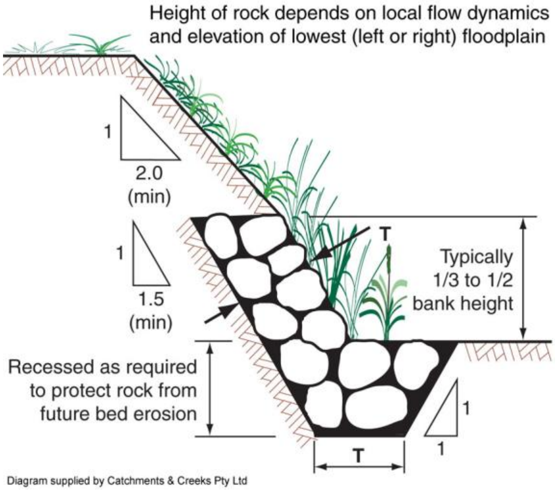
Problems can occur with lateral inflows (i.e. local stormwater runoff) entering into, or passing under, the rock.

Can result in reduced aquatic habitat values given the absence of vegetation.

Use:

Ideally, this method of rock placement should have limited usage in new works.

Typically used on the inside face of fully shaded, high velocity channel bends.



Rock placement with soil-filled voids

Advantages:

Improved aquatic habitat values.

Retention of riparian values.

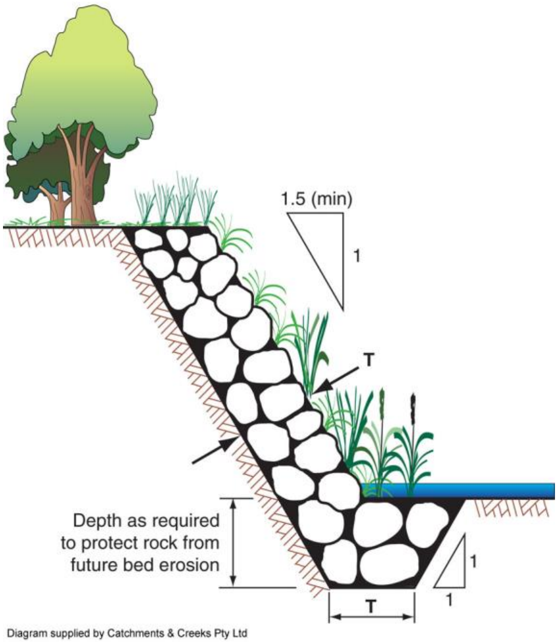
Disadvantages:

Care must be taken to ensure all voids are filled with soil to prevent the seepage of the upper bank soil into the lower rock layer.

Use:

Used for the toe protection of channel banks in regions of high flow velocity, or areas where the channel bed may experience scour.

This is generally the preferred method of rock placement within waterways.



Full-height rock placement

Advantages:

Very high scour protection once vegetation is established.

Retention of aquatic habitat values.

Retention of riparian values.

Banks can be steeper than vegetated banks that do not contain rock protection.

Disadvantages:

High installation cost.

Use:

Used on the outside face of high velocity or sharp channel bends.

Also, used in areas where both the channel velocity and overbank flow velocities are likely to be very high and thus erosive.

Rock placement on banks

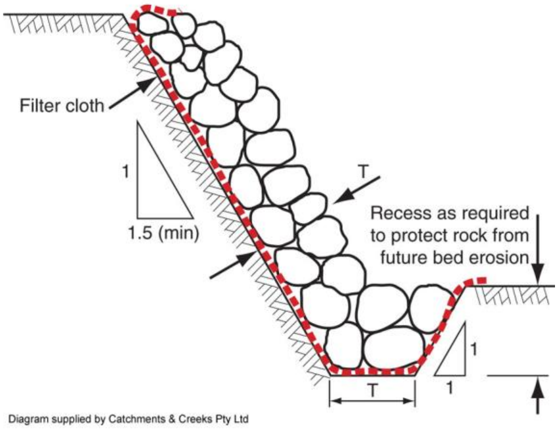


Diagram supplied by Catchments & Creeks Pty Ltd

Full-height with open voids

Advantages:

Cheaper installation cost compared to vegetated rock protection.

Disadvantages:

Poor aesthetics.

Poor aquatic habitat and fish passage.

High risk of weed invasion unless fully shaded.

Use:

Heavily shaded, high velocity areas.

Outside face of fully shaded channel bends.

Very high velocity regions where vegetation is not expected to survive.

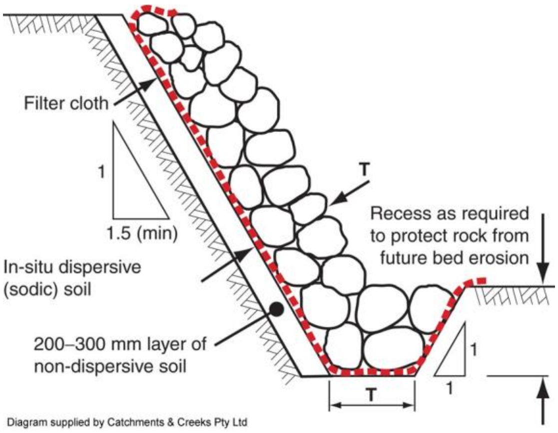


Diagram supplied by Catchments & Creeks Pty Ltd

Rock placement over dispersive soils

Advantages:

Long-term protection of highly erodible soils.

Disadvantages:

Poor aesthetics.

Poor aquatic habitat and fish passage.

High risk of weed invasion unless fully shaded.

Use:

Heavily shaded areas containing dispersive soils.

Outside face of fully shaded channel bends.

Very high velocity regions where vegetation is not expected to survive.

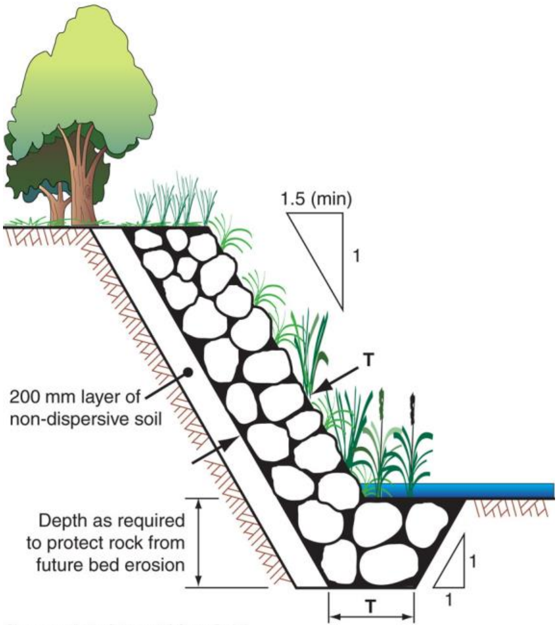


Diagram supplied by Catchments & Creeks Pty Ltd

Vegetated rock placement over poor soils

Advantages:

Retention of aquatic habitat values.

Long-term protection of highly erodible soils.

Reduced maintenance costs.

Disadvantages:

Higher installation cost compared to non-vegetated rock protection.

Use:

Outside face of high velocity or sharp channel bends in dispersive soil regions.

Dispersive soil areas where both the channel velocity and over-bank flow velocities are likely to be very high and therefore erosive.

Common problems associated with rock stabilisation of waterways

Rock placement without planting

Failure to introduce suitable vegetation cover

- The placement of loose rock on waterway banks may initially appear as a cheap scour control option, but weed infestation can lead to ongoing maintenance costs.
- Wherever practical, rock-lined surfaces should be lightly covered with soil and appropriately planted.

Rock placement without planting

Same location (left) after weed infestation

Weak sandy bed structure after a flood

Placement of rock on sandy bed waterways

- Sand-based waterways often contain a deep bed of sand, which can liquefy during floods and migrate down the waterway like a viscous liquid.
- If heavy rocks are placed on the bed of a sand-based waterway, then these rocks may simply sink into the sand during flood events.
- The risk of the rocks displacing during floods depends on the depth of sand and the type of sand movement during floods.

Rocks displaced down filter cloth

Rocks slipping down smooth filter cloth

- In certain conditions, filter cloth effectively acts as a low-friction surface, which can cause rocks to slowly slide down the face of a slope.
- If rocks need to be placed on steep slopes, then the rocks should be 'keyed' into the bank.
- Keying can be done by 'stair-stepping' the bank prior to placing the filter cloth, or providing suitable toe rock.

Common problems associated with rock stabilisation of waterways

Bank erosion at d/s end of rock work

Bank erosion at downstream end of rock-lined banks

- In the absence of a vegetative cover, rock-lined surfaces can act as hydraulically-smooth surfaces that can induce high flow velocities to exist adjacent the bank.
- These same high velocities can then pass over the unprotected bank immediately downstream of the rock-lined surface causing soil erosion.
- Erosion along the toe of the rock is also a common occurrence.

Tunnel erosion under rocks

Rock placed on dispersive or slaking soils

- Rocks should <u>**not**</u> be placed directly onto a dispersive, sodic, or slaking soil.
- Tunnel erosion is a common occurrence when rocks are placed directly over a dispersive soil.

Batter chute placed on a dispersive soil

Placement of rock over dispersive soils

- If the rock is placed on a dispersive (e.g. sodic) soil, then **prior** to placing the filter cloth, the exposed soil **must** first be covered with a layer of non-dispersive soil, typically minimum 200 mm thickness, but preferably 300 mm.
- It is noted that filter cloth, no matter how thick, cannot seal a dispersive soil, and thus should not be relied upon as the sole underlay for rock placed on a dispersive soil.

Grouted rock placed on dispersive soil

Placement of grouted rock over dispersive soils

- If loose or grouted rock is to be placed on a dispersive (e.g. sodic) soil, then **prior** to placing the filter cloth, the exposed soil **must** first be covered with a layer of non-dispersive soil.
- It is noted that filter cloth, no matter how thick, cannot seal a dispersive soil, and thus should not be relied upon as the sole underlay for rock placed on a dispersive soil.

Identification of dispersive and slaking soils


Photo supplied by Catchments & Creeks Pty Ltd

Collapse of a slaking soil in water

Dispersive and slaking soils

- Dispersive soils are structurally unstable when immersed in water, breaking down into their constituent particles (sand, silt and clay) thus allowing the dispersive clay fraction to disperse and cloud the water.
- 'Slaking' is the natural collapse of a soil aggregate in water when its mechanical strength is insufficient to withstand the swelling of clay and the expulsion of air from pore spaces—it does not include the effects of soil dispersion.


Photo supplied by Catchments & Creeks Pty Ltd

Fluting erosion in a dispersive soil

Identification of dispersive soils

- Ideally, dispersive and slaking soils should be identified through appropriate pre-construction soil testing, such as:
  - exchangeable sodium percentage > 6%
  - Emerson aggregate classes 1 to 5, note classes 3(2), 3(1) and 5 also have a slight risk of dispersive problems.
- The *'Aggregate Immersion Test'* is an on-site indicator of the soil properties.
- Dispersive soils may also be identified by their distinctive erosion patterns (left).


Photo supplied by Catchments & Creeks Pty Ltd

Dispersion of a dispersive soil

Aggregate immersion test

- At best, soil tests conducted on-site can only 'indicate' the existence of a potential soil problem.
- Such field tests are **not** a substitute for official soil sampling and testing.
- An aggregate immersion test (left) can be used as an indicator of potentially dispersive or slaking soils.
- Slaking soils (soils that readily collapse in water, but do not necessarily cloud the water) can be just as problematic.


Photo supplied by Catchments & Creeks Pty Ltd

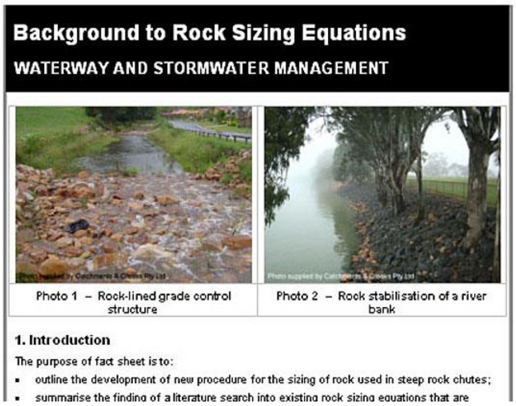
Fluting erosion in a dispersive soil

Stabilisation of dispersive soils

- Dispersive soils are highly susceptible to deep, narrow rilling (fluting) on slopes and along the invert of drains.
- Dispersive soils **must** be treated (with gypsum or the like), or buried under a minimum 200–300 mm layer of non-dispersive soil before placing any vegetation or erosion control measures.

7. Rock Riprap Characteristics

Introduction


Background to Rock Sizing Equations

WATERWAY AND STORMWATER MANAGEMENT

Photo supplied by Catchments & Creeks Pty Ltd

Photo 1 – Rock-lined grade control structure

Photo supplied by Catchments & Creeks Pty Ltd

Photo 2 – Rock stabilisation of a river bank

1. Introduction

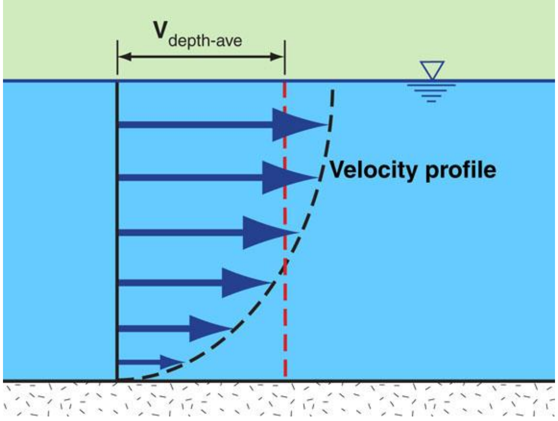
The purpose of fact sheet is to:

- outline the development of new procedure for the sizing of rock used in steep rock chutes;
- summarise the finding of a literature search into existing rock sizing equations that are

C&C website Fact Sheet (2011)

Background to rock sizing equations presented for 'minor' bridges

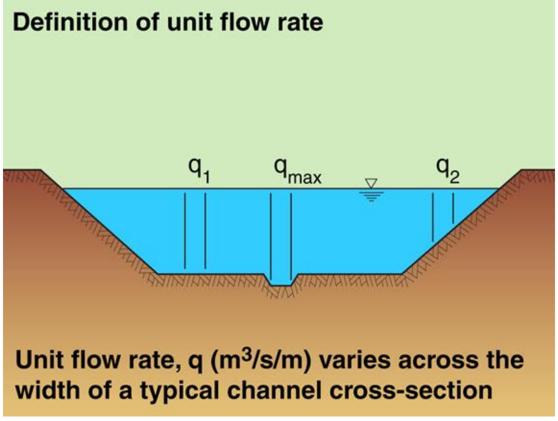
- Section 5 of this Field Guide provides an alternative equation (Eqn. 1) for the sizing of rock placed around 'minor' bridges.
- The following pages provide additional information relating to the use of this equation—this information may or may not apply to the equations previously presented for 'major' bridges.
- Additional background information can be found in a separate Fact Sheet available on the *Catchments and Creeks* website.



Depth-average flow velocity

Use of 'average', 'depth-average' and 'local' flow velocity in sizing rock

- Rock displacement occurs as a result of local forces, local shear stresses, and local flow velocities.
- Wherever possible, local flow velocities or shear stresses should be used to determine rock size.
- However, the practicalities of fluid dynamics means that designers often only have access to the 'average' flow conditions at a given cross-section.



Unit flow rate within an irregular channel

Use of unit flow rate (q) as the preferred equation variable

- To avoid the potential problems cause by the use of an 'average' flow velocity instead of a 'local' flow velocity, some rock sizing equations use the 'unit flow rate' (q) as the preferred equation variable.
- Units of 'q' are $m^3/s/m$

$$q = (1/n) . Y^{5/3} . S^{1/2} \qquad [3]$$

where Y = water depth at given location, and S = hydraulic gradient of flow.

Rocks placed on a steep slope (Qld)

Problems associated with the use of shear stress and the Shield's equation in determining rock size

- Traditionally, rock sizing equations have used shear stress as the primary variable, which resulted in the development of the Shield's equation.
- However, the Shield's equation does not take into account the additional restraining forces associated with the weight of the upper rocks sitting on the lower rocks, which is a critical factor when rocks are placed on steep slopes.

Design issues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Bank stabilisation (Qld)

Safety factor (SF)

- For low risk structures, such as most bank stabilisation measures, a safety factor (SF) of 1.2 is recommended.
- For high risk structures, such as some bed stabilisation structures, a safety factor of 1.5 is recommended.
- The rock sizing equations presented for 'major' bridges (sections 3 & 4) already include a safety factor.


Photo supplied by Catchments & Creeks Pty Ltd

Fractured rock

Effects of rock shape (K_1)

- Crushed rock is generally more stable than natural rounded rock.
- Most rock sizing equations, including those presented within this publication, are primarily based on the use of angular fractured rock.
- A correction factor ($K_1 = 1.36$) must be applied if rounded rock is used.


Photo supplied by Catchments & Creeks Pty Ltd

Rock weir made from round natural stone

Use of rounded natural stone

- Rounded rock has a more 'natural' appearance, but in many cases the appearance/colour of the rock becomes irrelevant because vegetation eventually hides the rock.
- In waterway environments, introduced rock should not dominate the landscape, rather the rock should be incorporated (disappear) into the landscape.

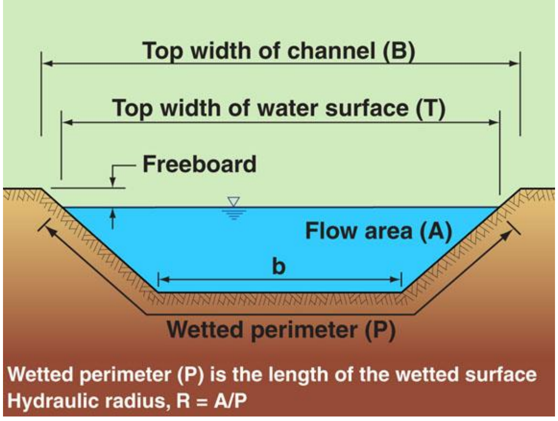

Photo supplied by Bruce Carey

Individual placement of rocks (Qld)

Effects of rock placement on rock stability

- Rock-lined surfaces formed by the individual placement (stacking) of rocks are generally more stable than rock-lined surfaces produced by simply dumping the rock.
- Rocks dumped from a height, such as being dumped from a truck, will fall to a lower bank slope (angle of repose) than can be achieved through the selective placement of the rocks.

Manning's roughness of rock-lined surfaces



Channel geometry and flow conditions


Photo supplied by Catchments & Creeks Pty Ltd

Gravel-based alluvial waterway (Tas)


Photo supplied by Catchments & Creeks Pty Ltd

Deepwater flow conditions (SA)


Photo supplied by Catchments & Creeks Pty Ltd

Shallow water flow conditions (Qld)

Manning's equation

- The **average** channel flow velocity may be calculated using Manning's equation:

$$V = (1/n) \cdot R^{2/3} \cdot S^{1/2} \qquad [5]$$

where:

V = average flow velocity (m/s)
n = Manning's roughness coefficient
R = hydraulic radius (m) = A/P
A = effective flow area of channel (m^2)
P = wetted perimeter of flow (m)
S = channel slope (m/m)

Factors affecting the hydraulic roughness of rock-lined surfaces

- The effective Manning's roughness of rock-lined surfaces depends on:
  - average rock size (d_{50})
  - the distribution of rock sizes, defined in this case by a ratio: d_{50}/d_{90}
  - the depth of water flow, usually defined by the hydraulic radius of flow (R)
  - the existence of vegetation
  - the occurrence of aerated 'whitewater' (not directly considered here).

Manning's roughness in deepwater

- The Strickler formula for deepwater may be presented in the modified form:

$$n = ((d_{50})^{1/6})/21.1 \qquad [6]$$

- An alternative equation was developed by Meyer-Peter & Muller:

$$n = ((d_{90})^{1/6})/26.0 \qquad [7]$$

  - d_{50} = rock size for which 50% of rocks are smaller [m]
  - d_{90} = rock size for which 90% of rocks are smaller [m]

Manning's roughness in shallow water

- The Manning's roughness (n) of rock-lined surfaces in both shallow-water and deep-water flow conditions is provided below.

$$n = \frac{d_{90}^{\;1/6}}{26(1 - 0.3593^{m})} \qquad [8]$$

  - $m = [(R/d_{90})(d_{50}/d_{90})]^{0.7}$
  - R = hydraulic radius of flow [m]

- The relative roughness (d_{50}/d_{90}) of rock extracted from streambeds is typically in the range 0.2 to 0.5; while quarried rock is commonly in the range 0.5 to 0.8.

Manning’s roughness of rock-lined surfaces

The Manning’s (n) roughness for rock-lined surfaces can be determined from Table 4 or equation 8.

Table 4 – Manning’s (n) roughness of rock-lined surfaces

	$d_{50}/d_{90} = 0.5$				$d_{50}/d_{90} = 0.8$			
d_{50} =	**200mm**	**300mm**	**400mm**	**500mm**	**200mm**	**300mm**	**400mm**	**500mm**
R (m)	Manning’s roughness (n)				Manning’s roughness (n)			
0.2	0.10	0.14	0.17	0.21	0.06	0.08	0.09	0.11
0.3	0.08	0.11	0.14	0.16	0.05	0.06	0.08	0.09
0.4	0.07	0.09	0.12	0.14	0.04	0.05	0.07	0.08
0.5	0.06	0.08	0.10	0.12	0.04	0.05	0.06	0.07
0.6	0.06	0.08	0.09	0.11	0.04	0.05	0.05	0.06
0.8	0.05	0.07	0.08	0.09	0.04	0.04	0.05	0.06
1.0	0.04	0.06	0.07	0.08	0.03	0.04	0.05	0.05

Equation 8 is considered to produce significantly better estimates of the Manning’s roughness of rock-lined surfaces in shallow water flow compared to the use of traditional deepwater equations such as the Strickler, Meyer-Peter & Muller or Limerinos equations.

Given the high variability of Manning’s n, and the wide range of variables that are believed to influence the hydraulic roughness of a rock-lined channel, equation 8 is considered well within the limits of accuracy expected for Manning’s n selection.

Data analysis during the development of equation 8 indicated that the Meyer-Peter & Muller equation (equation 7) produced more reliable estimates of the deepwater Manning's roughness values than the Strickler equation (equation 6). Possibly the choice between the two equations would come down to how reliable the determination of the d_{50} and d_{90} values were. If the estimate of d_{90} is not reliable, then it would be more appropriate to rely on the Strickler equation for the determination of the deepwater Manning's n value, and visa versa.

Table 5 provides the range of data values used in the development of equation 8. This table also contains the data range for the selected variables for which the calculated Manning’s n value using equation 8 fall within +/-10% of the observed Manning’s n.

Table 5 – Data range used in determination of equation 5

	d_{50} (mm)	**d_{90} (mm)**	**R/d_{50}**	**R/d_{90}**	**n_o/n**	**d_{50}/d_{90}**
Min (+/-10%)	16	90	2.31	0.73	0.284	0.080
Max (+/-10%)	112	350	55.6	12.0	1.080	0.661
Min (All data)	16	90	1.17	0.31	0.097	0.080
Max (All data)	397	1080	66.9	12.9	1.120	0.661

Maximum bank gradient

The recommended maximum desirable side slope of a large rock-lined chute is 1:2 (V:H); however, side slopes as steep as 1:1.5 can be stable if the rock is individually placed rather than bumped. Typical angles of repose for dumped rock are provided in Table 6.

Table 6 – Typical angle of repose for rock

Rock shape	**Angle of repose (degrees)**	
	Rock size > 100 mm	**Rock size > 500 mm**
Very angular rock	41^o	42^o
Slightly angular rock	40^o	41^o
Moderately rounded rock	39^o	40^o

Typical properties of rock

Crushed rock is generally more stable than natural rounded rock; however, rounded rock has a more ‘natural’ appearance. A 36% increase in rock size is recommended if rounded rock is used (i.e. $K_1 = 1.36$).

The rock should be durable and resistant to weathering, and should be proportioned so that neither the breadth nor the thickness of a single rock is less than one-third of its length.

Maximum rock size generally should not exceed twice the nominal (d_{50}) rock size, but in some cases a maximum rock size of 1.5 times the average rock size may be specified.

Typical rock densities (s_r) are presented in Table 7.

Table 7 – Relative density (specific gravity) of rock

Rock type	Relative density (s_r)
Sandstone	2.1 to 2.4
Granite	2.5 to 3.1 (commonly 2.6)
Limestone	2.6
Basalt	2.7 to 3.2

Table 8 provides a suggested distribution of rock sizes for waterway chutes. The distribution of rock size can also be described by the coefficient of uniformity, $C_u = d_{60}/d_{10}$, which usually falls in the range 1.1 to 2.70, but typically around 2.1. Witter & Abt (1990) reported that poorly graded rock ($C_u = 1.1$) has a critical discharge 8% greater than well-graded rock ($C_u = 2.2$).

Table 8 – Typical distribution of rock size for fish friendly structures (guide only)

Rock size ratio	Assumed distribution value
d_{100}/d_{50}	2.0
d_{90}/d_{50}	1.8
d_{75}/d_{50}	1.5
d_{65}/d_{50}	1.3
d_{40}/d_{50}	0.65
d_{33}/d_{50}	0.50
d_{10}/d_{50}	0.20

Thickness and height of rock layer

The thickness of the armour layer should be sufficient to allow at least two overlapping layers of the nominal rock size. The thickness of rock protection must also be sufficient to accommodate the largest rock size. It is noted that increasing the thickness of the rock placement will **not** compensate for the use of undersized rock.

In order to allow at least two layers of rock, the minimum thickness of rock protection (T) can be approximated by the values presented in Table 9.

Table 9 – Minimum thickness (T) of rock lining

Min. thickness (T)	Size distribution (d_{50}/d_{90})	Description
1.4 d_{50}	1.0	Highly uniform rock size
1.6 d_{50}	0.8	Typical upper limit of quarry rock
1.8 d_{50}	0.67	Recommended lower limit of distribution
2.1 d_{50}	0.5	Typical lower limit of quarry rock

8. Other Scour Control Measures

Stacked boulder walls


Photo supplied by Catchments & Creeks Pty Ltd

Stacked boulder wall (Qld)

Stacked bounders

- As the slope of a boulder wall increases, an increasing proportion of the boulder weight rests on the lower boulders and ultimately the channel bed rather than on the channel bank.
- This means that if there is a significant flood and the creek bed erodes or weakens, then there is the risk that the entire boulder wall will slide down the face of the bank into the waterway.


Photo supplied by Catchments & Creeks Pty Ltd

Stacked small river gravel (Qld)

Use of boulder walls

- Stacked boulder walls can be used to:
  - form steep banks to protect bridge piers
  - form steep banks that protect the river bank from the turbulence caused by in-channel bridge piers.


Photo supplied by Catchments & Creeks Pty Ltd

Stacked boulder wall (Qld)

Problems commonly associated with stacked boulder walls

- In the absence of vegetation, hydraulically-smooth boulder walls can cause high flow velocities to occur adjacent the surface of the boulders.
- These same high velocities will also exist adjacent the creek bed, possibly causing bed scour.
- Toe erosion at the base of the boulder wall can caused the rocks to slide down the face of the bank into the waterway.


Photo supplied by Catchments & Creeks Pty Ltd

Failed boulder wall (Qld)

Importance of stable subsoil conditions

- Unstable and/or dispersive subsoils can cause the failure of staked boulder walls.
- The stability of boulder walls can be increased by incorporating earth reinforcing mesh into the wall and extending this mesh into the adjacent river bank.

Gabions and rock mattresses


Photo supplied by Catchments & Creeks Pty Ltd

Gabion-protected bridge abutment (Qld)

Gabions

- Gabions are a well-established scour control measure, but the wire baskets can be damaged by flood debris.


Photo supplied by Catchments & Creeks Pty Ltd

Newman Road, Wavell Heights, Qld

Displacement of rock mattresses

- Typical shear forces associated with bridge structures in flood have been found to be sufficient to 'roll' rock mattresses from their earth bedding.
- The incorporation of vegetation into the rock mattresses can reduce the risk of this type of failure.


Photo supplied by Catchments & Creeks Pty Ltd

Bridge outlet, Fairfield, NSW

Failure of wire baskets

- Unless appropriately vegetated, gabion and rock mattress structures placed next to waterways will be subject to the eventual failure of the wire, and the associated loss of rock and structural integrity.


Photo supplied by Catchments & Creeks Pty Ltd

Terrys Creek, Sydney, NSW

Invasion of vines and invasive weeds

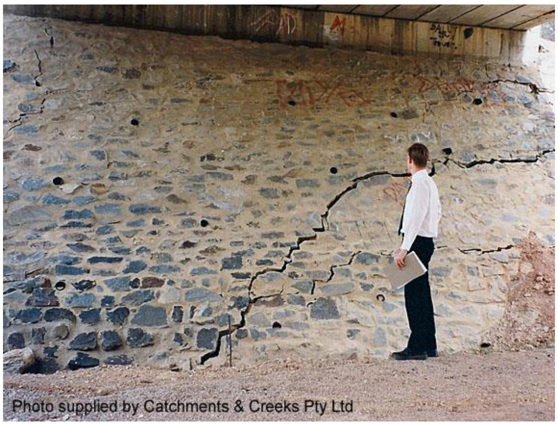
- If not appropriately vegetated at the time of installation, gabion and rock mattress structures can attract vines and weed species that can invade the adjacent bushland.

Grouted stone pitching

Old Toowoomba Rd, Ipswich (Qld)

Grouted stone pitching

- Grouted stone pitching produces a hard surface that is prone to cracking under ongoing compaction and movement.
- The exposed surface is hydraulically smooth, which encourages high flow velocities (and shear stresses) at the base of the bridge abutment.



Johnson Rd, Oxley Ck, Forestdale (Qld)

Cracking of grouted stone pitching resulting from movement of the abutment foundations

- The cracking of these surfaces should be considered inevitable.

Old Toowoomba Rd, Ipswich (Qld)

Failure of grouted stone pitching

- During flood events, flow velocities can vary significantly as floodwaters accelerate towards the bridge constriction.
- This variation in flow velocity results in a corresponding change in hydraulic pressure.
- Cracks in the stone pitching can cause significant pressure gradients to exist under the stone pitching relative to external water pressures, which can result in large section of the grouted rock lifting off the abutment during floods.

Failed stone pitching (NT)

Failure of grouted rock placed over a dispersive soil

- Grouted rock <u>must</u> not be placed directly over a sodic or dispersive soil.
- If grouted rock is to be placed over a dispersive soil, then the exposed soil **must** first be covered with a layer of non-dispersive soil, typically minimum 200 mm thickness.

Other scour control techniques

Pile field (Oxley Creek, Willawong, Qld)

Pile field

- Pile fields can be installed under the deck of a new bridge prior to its construction in order to control the extent (depth) of bed scour in sand-based waterways during severe floods.
- This system allows for:
  - the natural migration of the bed substrate
  - ongoing adjustments in the elevation of the waterway bed, and
  - fish passage (even after bed scour has occurred).

Cleveland-Redland Bay Road, Qld

Concrete

- Bridge abutments can be protected with reinforced concrete; however, the pressure gradient issues previously discussed for grouted stone pitching also apply to sheet concrete.
- Steep concrete abutment aprons that fall directly into the waterway (i.e. with no overbank floodway provided) can act as a barrier to the migration of large terrestrial wildlife.

Grout-filled mattress

Grout-filled mattresses

- Refer to the discussion on grouted stone pitching.
- The pressure gradient issues previously discussed for grouted stone pitching also apply to the use of grout-filled mattresses.

Precast concrete blocks

Precast concrete blocks

- Several different types of pre-cast concrete blocks are commercially available.
- As for grouted stone pitching and sheet concrete, the exposed surface is generally hydraulically smooth, which encourages high flow velocities (and shear stresses) at the base of the block wall.

9. Road Pavement Scour

Introduction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Floodwater passing over approach road

Pavement damage during overtopping flows

- Floodwaters overtopping floodways and bridge approach roads can cause damage to road pavements.
- In many cases this damage is the result of excessive hydraulic pressure gradients rather than excessive flow velocities.
- It was probably wrong to title this chapter 'pavement scour' when mostly it is not a scour issue.

Pavement failure, Queensland, 2011

Failure modes

- Flood damage to road pavements can result from several modes of failure, including:
  - vehicles driving on flooded road where water is trapped under the pavement
  - failure of the road base or sub-base
  - undermining of the pavement as a result of embankment or culvert failure
  - adverse pressure gradients; that is, variations in hydraulic pressure above and below the pavement.

Road pavement lifted by floodwater

Pavements lifted by adverse pressure gradients

- It takes a great force to lift a road pavement.
- The pressure differential acting on a flooded pavement may be small, but because a 'new' pavement is a continuous surface, the area over which this pressure acts can be very large.
- If the weight of water pushing down on a pavement is exceeded by the hydraulic force pushing up on the pavement, then the pavement can lift.


Photo supplied by Catchments & Creeks Pty Ltd

Flood damage to grouted stone pitching

Failure of scour protection on abutments

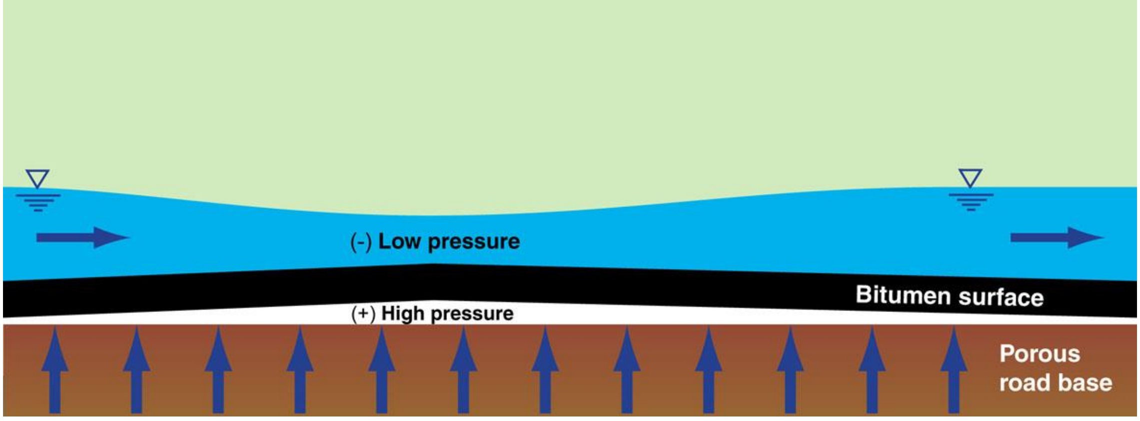
- We know that adverse hydraulic pressures can cause, or at least contribute to, the failure of hard-skin scour control measures such as grouted stone pitching.
- The adverse pressure gradients result from the fact that the water pressures on the outside of the stone pitching vary with the flow velocity; however, the water pressure under the stone pitching is dependent on the water pressure adjacent the nearest weep hole or surface crack.
- The same issues can apply to pavements.

Potential pressure changes under flooded pavements

Floodwaters passing over a road

Flooded roads

- As shallow floodwaters pass over the crown of a floodway there can be an acceleration in flow velocity above the crown, which causes a reduction in water level and the weight of water above the crown.
- If the water pressure in the porous road base under the pavement is equal to the water pressure on the edge of the road (where the road base is in contact with the floodwater), then this can result in a net upwards force on the pavement.



Variations in hydraulic pressure during minor overtopping of a roadway

Gowrie Creek, Toowoomba, Qld (2011)

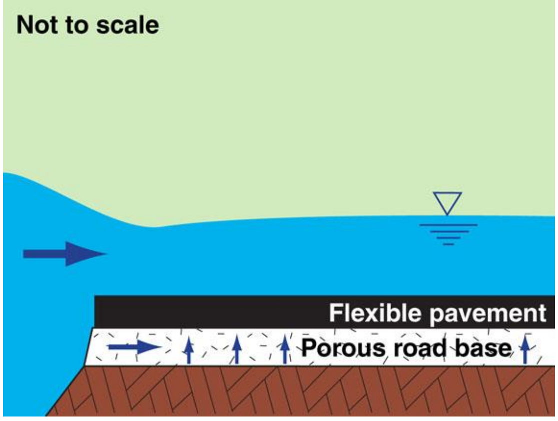
Highly variable flow conditions

- When high-velocity floodwaters overtop a bridge or culvert, both the flow velocity and flow depth can be highly variable as standing waves are formed on either side of the road.
- Standing waves can be generated by the edge of the bridge, or as a result of rapid changes in flow velocity.

Mount Sylvia Rd, East Haldon, Qld (2010)

Same bridge (left) post flood (2011)

Potential pressure changes under flooded pavements



Hydraulic uplift pressures

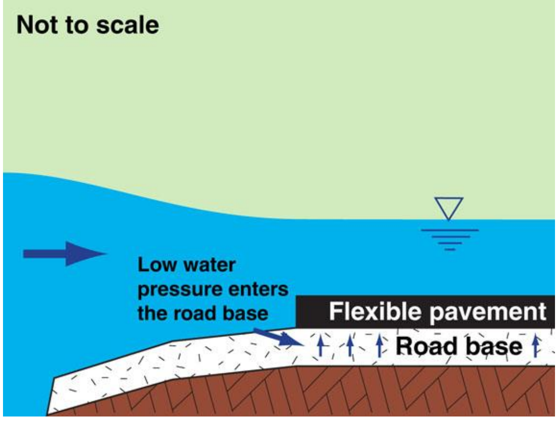
Hydraulic uplift pressures

- As previously discussed, if the weight of water pushing down on a pavement is exceeded by the hydraulic pressure pushing up on the pavement through the road base, then the pavement can lift.
- Once the pavement lifts, pressures above and below the pavement quickly equalise and the pavement falls back onto the road; however, in that short period, fast-flowing floodwater can move the pavement slightly downstream.

Pavement damage (Qld, 2010)

Age of the road pavement

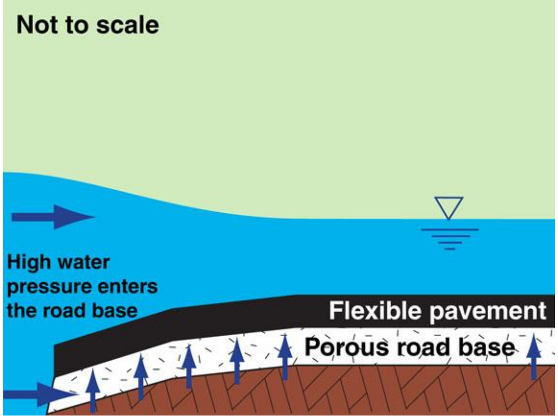
- This type of pavement damage requires large areas of the pavement to be free of cracks that would otherwise help to equalise pressure gradients.
- This means pavement failures are more likely to occur if a flood occurs just after a road is constructed, or after a new pavement has been layed.



Open shoulder on a road floodway

Open road shoulder

- If the edge of the pavement is located away from the edge of an elevated floodway, then the water depth at the edge of the pavement may have already reduced in depth as a response to the increased flow velocity.
- This means the hydraulic pressure under the pavement may be close to the pressure above the pavement, which means pavement failure is unlikely to occur.



Sealed shoulder on a road floodway

Sealed road shoulder

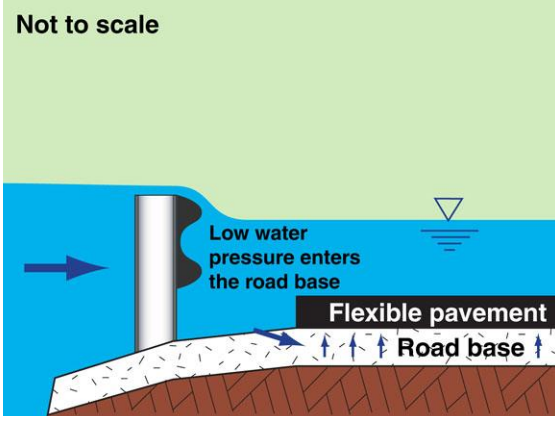
- If the edge of the pavement extends to the edge of an elevated floodway, then the water depth at the edge of the pavement may be significantly higher than the water depth passing over the floodway.
- This means the hydraulic pressure under the pavement may be significantly greater than the pressure above the pavement, which means pavement failure is more likely to occur during a flood event.
- Of course it can take some time for these hydraulic pressures to build-up under a pavement.

The potential effects of guardrails on pavement failures

Floodwater passing under a guardrail

The potential impact of a guardrail on a pavement failure

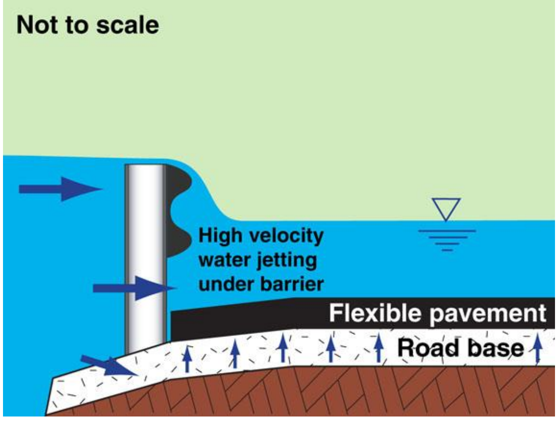
- The author has had discussions with road maintenance personnel that have claimed that a particular pavement failure occurred only after a guardrail was installed along the floodway.
- Prior to the installation of the guardrail the road had experienced several flood events without pavement failure.
- Of course the failure may also be linked to the resurfacing of the pavement at the same time.



Pavement edge away from a guardrail

Pavement edge away from a guardrail

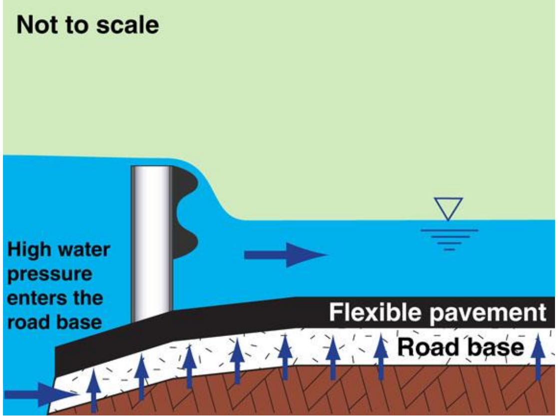
- If the edge of the pavement is located away from the guardrail, then the water depth at the edge of the pavement may have already reduced.
- This means the hydraulic pressure under the pavement may be close to the pressure above the pavement, which means pavement failure is unlikely to occur.



Pavement edge near a guardrail

Pavement edge near a guardrail

- If the edge of the pavement is located near the guardrail, then the water depth at the edge of the pavement may be higher than the water depth passing over the floodway.
- This means the hydraulic pressure under the pavement may be significantly greater than the pressure above the pavement.
- Also, water ‘jetting’ under the guardrail can help lift the edge of a weakened pavement.



Pavement edge beyond a guardrail

Pavement edge beyond a guardrail

- If the edge of the pavement extends beyond the guardrail, then the water depth at the edge of the pavement will likely be significantly higher than the water depth passing over the floodway.
- This means pavement failure is more likely to occur during a flood event.
- Debris blockage of the guardrail will likely increase the adverse pressure gradient acting on the pavement.

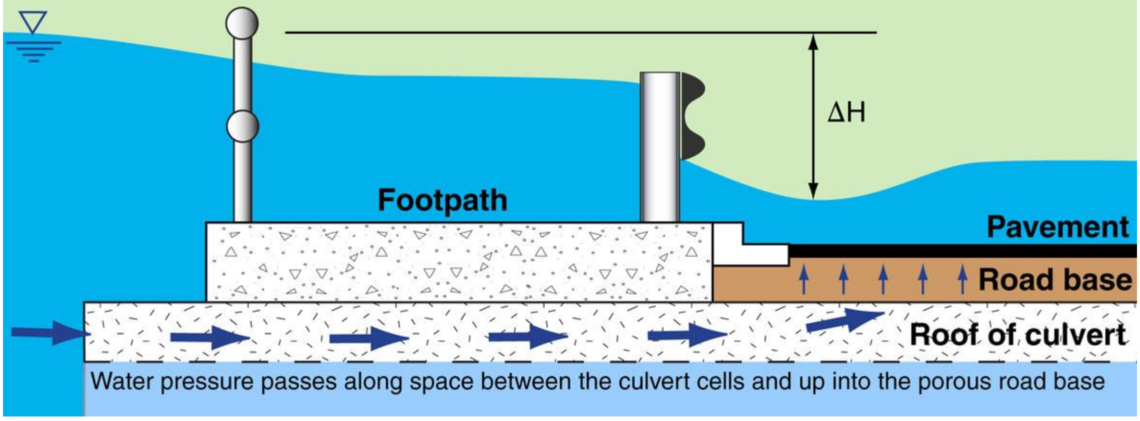
Pavement failure at culvert crossings


Photo supplied by Brisbane City Council

Pavement failure over a culvert

Porous road base placed on a road culvert

- In this case (left) a concrete deck was not formed over the box culverts because a minimum deck thickness was desired for reasons of flood control.
- Instead, a porous road base was placed directly on the box culverts, and then the pavement was placed on the road base.
- During an overtopping flood, high water pressure passed between the box culverts and up into the road base, lifting the newly layed pavement.



High water pressure passes between the culvert legs and up into the porous road base


Photo supplied by Catchments & Creeks Pty Ltd

Open gap between culvert legs

Open gap between the culvert legs

- The potential hydraulic problems caused by <u>not</u> filling the gap between the legs of a box culvert can be avoided by covering the box culverts with a concrete deck, but this adds to the overall thickness of the deck, which can increase the potential flood afflux.

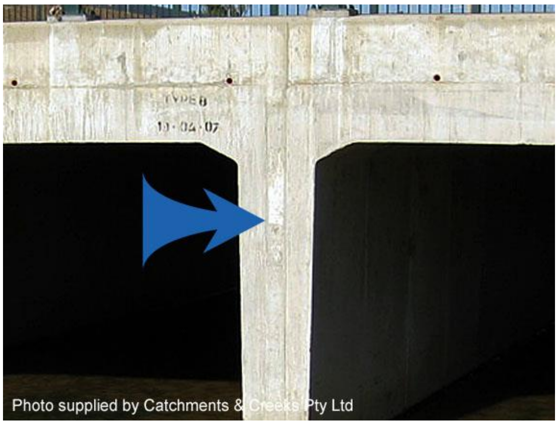


Photo supplied by Catchments & Creeks Pty Ltd

Gap between culvert legs filled with grout

The gap between the culvert legs filled with grout

- Some construction drawings specify that a 50 mm gap must exist between each culvert leg, and that this gap must be filled with pumped grout.
- This construction detail prevents water pressure passing between the culvert legs.

10. Bridge Scour Case Studies

Bulimba Creek, Pine Mountain Road, Carindale, Qld

Location map

Aerial image of the site


Photo supplied by Catchments & Creeks Pty Ltd

Looking upstream from bridge (1995)

Site history

- In 1995 a bridge was constructed over Bulimba Creek joining the east and west sections of Pine Mountain Road.
- The bridge was located on a small meander (S-bend) of the creek.
- To prevent the creek from eroding into the foundations of the bridge's eastern abutment, the creek bank was stabilised with a gabion wall.

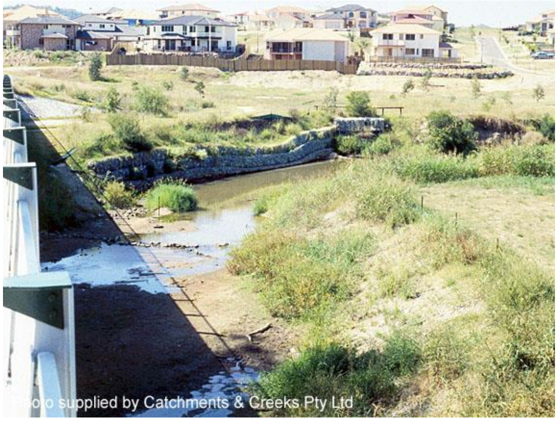
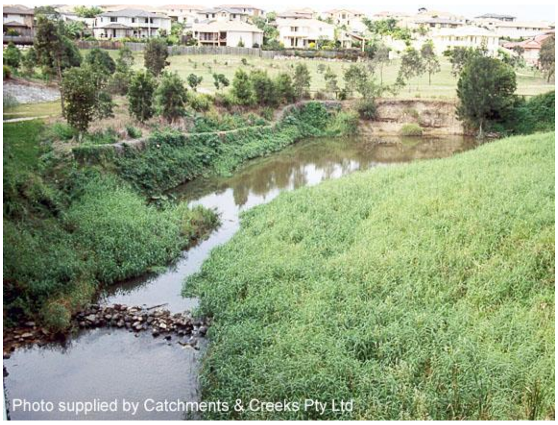


Photo supplied by Catchments & Creeks Pty Ltd

Looking upstream from bridge (1996)

The problem

- The problem caused by the placement of the gabion wall on the outside of a significant channel bend was that it induced high flow velocities along the face of the gabion wall.
- As a result, the same high flow velocities also existed near the creek bed causing a scour hole to form at the base of the gabion wall.
- Consequently, the gabion wall started to slide (slump) into the creek bed.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Looking upstream from bridge (2000)

Year 2000

- One of the main problems associated with gabion structures in Brisbane waterways is their propensity to attract non-native vines.
- Once established within the gabions, these vines can then move into the adjacent riparian zone.
- By the year 2000, vines had established along the gabion wall.

Bulimba Creek, Pine Mountain Road, Carindale, Qld

Looking upstream from bridge (2001)

Year 2001

- Maintenance work had cleared the gabions of the vines.
- The gabion wall continues to slump into the creek bed.

Looking upstream from bridge (2008)

Year 2008

- The gabion wall is now heavily vegetated, mainly with weed species.

Looking upstream from bridge (2014)

Year (early) 2014

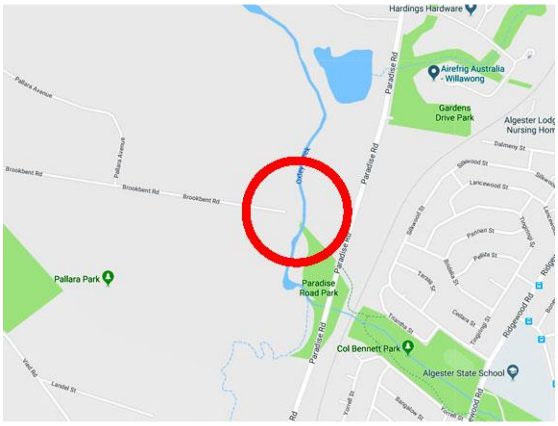
- The ongoing slumping of the creek bank and associated gabion wall has allowed a lower bench to form at the base of the bank.
- The formation of this bench, and the ongoing establishment of woody species should see the creek bank achieve a more ‘natural’ profile and stability.

Looking upstream from bridge (2014)

Year (late) 2014

- No visible indications left of the gabion wall.
- Weeds still dominate the creek bank, but the bank now appears to be stable.

Brookbent Road, Oxley Creek, Willawong, Qld



Site location

Aerial image

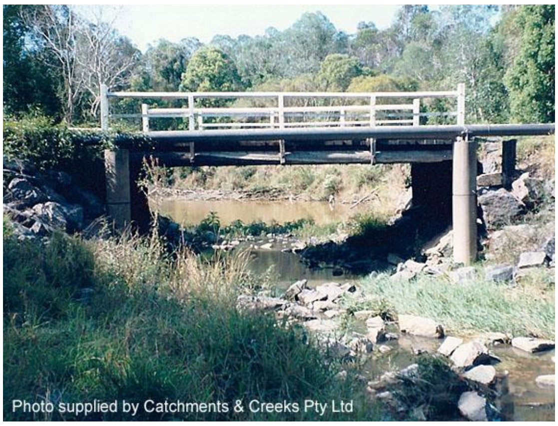


Photo supplied by Catchments & Creeks Pty Ltd

Pre-flood bridge, 1993

Photo supplied by Catchments & Creeks Pty Ltd

Looking upstream, 1993

Photo supplied by Brisbane City Council

Post May 1996 flood damage

Oxley Creek

- Oxley Creek is a deep-substrate, sand-based waterway.
- Sand movement during major floods is significant and during May 1996 bed movement within the creek caused the loss of all vegetation, including trees, along the waterway.
- Head-cut erosion began to cut through the approach roads each side of the bridge during the flood; however, the head-cut cut on the eastern side was the first to cut through the road.

Photo supplied by Catchments & Creeks Pty Ltd

Post flood damage looking upstream, 1996

Brookbent Road, Oxley Creek, Willawong, Qld

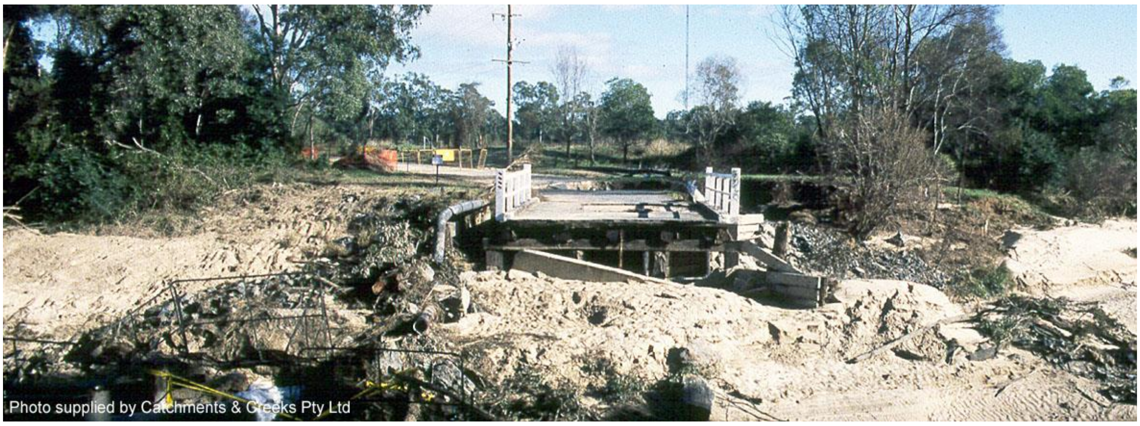


Photo supplied by Catchments & Creeks Pty Ltd

May 1996 flood damage (looking west)


Photo supplied by Brisbane City Council

May 1996 flood damage (upstream is on the right-hand side)


Photo supplied by Brisbane City Council

May 1996 flood damage (looking downstream)

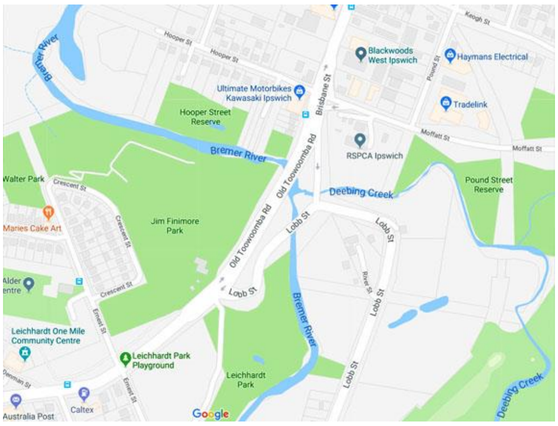

Photo supplied by Catchments & Creeks Pty Ltd

Pile field, Oxley Creek, 2010

Pile field

- A trial pile field was installed across part of the creek bed just downstream of the old bridge in an attempt to control ongoing bed scour which had the potential to impact upon upstream assets.

Old Toowoomba Road, Bremer River, Ipswich, Qld



Location map

Aerial image


Photo supplied by Catchments & Creeks Pty Ltd

Abutment scour, December 2008


Photo supplied by Catchments & Creeks Pty Ltd

Abutment scour, December 2008


Photo supplied by Catchments & Creeks Pty Ltd

Abutment scour, December 2008


Photo supplied by Catchments & Creeks Pty Ltd

Abutment scour, December 2008

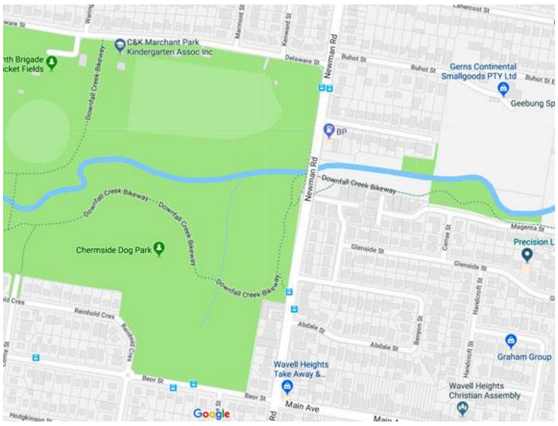

Photo supplied by Catchments & Creeks Pty Ltd

Pier scour, December 2008


Photo supplied by Catchments & Creeks Pty Ltd

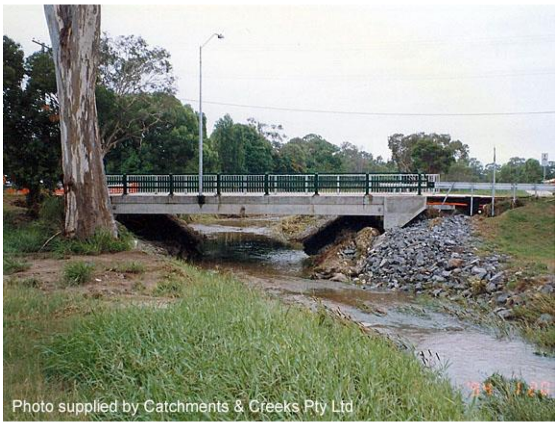
Pier scour, December 2008

Newman Road, Downfall Creek, Wavell Heights, Qld



Location map

Aerial image



Looking downstream, January 1994

Downstream of bridge, 1994

Upstream of bridge, 1994

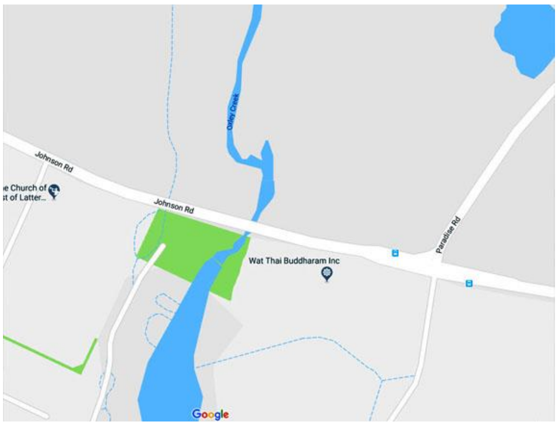
Damage to rock mattresses

- This 1994 flood event demonstrates the type of damage that can occur to rock mattresses during high-velocity flood flows.
- The rock mattresses 'rolled' away from the waterway banks due to:
  - the contracting flows on the upstream side, and
  - overtopping flows on the downstream side.

Damage to abutment footing, 1994

Damage to footpath and traffic barrier

Johnson Road, Oxley Creek, Forestdale, Qld



Location map

Aerial image

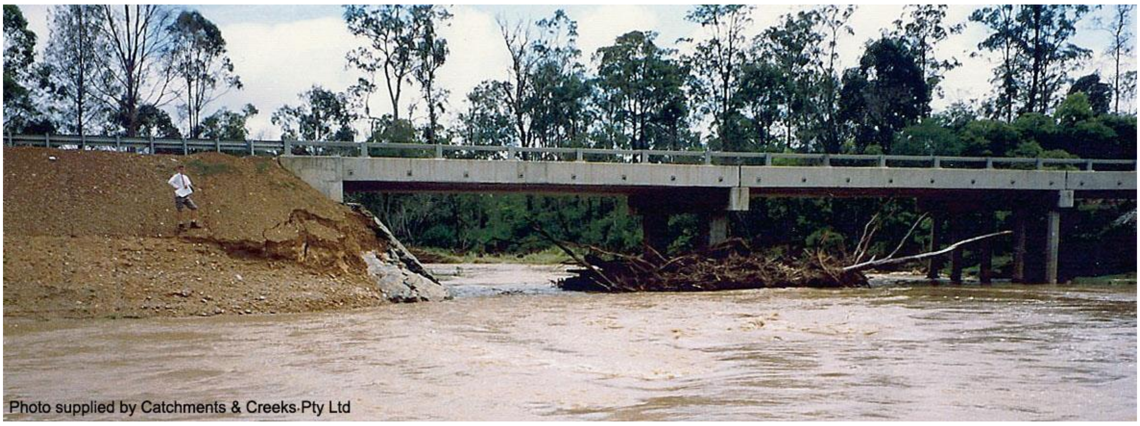


Photo supplied by Catchments & Creeks Pty Ltd

Debris raft captured by a bridge pier, 13 December 1991 (looking downstream)


Photo supplied by Catchments & Creeks Pty Ltd

Post flood debris raft, 1991

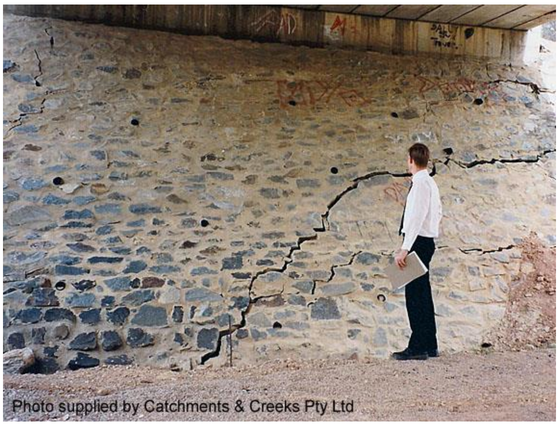


Photo supplied by Catchments & Creeks Pty Ltd

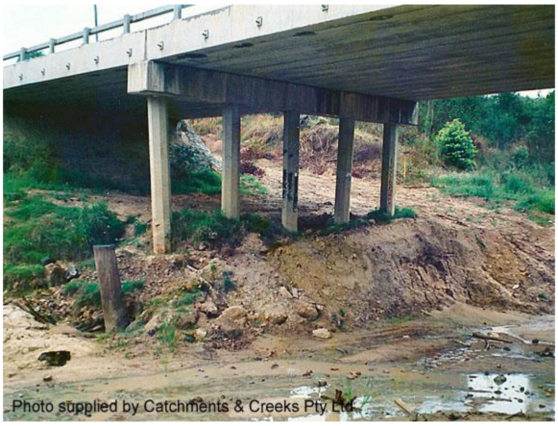
Damage to abutment stone pitching, 1991


Photo supplied by Catchments & Creeks Pty Ltd

Post flood waterway scour, December 1991 (looking upstream)

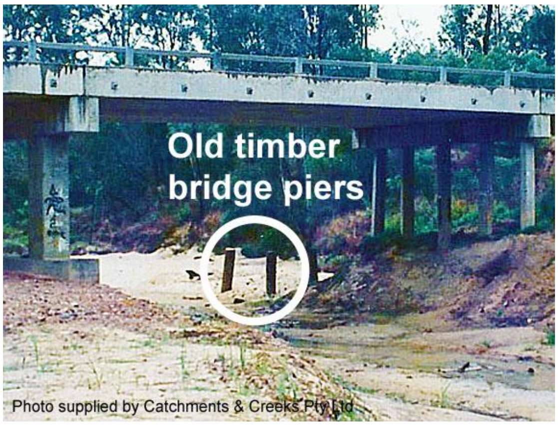
Johnson Road, Oxley Creek, Forestdale, Qld

Pre-1991 flood showing existing flood damage, November 1991



Pre-1991 flood, east pier

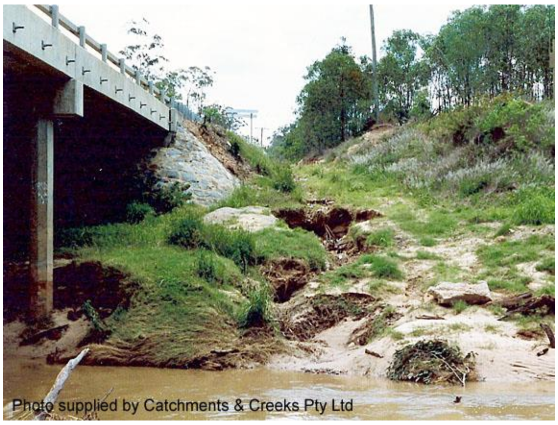
Post-1991 flood damage, east pier



Old timber bridge piers (1991)

Pre-1991 timber bridge

- A smaller, low-level, timber bridge existed on the site prior to the construction of the current concrete bridge.
- The old timber bridge had significantly less available flow area under the bridge, but the waterway under the bridge was well vegetated.



Diversion drain scour (1991)

Local stormwater damage

- During the 1991 storm, the diversion drain adjacent the bridge experienced some gully erosion (head-cut erosion).

Johnson Road, Oxley Creek – scour control measures


Photo supplied by Catchments & Creeks Pty Ltd

Installation of tie-beam (1992)

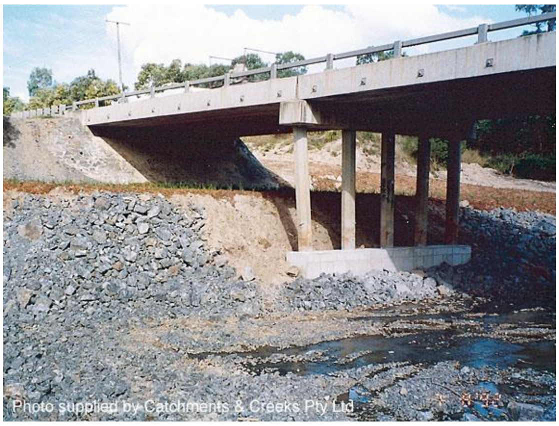


Photo supplied by Catchments & Creeks Pty Ltd

Tie-beam installed on east piers (1992)


Photo supplied by Catchments & Creeks Pty Ltd

Rock stabilisation of the creek banks and creek bed (June 1992)

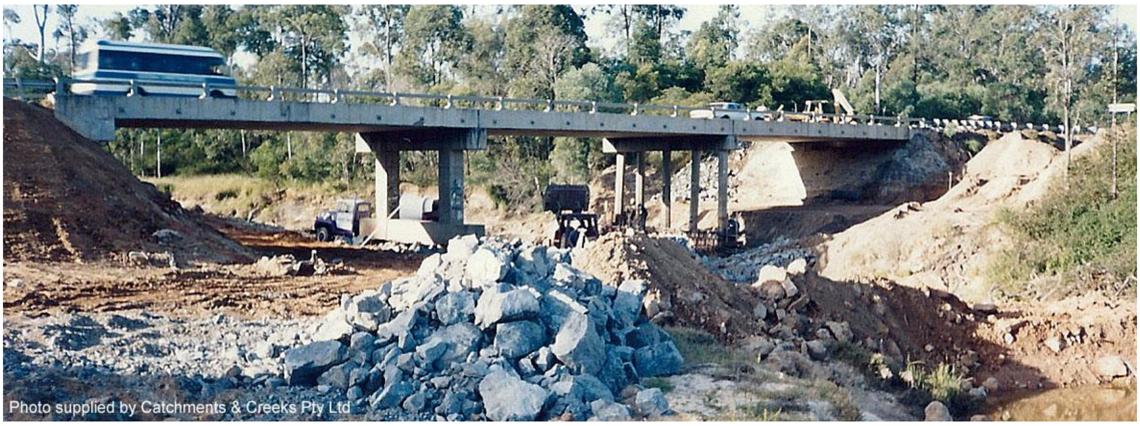


Photo supplied by Catchments & Creeks Pty Ltd

Rock stabilisation of the creek banks and creek bed (June 1992)

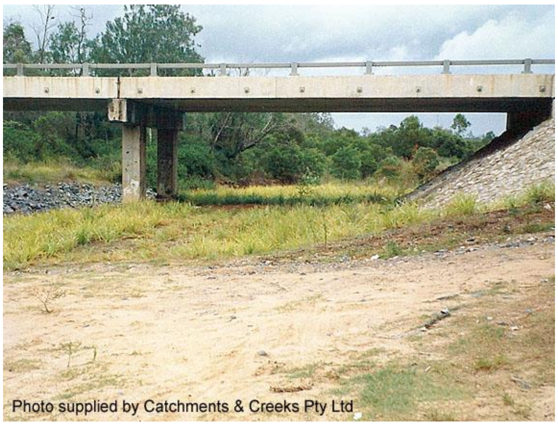

Photo supplied by Catchments & Creeks Pty Ltd

Rock placement on creek bed (1992)


Photo supplied by Catchments & Creeks Pty Ltd

Rock placement on creek banks (1992)

Johnson Road, Oxley Creek – scour control measures



Scour control, 1994

Stabilisation of overbank areas

- Site investigations identified that long-term scour control outcomes would benefit from the active incorporation of vegetation into the rock stabilisation measures.
- A critical concern at the site was allowing for the natural downstream migration of the sandy bed material, and the expected lowering of the creek bed.

Pile field (Oxley Creek, Willawong)

Alternative design option that was not adopted

- Two treatment options were considered:
  - a floating rock/mesh combination
  - a pile field
- The pile field option was considered desirable because it is compatible with a moving sandy substrate, and it allows for possible future lowering of the creek bed.
- Investigations into the pile field option were never concluded because in 1992 it was considered an untested concept.

Overbank floodway stabilisation, 1992

Adopted treatment option

- A unique scour control system was proposed that incorporated rock, rockfall netting and vegetation.
- Initially the sandy surface soil was removed and stockpiled.

Trenching of rockfall netting, 1992

Use of rockfall netting

- A trench was formed around the overbank floodway that passes under the bridge deck.
- Rockfall netting was anchored into this trench.

Johnson Road, Oxley Creek – scour control measures

Rock placement

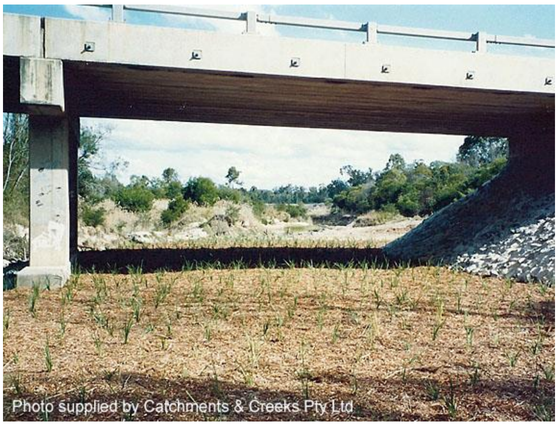
Rock placement

- Rock was then placed over the floodway.
- The anchored rockfall netting was then layed over this rock and anchored (trenched) on the other side of the rock-protected area.

Concrete ribs

Concrete ribs

- At specified intervals, concrete was poured in strips over the rockfall netting to attach it to the underlying rock.



Revegetation, 1992

Placement of vegetation

- The original overbank sand was then replaced over the rock stabilisation.
- This area was planted with *Lomandra*, which has a vigorous, fibrous root system, that further anchored the rockfall netting to the underlying rock.

Finished bridge scour works, January 1994

Johnson Road, Oxley Creek – May 1996 flood

Post May 1996 flood image

May 1996 flood

- The May 1996 flood was a significant event for Oxley Creek.
- The estimated return period for the 'storm' was originally reported a around a 1 in 20 year event; however, flood studies identified that this storm resulted in only a 1 in 5 year flood due to the very dry catchment conditions.
- The flood cause significant displacement of the rock placed along the creek bed, which is expected for a sand-based waterway such as Oxley Creek.

Debris on bridge pier, 1996

Debris capture

- During the May 1996 flood, woody debris once again wrapped around the central bridge pier causing a local acceleration of stream flows.

Loss of vegetation cover, 1996

Loss of some plants

- Almost all the Lomandra plants were scoured away from under the bridge, but not those plants located outside of the area shaded by the bridge deck (i.e. upstream and downstream of the bridge).

Overbank area under bridge deck, 2005

Final assessment of overall scour design

- This design approach is a low cost, but a high risk scour control option that is likely to require maintenance repairs after each flood event.
- Post flood maintenance is likely to include:
  - replacement of sand on the overbank areas under the bridge deck, and
  - replanting.

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