

Volume-2
Detailed Design,
Construction &
Maintenance

Small Structures for Rural Roads

A Practical Planning, Design,
Construction & Maintenance Guide

Paul Larcher, Robert Petts & Robin Spence
English Version, May 2010



global Transport
Knowledge Partnership

committed to sustainable transport



Acknowledgements

The initial funding for the research and drafting of this guideline was provided by DFID (Department for International Development) through their Knowledge and Research (KaR) programme. The guideline has benefited from constructive advice and guidance from a large number of different people, too numerous to mention, for which the authors are very grateful. The following people have contributed in detail to the work; Andreas Beusch, Michael Broadbent, Able Chiteshe, Jasper Cook, Simon Done, Robert Geddes, Colin Gourley, Kingstone Gongera, Heng Kackada, Tesfaye Kunbi, Kamal Pande, David Salter, Dave Stiedl, Julie Turner. The diagrams have been drawn by Patricia Petts. The authors are grateful to Simon Done, John Howe, Intech Associates and TRL for contributing a number of photographs for the guideline.

The original draft document (2005) was an output from a project funded by the UK Department for International Development (DFID) for the benefit of low-income countries. This current edition (2010) was updated and edited by TRL Ltd in association with Intech Associates, OtB Engineering (International) Ltd and KACE (Cambodia) through the DFID-South East Asia Community Access Programme (SEACAP). The document has been reviewed and finalised by the Global Transport Knowledge Partnership (gTKP) under management of the International Road Federation (IRF) with contributions from the Asian Development Bank and the Africa Community Access Programme (AFCAP).

The aim of this document is to provide guidance to planners, designers and practitioners of rural roads in developing and transition countries. It is based on proven techniques and experience and should be the basis of introduction of low cost but durable construction practices in environments experiencing severe resource restrictions. It is intended that rural road practitioners and professionals will be able to utilise and adapt the knowledge in this document to introduce more appropriate, affordable and sustainable techniques, standards and specifications into everyday practice, academic curricula and training, and contribute to rural poverty reduction.

© Paul Larcher et al., 2010

Larcher P., Petts R. and Spence R. (2010)

Any part of this publication, including the illustrations (except items taken from other publications where the authors do not hold copyright) may be copied, reproduced or adapted to meet local needs without permission from the authors, provided the parts are distributed free, or at cost and not for commercial ends, and the source is fully acknowledged as given below.

The views expressed are not necessarily those of DFID, ADB or IRF. All contributions are gratefully acknowledged. The authors are, of course, solely responsible for the opinions in this guideline.

We also thank the following organizations for their contributions:

DFID Department for International Development

 INTERNATIONAL ROAD FEDERATION
FEDERATION ROUTIERE INTERNATIONALE



ADB

**SEACAP
AFCAP**

© Paul Larcher et al., 2010

Larcher P., Petts R. and Spence R. (2010)

Small Structures for Rural Roads; A Practical Planning, Design, Construction & Maintenance Guide (SSRRG)

Table of Contents

Acknowledgements	02
Contents	03
Glossary	04

Volume-2: Detailed Design Construction & Maintenance

8. Structural Design	
Scour	10
Foundations	15
Structural slabs	17
Cut off walls	20
Pipes	21
Headwalls and wingwalls	33
Apron	37
Approach ramps	38
Downstream protection	40
Arches	46
Bridge design	50
Other design issues	64
9. Construction	65
10. Maintenance	85
References	91

Published in separate volumes:

Volume-1: Planning & Initial Design

1. Introduction	
2. Project Planning	
3. Design Criteria	
4. Structural Options	
5. Site Selection and Appraisal	
6. Watercourse Characteristics	
7. Materials	
Stone and stone masonry	
Brick and block masonry	
Timber and organic materials	
Plain and Reinforced Concrete	

Volume-3: Design Drawings and Bills of Quantities

Volume-4: Design Drawings (A3)

Glossary

The list below contains the abbreviations and engineering words along with their meanings as they have been used in the guideline. Words in italics are also listed in the glossary.

Abutment	The support for each end of a bridge deck that also retains the material forming the approach embankments.
Aggregate	Stone, sand, gravel or other inert material forming the major constituent of concrete. Fine aggregate is less than about 5mm in diameter, coarse aggregate is greater than about 5mm in diameter.
Approach Embankments	The earthworks that carry a road to a bridge, culvert or other structure
Apron	The flat area at the inlet and outlet of a culvert or the area of the watercourse bed which is protected downstream of a structure.
Arch bridge	A structure consisting of a curved beam spanning between the abutments, which may support a road over a watercourse, rail line or other road.
Barrel	<ol style="list-style-type: none"> 1. The main part of an arch which supports fill material or masonry superstructure. 2. The pipe or box part of a culvert which carries the flow of water.
Bearing	A connection between a bridge deck and abutment or pier that allows differential movement between the deck and supports.
Bill of Quantities	A list of all construction activities (materials, labour, supervision, transport, etc.) and other measures and requirements necessary to build a structure, which enables a total cost of the structure to be calculated through the application of quantities and unit rates.
Bio-engineering	The use of vegetation in engineering design to protect natural terrain and man-made structures from the problems associated with soil erosion.
Block(s)	Blocks are uniformly sized masonry units, normally made from aggregates and cement and designed to satisfy standards requiring a minimum crushing strength.
BoQ	See Bill of Quantities.
Brick(s)	A rectangular masonry unit made of baked clay or sand/cement, for example with dimensions 225 x 112.5 x 75mm.
Bridge	A structure with a span of 3 metres or more which permits the crossing of a watercourse (or another road or railway etc.) consisting of abutments and a deck. Bridges may also have wingwalls, approach embankments and pier(s). [This guideline considers bridges with spans up to 10m].

Camber	A slope across the width of the road to ensure water drains off the carriageway.
Carriageway	The part of the road that is normally driven over by vehicles.
Catchment area	The area drained by a watercourse.
Causeway	Similar to a vented drift. Causeways tend to be longer than vented drifts and have a larger number of openings.
Cement	A grey powdered substance, usually derived from processed limestone, which when mixed with water sets and hardens to form the binder in concrete.
Cofferdam	A temporary dam to exclude water from a submerged area allowing construction or maintenance work to be carried out.
Concrete	A manmade material which has similar properties to stone and is made from cement, aggregates and water.
Contours	Lines on a map which join points of the same altitude.
Cover	<ol style="list-style-type: none">1. The thickness of fill material between the top of a culvert pipe or arch and the road surface.2. The thickness of concrete between its outside face and a reinforcement bar.
Culvert	A structure which allows water to flow under a road. Culverts are usually up to 1.2m in diameter and may be round, square or arched.
Dead load	The weight of a structure including any items fixed to it.
Debris rack / grill	An open structure built upstream of a culvert, drift or bridge to collect debris (e.g. driftwood) and thereby prevent clogging of the road structure.
Deck	A part of a bridge which spans between abutments or piers and is driven on by traffic.
Design flood	The discharge of water used to calculate the size of a bridge or culvert opening. The design flood is normally based on an estimated probability of occurrence at a certain return period.
Dia	Diameter
Discharge	The amount of water which flows past a point in a watercourse in a given time.
Downstream protection	Engineering work carried out in a watercourse to prevent scour or erosion.
Dressed (stone)	Stone that has been shaped into rectangular blocks.
Drift	A simple structure, constructed from local or imported materials, which provides vehicles with a firm surface to drive through a watercourse.

Embankment	Compacted earth which supports a road above the normal ground level.
Falsework	Temporary boards or sheets and other materials used to support the underside of a concrete structure during hardening e.g. on the deck of a bridge. See <i>Formwork</i>
Ford	See <i>Drift</i>
Formwork	<ol style="list-style-type: none">1. Temporary boards or sheets and other materials used to contain concrete and produce its final shape during hardening.2. Temporary boards or sheets used to provide support and give arches their shape during construction. See <i>Falsework</i>
Foundation	The lowest part of a structure on which the rest of the structure is supported. Foundations are usually under the ground.
Gabion	Stone filled steel wire or mesh cage. Gabions can be used for retaining walls, abutments, downstream protection and drifts.
Headwall	A wall at each end of a culvert pipe used to retain the road formation.
High flood	The highest flood level that is known to have occurred in a watercourse.
IMT	Intermediate Means of Transport (e.g. bicycles, motorcycles, carts)
Invert	The floor of a culvert or channel.
Invert slab	See <i>drift</i> .
Irish bridge	See <i>drift</i> .
Kerb	A hard edge to a road that stands up above the level of the carriageway.
Large bore culvert	A culvert with a diameter of greater than 1 metre.
Live load	A temporary load on a structure e.g. pedestrian or vehicle.
Low level water crossing	<i>Drift, splash, causeway, Irish bridge or (vented) ford.</i>
m	metre
mm	millimetre
m³/s	cubic metres per second
Masonry	A generic term used to describe the following materials; <i>bricks, blocks, dressed stone, random stone, rubble.</i>

Mass concrete	Concrete without any reinforcing steel.
MFL	Maximum Flood Level.
Mortar	Mortars are composed of clean sand and a binding agent (such as cement) and are used to bond masonry units together.
N	Newton
N/A	Not Appropriate
Outfall	The point where a culvert or channel discharges water.
Overtopping	When water flows are greater than the capacity of a channel or culvert, water will flow onto surrounding ground, above the channel. Embankments may also be overtopped.
Parapet	The protective barrier, wall or railing at the edge of a bridge deck or other structure.
Permeability	The rate at which water (or other liquid) will flow through the soil.
Pier	A wide column or wall used to support long bridge decks.
Pile	A pole driven into the ground, used as a foundation. Piles can be made from timber, steel or concrete. (guidance on the use of piles is not covered in this guideline).
Piped drift	See <i>vented ford</i> .
Plasticiser	A plasticiser is an additive to the mortar used in small quantities to improve the workability of the mix or to achieve the same workability with less water, thus improving both strength and durability.
Plum	A large stone put into mass concrete to reduce the volume of cement required.
Pozzolan	A natural or man-made material which when mixed with water displays similar properties to cement.
Prestressed (concrete)	A method of increasing the strength of concrete using high strength steel bars, prestressed before the concrete sets (not covered in this guideline).
Post-tensioned (concrete)	A method of increasing the strength of concrete using high strength steel bars or cables, tensioned after the concrete sets (not covered in this guideline).
Random stone masonry	Masonry constructed from stones with minimal dressing.
Reinforcement (concrete)	Steel rods or mesh placed into concrete to increase it's strength.
Reno mattress	A long wide, flat <i>gabion</i> .
Retaining wall	A wall used to hold back soil.

Return period	The average time between two storms producing the same design flood.
Rip-rap	Stones, generally between 5kg and 100+kg, used to protect a watercourse from scour.
Road structure inventory	A list or database of all the structures on the road network, which allows planning of inspection and maintenance.
Rubble masonry	See <i>Random stone masonry</i> .
Running board	Boards which are fixed to the bridge deck in the direction of traffic flow, on which the vehicle wheels run. They provide protection to the floor planking from wear and tear from heavy vehicles.
Runoff	Water which flows over the ground as a result of rain.
Scour	The deepening and/or widening of a watercourse or channel due to erosion by flowing water.
Scupper	A vertical or horizontal hole through a bridge deck or parapet for the purpose of deck drainage
Settlement	Small movements (downwards) of part or all of a structure due to compression of the ground below.
Shuttering	The part of formwork that is actually in touch with the concrete.
Soffit	The underside surface of a beam, deck slab or an arch shape e.g. in a culvert pipe.
Splash	See <i>ford</i> .
Springing	The ends of the curve of an arch.
Substructure	The foundations, abutments, piers and other parts of a bridge that support the deck and associated items (see <i>superstructure</i>).
Superstructure	The deck, beams, parapets and other items associated with the deck of a bridge.
Surcharge	Material placed above and behind a <i>retaining wall</i> which has the effect of applying an additional horizontal load on the wall.
Topography	The characteristics of land in terms of elevation, slope and orientation.
Trial pit	A pit dug to determine the ground conditions at a proposed structure site.
Vented ford / drift	A low level structure built across a stream or river with openings to allow water to pass through. After heavy rain additional water may flow over the top of the structure temporarily submerging the roadway.

vpd	vehicles per day
Watercourse	A natural drainage channel in which water may or may not be flowing.
Watershed	An imaginary line along a ridge between two catchment areas, from which water flows away in both directions – the limit of a water catchment.
Watertable	The level at which the ground is fully saturated with water.
Waterway	An artificial (manmade) channel designed to carry water.
Weep holes	Small openings (often pipes) in the bottom of retaining walls and abutments to allow drainage of water from behind a structure, reducing the pressure on that structure.
Whole life cost	The total cost of a structure which includes design and construction costs, in addition to regular and periodic maintenance over a period of time (the life of the structure).
Wingwall	A retaining wall adjacent to a bridge abutment to support the embankment fill. Wingwalls may also be found adjacent to a culvert headwall.
x-section	Cross section

Chapters 1-7 of this publication are published in Volume-1

8. Structure Design

There is a large amount of energy stored in flowing water. A fast flowing river 0.5m deep can wash away a car or pickup truck. Even at lower volumes and velocities, water can wash away road structures. A high priority task in designing a road structure is therefore to minimise the disturbance to the water flow in the channel, which then minimises the potential damage to the structure and scouring of the watercourse.

The vast majority of structural failures occur during flood periods and over 50% of these failures can be attributed to scour. The initial section of this chapter deals with scour and how to design and construct a structure to withstand scour effects.

There are often a number of elements which form a road structure. In some cases these are common to a range of structures. After the section dealing with scour this chapter is broken down into sections which each cover an individual structural element. The table below shows the sections which must be consulted for the design of different structural elements for water crossing structures.

Structural Item	Drift	Culvert	Vented Drift	Large-bore Culvert	Bridge
Foundations	o	o	o	o	o
Structural slabs	o		o	o	
Cut off walls	o	o	o	o	o
Pipes		o	o		
Headwalls & wingwalls		o	o	o	o
Apron	o	o	o		
Approach ramps			o	o	o
Downstream protection	o	o	o	o	o
Arches				o	
Bridge design:				o	o
- general				(arch bridges)	
- deck					
- abutments					
- piers					
- bearings & joints					

Scour



Figure 8.1 Bridge damage due to scour of abutment

Scour is the erosion of material from the river sides and bed due to water flow. Damage due to scour is the most likely cause of structural failure. Minimising or eliminating the effects of scour should therefore receive the most attention when designing any structure. Scour can occur during any flow but the risk is generally greater during floods.

There are three major types of scour to be considered:

1. River morphology: these are long-term changes in the river due to bends and contractions in the channel affecting the shape and course of the channel.
2. Construction scour: this is the scour experienced around road structures where the natural channel flow is restricted by the opening in the structure. The speed of the water increases through the restriction and results in more erosive power, removing material from the banks and bed.
3. Local scour: occurs around abutments and piers due to the increased velocity of the water and vortices around these obstructions.

The latter two scour types are the most important to consider when designing a structure. The amount of scour at a structure will be affected by the following factors:

Slope, alignment and bed material of the stream

The amount of scour is dependent on the speed of the water flow and the erodability of the bed material. Higher water velocities result in more scour.

Vegetation in the stream

Any vegetation growing in the stream can improve the strength of the river bed, reducing scour. The vegetation can also reduce the speed of the water.

Depth, velocity and alignment of the flow through the bridge

The faster the flow, the more scour will occur. If the flow is not parallel to the constriction more scour will occur on one side of the constriction.

Alignment, size, shape and orientation of piers, abutments and other obstructions

Water is accelerated around these obstructions, creating vortices with high velocities at abrupt edges on the obstruction, increasing the scour depth.

Trapped debris

Debris can restrict the flow of water and cause an increase in water velocity. It is important that structures are designed to minimise the chances of debris being trapped and to ensure that inspections and maintenance

are carried out after flood periods to remove any lodged debris.

Amount of bed material in the water

If the water is already carrying a large amount of material eroded from further upstream a greater amount of scour will occur at the structure.

It is difficult to accurately predict the level of scour that may be experienced for a particular design. There are many formulae for predicting the amount of scour around a structure but these formulae, in general, require detailed knowledge of the river and bed characteristics. They are also based on empirical data and will often give different design scour depths. Engineering judgement will be required. This guideline proposes a number of 'rules' for designing to resist scour. It must be stressed that these rules are not infallible and local knowledge should also be taken into account when designing a structure.

Rule 1 - Provide minimum foundation or cut off wall depths

Regardless of the required depth for foundations determined by the ground conditions and predicted scour, the minimum foundation depths shown in the table below should be provided. The depth is measured from the lowest point in the bed of the watercourse at the crossing point. These depths can only be reduced where firm rock is encountered at a shallower depth and the foundations are firmly keyed into the rock.

Structure	Foundation Depth	Cut off wall depth
Drift	Not applicable	1.5m
Relief culvert	Not applicable	1.0m
Watercourse culvert	Not applicable	1.5m (headwalls and wingwalls)
Vented drift	Not applicable	2m
Large bore culverts	3m	3m
Bridges	3m	3m

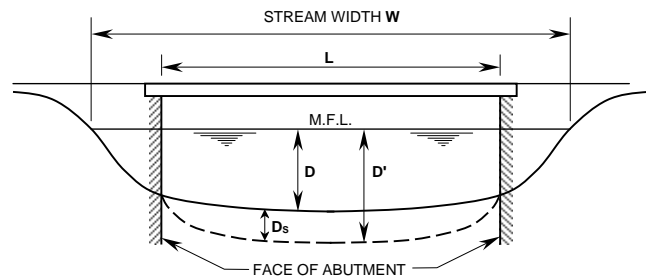
Rule 2 - Create a minimal constriction to the water flow

The amount of scour experienced at a structure is proportional to the restriction in the normal water flow. If the flow is considered unconstrained then scour will not exist. If the site conditions permit, the following opening widths should be provided to eliminate the effects of scour.

Peak flood flow rate	0.5	1	2	4	6	8	10	15	20	25	30	m³/s
Minimum width (W)	3.5	5	7	10	12	14	15	19	21	24	26	m

In some cases, particularly for bridges and larger flows, it will not be possible to provide the opening widths shown in the table above. The design, particularly the level of foundations, should allow for a lowering of the river bed level due to scour. The amount of scour that will occur depends on the following 3 factors:

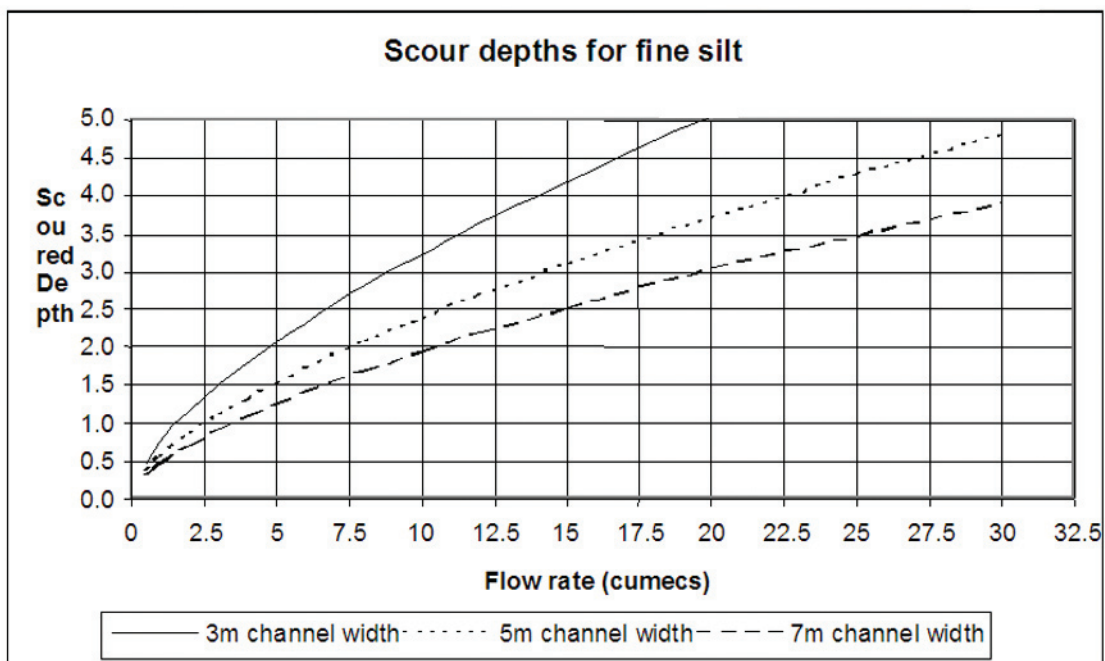
- constricted flow width
- maximum flow rate
- the type of material forming the sides and bottom of the watercourse.

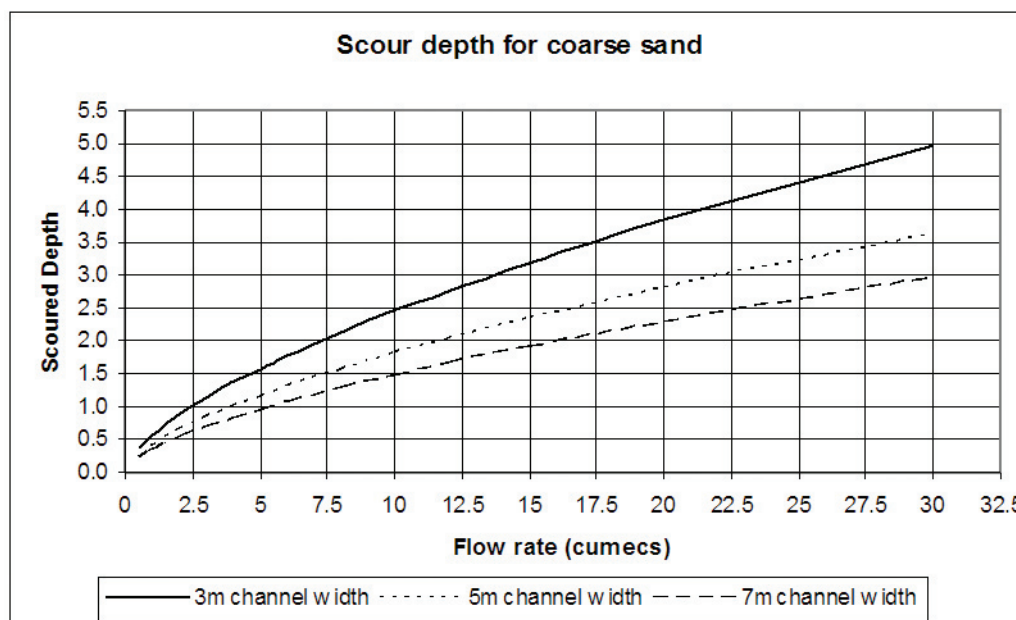
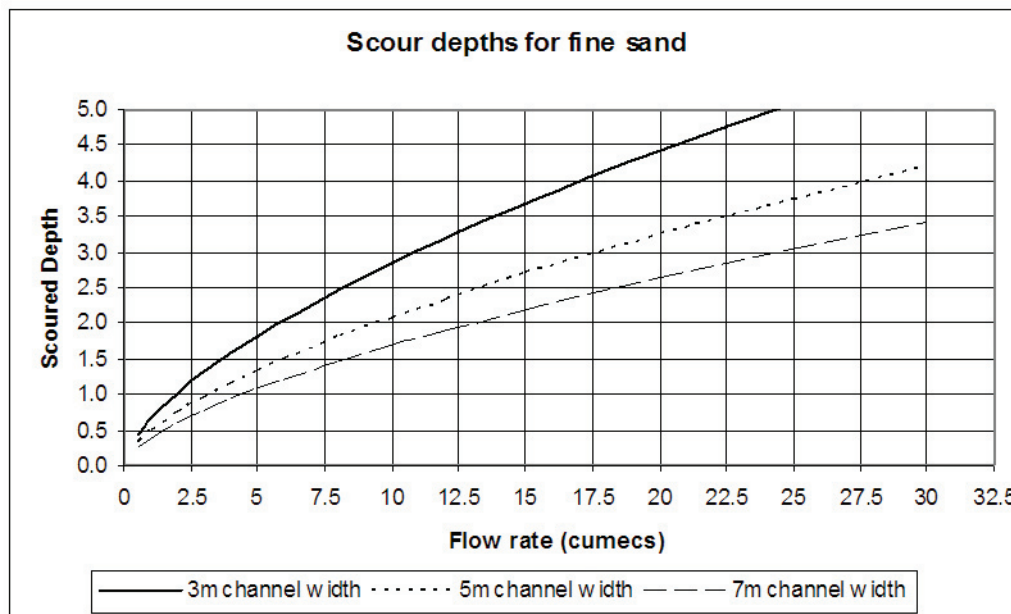


W = THE ORIGINAL WIDTH OF THE STREAM
 L = THE DESIGNED WATERWAY. WHEN THE BRIDGE IS ASSUMED TO CAUSE CONTRACTION, L IS LESS THAN W
 D = THE ORIGINAL DEPTH OF STREAM
 D' = THE EXPECTED SCOUR DEPTH UNDER THE BRIDGE DUE TO ITS CONSTRUCTION
 D_s = ADDITIONAL DEPTH OF SCOUR DUE TO CONSTRICTION OF BRIDGE

The depth of scour is therefore:
 Depth of scour = flood water depth at structure - original unconstrained watercourse depth
D_s = D' - D

The three following graphs allow the prediction of the water depth in the channel, which will allow the depth of scour to be calculated.





The depth of scour indicates the general level of erosion that will occur in the river bed. Additional local scour will occur near bridge abutments and wingwalls and also at the edges of aprons. The following table shows the factor that the general scour should be multiplied by to calculate the depth of scour that may be encountered near structural elements.

All foundations should be constructed below the predicted depth of scour.
 Predicted maximum **depth of scour = depth of general scour x local scour multiplier**

Local scour at structural elements	Local scour multiplier
Long abutments parallel to water flow in straight channels	1.5
Abutments in curving channels and/or part of structures with multiple openings	2.0
Abutments and wingwalls where flow reaches structure at an angle greater than 20 degrees	2.25
Ends of protective aprons or drift slabs	2.5

Rule 3 - Avoid the use of piers

If piers are absolutely necessary they should be aligned exactly in the direction of water flow.

The following graph shows the likely depth of scour that may be encountered around piers that are aligned in the direction of water flow. Scour around piers will be doubled for piers that are aligned 10-15° away from the direction of water flow.

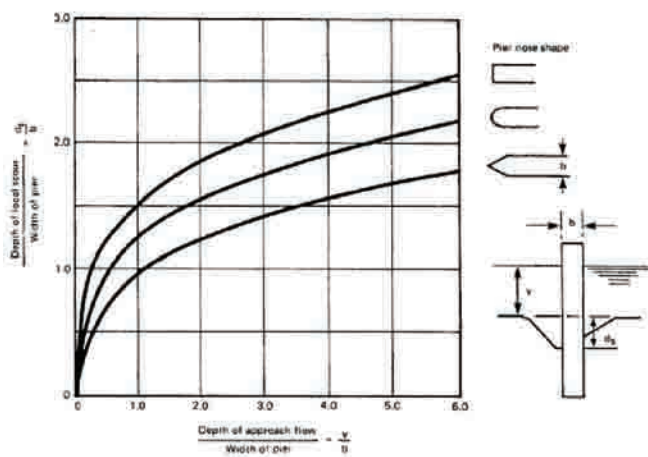


Figure 8.2 From TRL ORN9



Figure 8.3 Failure of structure due to a combination of constriction of the watercourse (structure too small), scour and inadequate protection of abutments.

Foundations

The strength and durability of any structure will be determined by the quality of its foundation and the bearing capacity of the soil (refer to chapter on site selection and appraisal).

For small, simple structures such as drifts, culverts and vented fords it will be sufficient to construct the structure on well drained, firm soil. Referring to the soil bearing capacity tables in chapter 5 these conditions include any rock, clays and silts that are at least “firm” or sands and gravels that are at least “loose”. These conditions

can be determined on site by checking for footprints when walking over the proposed location. If more than a faint footprint is left it will be necessary to improve the ground before construction commences.

If the ground conditions are poor at the proposed level of the structure's foundation it will be necessary to continue excavation to firm material that can provide sufficient bearing capacity. The engineer then will have three options for the construction of the structure:

- Alter the design to lower the level of the foundations,
- Replace the poor excavated material with new material that has a better bearing capacity (e.g. a well graded sand and gravel) that is compacted into the excavation in 300mm layers,
- Provide a piled foundation (not covered by this guideline).

For all structures it is necessary to start the construction on a well drained, level base. The excavations for all structures, apart from those built on rock, should be dug an additional 300 mm below the proposed foundation level. A 300mm layer of sand and fine gravel should then be placed and levelled in the bottom of the excavation to provide a good base for the structure. Alternatively at least 10 cm of lean concrete blinding should be laid to provide a firm clean working platform.

A rough method for calculating the load exerted by the foundations of a vented ford or large bore culvert on the ground will be to calculate the load of the structural fill material and multiply by a safety factor.

Material	Load per metre of fill	Safety factor
Concrete/gravel	25kN	1.5
Earth	20kN	1.5

For example:

The central section of a vented ford is 2m high (from its foundation level) and has masonry walls with an earth fill inside. What is the foundation loading?

The load exerted on the soil below the structure will be: $2 \times 20 \times 1.5 = 60 \text{ kN/m}^2$

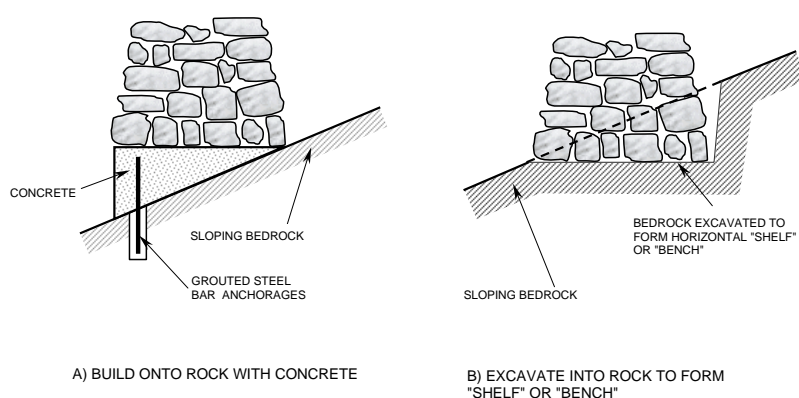


Figure 8.4 Construction on sloping bedrock

Where a foundation is to be built on rock which may be sloping down to the watercourse, it will be necessary to form a level platform for the foundation. This may be achieved by either breaking out the rock to give a level foundation or building up the foundation to level by placing concrete around drilled and grouted mild steel bars. The preferred option which should be adopted, unless the rock is too

hard to break out, will be to break out a level platform. Sloping firm rock abutments are of course suitable for arch bridge springings. In these circumstances the rock should be excavated approximately to a plane roughly at right angles to the slope of invert of the arch at the springing. The face may be cut in steps to increase bond between the structure and rock foundation.

Structural Slabs

Drifts

The primary objective in the design of a drift is to provide a suitable surface for vehicles to drive across while creating minimal disturbance to the water flow. Drift slabs should therefore follow, as closely as possible, the bed of the watercourse. The drift slab surface should be no more than 200mm above the existing bed level. However, it is desirable to construct the drift with a finished level at the same level as the river bed. Slabs which are constructed more than 200mm above the existing bed level are likely to cause severe erosion downstream of the drift, requiring frequent maintenance.

NOTE: There is one situation where it may be permissible to raise the finished level of the drift above the river bed. If the site selected for the drift appears to suffer from silting the final level of the drift could be raised 200-300mm above the natural river bed. This raising of the level will cause water to flow slightly faster over the drift and reduce the potential for the drift to silt up.

If the river is flowing in a channel with banks on each side it will be necessary to ensure that there is a suitable approach slope from the road on each side to the drift in the bottom of the river bed. These approach slopes should not be so steep that vehicles get stuck at the bottom of the drift. A maximum gradient between 5 and 10% will be determined by the vehicles that are using the road. A gradient of 10% may be used if the only vehicles using the road are cars and light trucks. A gradient of 7.5% may be used for medium size trucks and small minibuses and a gradient of 5% used if lorries and buses are expected to travel along the road. Allowance should be made for the fact that heavier vehicles may use the road following improvement of the route.

Although vehicles may not be able to cross the drift during periods of high water it is essential that the drift slab extends beyond the highest flood level to ensure that scour and erosion will not take place at each end of the drift. It may, therefore, be necessary to construct the drift slab to the top of the river banks at the end of the approach slope.

To reduce the cost of construction it may be possible to reduce the width of the drift slab so that it is narrower than the normal road width.



Figure 8.5 Guide stones at the edge of a drift

Vehicles would not be able to pass each other on the drift so the designer must ensure that there is sufficient passing space on each side of the drift to allow vehicles to wait and pass each other. To prevent vehicles driving off the drift and possibly getting stuck in the soft or loose river bed, or vehicles attempting to pass each other on the drift, guide stones should be placed along the edges of the approaches and across the drift.

The width of the central or flat middle section of the drift should minimise disturbance to the water flow. The construction of the road will cause a larger amount of water to flow across the drift due to water flowing off the road along the side drains. Drifts should be constructed with the central flat sections of the following length:

River crossings	width of the watercourse
Relief and perennial stream drifts	width of the dry bed: minimum dimension of 2m

Drift slab construction

There are four possible solutions for constructing the drift slab, in descending cost:

1. concrete slab
2. cement bonded stone paving
3. dry pitched stone paving
4. gabions with gravel or broken stone

The main factors affecting the choice of construction method are:

1. the nature of the river bed
2. the expected volume and flow rates of the water
3. the availability of different construction materials
4. the cost of labour

If large volumes of fast flowing water are expected it will be necessary to use a concrete slab or cement bound stone paving as the water will erode gravel and dislodge hand pitched stones. In the cases of slower flowing water or small streams hand pitched stone or gabions are likely to be acceptable and a cheaper option.



Figure 8.6 Concrete slab drift

Concrete slab

Although concrete slabs are the most expensive they are a long lasting, low maintenance solution. The concrete slab should extend the full width of the drift between the cut off walls with a minimum thickness of 250mm. In areas where stone is locally available 'plums' may be put in the slab to reduce the amount of cement required and hence reduce the overall cost.

Where plums are used they should not have a dimension greater than 75mm (100mm where the slab is 300mm or thicker) and should be placed as far as possible in the middle of the slab.

Cement mortar bonded stone paving

Stone paving will offer a cheaper alternative to a concrete slab in areas where masonry or locally manufactured blocks of sufficient strength are available. The slab should be a minimum of 300mm thick which may require more than one course of paving to be laid. The blocks should be laid in an arrangement to ensure that the different courses interlock with each other.

Hand pitched stone

In areas where masonry stone is widely available this option is likely to be cheaper than constructing a concrete slab. However, it is only suitable for low velocity flows and can take a considerable length of time to construct for larger crossings. It is essential that the stones are well placed to ensure that they are interlocked to prevent them being washed out by the water. The whole structure can be washed away if the water can wash out one stone, as this weakens the remaining structure. Larger stones are better than smaller ones as they are less likely to be washed away. The best stones to use are angular and flat faced and should be placed on their edge, to give the greatest interlock between stones.



Figure 8.7 Hand pitched stone drift



Figure 8.8 Gabion drift



Figure 8.9 Natural fibre matting inserted in the top and face of the gabion can encourage vegetation growth to stabilise the gabion face and retained material.

Gabions and gravel

This option is likely to be the cheapest and quickest option for constructing a drift slab. Smaller stones may be used in the gabion than for hand pitched stone and maintenance does not require specialist skills. However, gabion baskets and gravel will be unable to withstand large flows of water. The drift basically consists of a gabion basket on the downstream side which acts as a dam to prevent the gravel being washed away. (note that the sand has been washed out on the photo but severe erosion has not occurred).

Where gravel may be washed away but there is a reasonable amount of gravel in the riverbed it may be possible to protect the riverbed and trap gravel and sand in the top of a gabion mattress to create a vehicle running surface. Gabion mattresses are

similar to gabion baskets except that they are a flatter section; usually 250-300mm deep, and cover a wider plan area. Sand and gravel will tend to be trapped on the top of the gabions which will prevent wear of the wire by traffic.

Slab construction (vented fords and large bore culverts)

The number of options available for the type of slab will depend on its ultimate use. If the slab is to be used on the top of a fill layer, as in the case of vented fords or causeways, it is likely that only a concrete slab or cement bonded stone paving would be suitable. The slab should also have a 2-3% crossfall in the direction of water flow to ensure that the deck drains quickly when overtopped and sand or silt is not deposited on the running surface.

Cut off walls

Cut off walls, also called curtain walls, should be provided at the edge of a structure. They prevent water eroding the material adjacent to the structure, which would eventually cause the structure to collapse.

Cut off wall locations

Structure	Locations
Drift	Upstream and downstream sides of drift slab
Culvert	Edges of inlet and outlet apron
Vented ford	Upstream and downstream sides of main structure and approach ramps
Large bore culvert	Upstream and downstream sides of approach ramps. The foundations of the main structure should be built at a greater depth than standard cut off walls; below the possible scour depth
Bridge	The foundations of the main structure should be built at a greater depth than standard cut off walls; below the possible scour depth

The absence of cut off walls at the inlet of the structure could allow water to seep under the apron and structure causing settlement and eventually collapse of the structure. At the downstream end of the structure the flowing water could erode the material next to the apron, eventually eroding under the apron and causing it to collapse.

The depth of the cut off walls will depend on the ground conditions. Where a rock layer is close to the ground surface the cut off walls should be built down to this level. If there is no firm stratum near the surface the cut off walls should extend the minimum dimensions listed in the previous section on scour. The method of construction of the cut off wall should be similar to the construction method and material used for the remaining parts of the structure, to facilitate the construction and reduce cost.

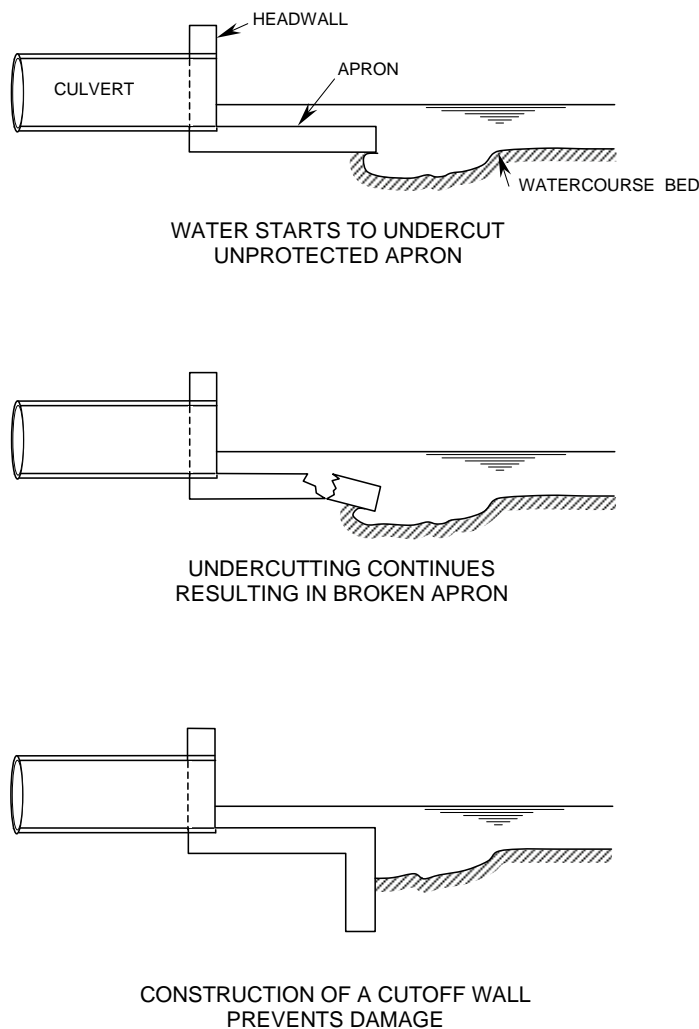


Figure 8.10 Cut off wall

Type A - Flat outfall (less than 5%)

This culvert type should be used in flat areas and for watercourses with shallow gradients. In these cases the road should be built up over the culvert with ramps 20-50m long or to comply with national road vertical alignment standards. A culvert will silt up if it is positioned too low to avoid the requirements of building up the road alignment.

Type B - Intermediate outfall (approx. 5 - 10 %)

This arrangement requires the culvert to be excavated slightly into the existing ground, although the invert of the culvert at the inlet should be at the same level as the bed of the watercourse. The outlet of the culvert will be below the existing ground level and will require an outfall ditch to be dug with a gradient of approximately 4%. The road will still have to be built up with ramps or alignment adjustment over the culvert to provide the minimum required cover.

Pipes

Pipes will be required for culverts and vented fords. This section initially covers the vertical positioning of culverts, followed by the sizing of pipes and then other design issues including types of culvert and construction options.

Vertical positioning of pipes

The vertical positioning of culverts requires particular attention. The consideration of the natural vertical alignment of the watercourse must take precedence over the vertical alignment of the road. Neglect of this factor has led to many culverts being installed incorrectly, leading to excessive silting, erosion and in some cases failure. It should be remembered that the water forces during peak flow will be actively promoting the return to the natural watercourse alignment.

There are three basic culvert installation situations. The most appropriate culvert type will depend on the outfall gradient. See also the section on setting out in chapter 9.

Type C - Steep outfall (more than 10%)

The culvert can be installed without building up the road level. The culvert should be buried to provide adequate cover over the pipe. A drop inlet will be required at the entrance to the pipe (see below) and a short outfall ditch at the exit. On steeply sloping ground careful attention should be given to preventing erosion downstream of the culvert. Further information on erosion protection is given in a later section in this chapter.

Pipe sizing

The most appropriate method for sizing pipes is to carry out a design based on one of the three cases shown below. However, this design process requires data on the culvert catchment area and predicted rainfall intensity. In the absence of other data the figure below suggests the size and number of pipes that are required to give a suitable culvert capacity for the recommended storm return period. Figure 8.11 is based on gentle/rolling ground with medium soil permeability.

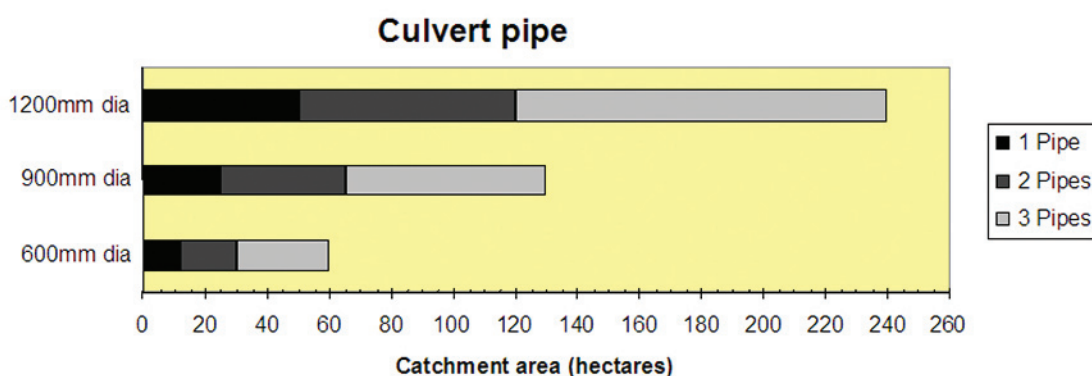


Figure 8.11 Culvert pipe requirements

The design process for sizing pipes will depend on the particular flow characteristics of the water through the pipes. There are three cases which must be considered as shown in the following drawings. Proceed with the following steps for the design of the pipe.

Maximum flow rates for 600mm diameter case 3 culvert

Invert slope	Max flow rate
1%	20 l/s
2%	40 l/s
3%	50 l/s
4%	60 l/s
5%	70 l/s

Step 1: Peak flood flow

The first stage in culvert pipe design is to estimate the maximum expected peak flood flow, which was discussed in chapter 6.

Step 2: Check for case 3

If case 3 exists it will not be necessary to carry out any further work, as the culvert size is determined by the requirements of minimum diameter for cleaning. The table opposite shows the maximum flow rates for assuming case 3 flow exists for a 600mm diameter culvert with an invert on different gradients. For case 3 to exist the flow at the downstream end of the culvert must be uninhibited. This will require the outfall from the culvert to have the same or greater slope than the invert of the culvert.

- **Case 1:** Case 1 has water backed up on the upstream side of the culvert, but the water is able to flow freely away from the downstream side of the culvert. This situation is likely to occur on sloping ground where the outfall continues down the hillside.
- **Case 2:** Case 2 has water backed up on both the upstream and downstream sides of the culvert. The flow of water through the culvert is less than in case 1 (for the same size culvert) as the water backed up downstream reduces the flow. This situation will exist in flat areas where the water in the culvert outfall flows slowly or ponds in the channel.
- **Case 3:** Case 3, with no water backed up at either end of the culvert, will only occur for low flow rates and where the water can flow away from the culvert in the downstream channel. If flow rates are low but the outfall slope is shallow the culvert is likely to operate under case 2.

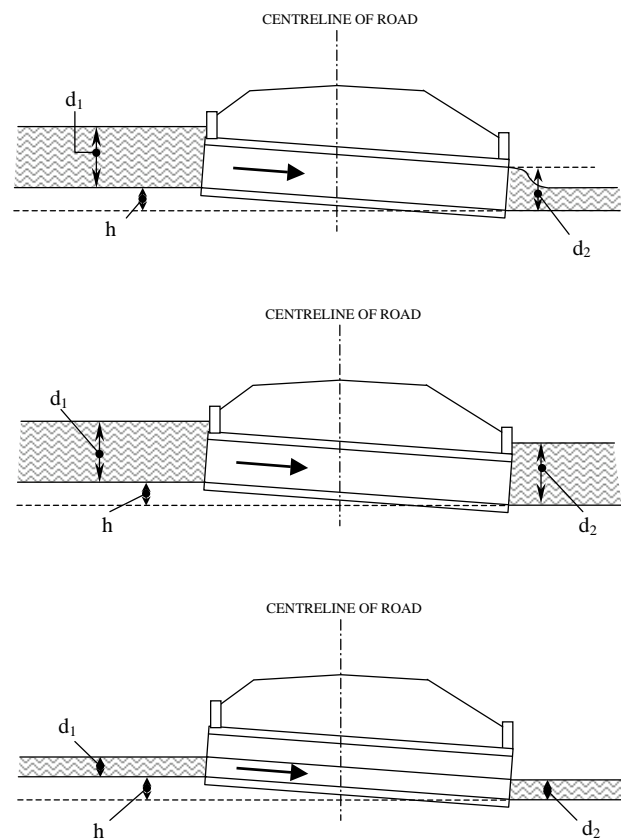


Figure 8.12 Pipe design cases

Step 3: Pipe dimensions

In order to design the pipe it will be necessary to guess a pipe size and invert level and gradient. These dimensions will be used for the flow calculations and then compared with the predicted peak flood flow. Through experience the designer will be able to make a good initial guess at the size and/or number of culvert pipes required. For designing a culvert a first guess should be taken as one 600mm pipe. A fall of 3-5% should be placed in the invert to ensure that water flows through the culvert without depositing silt and other debris (see the section below on culvert types for a discussion of inlet arrangements).

Regardless of the design water flow, all pipes should have a minimum diameter of 600mm to ensure that they can be manually cleaned when clogged

Step 4: Maximum upstream depth

During flood periods storm water will back up in the upstream channel of the culvert. The amount of back up will depend on the culvert characteristics. The amount of back up permitted should be chosen to ensure that the water does not flood cultivated land and property or overtop the road embankment and culvert headwall. The depth of water due to backing up is measured for the stream bed and is shown as d_1 in the Figure 8.12.

Step 5: Determine downstream characteristics

It will also be necessary to determine if the water is likely to pond and back up at the downstream end of the pipe. Ponding will depend on the slope of the channel.



Figure 8.13 Ponding at culvert outfall



Figure 8.14 Ponding in outfall channel

Step 6: Driving head

The driving head is the potential energy which causes the water to flow through the pipe.

$$\text{Driving head} = H = d_1 + h - d_2$$

where:

H is the driving head

d_1 is the upstream water depth

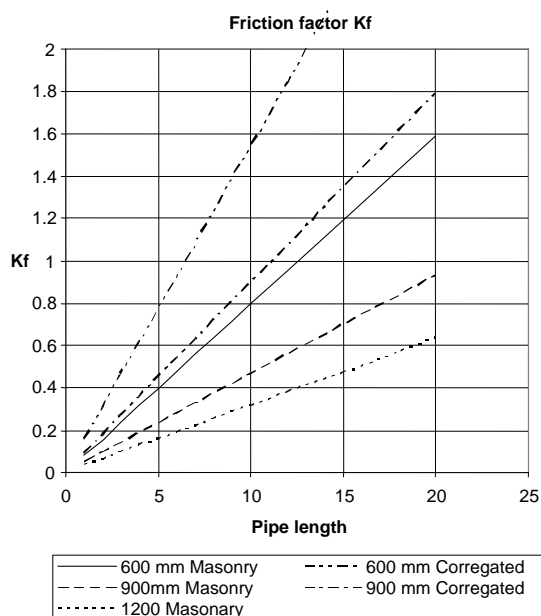
d_2 is the downstream water depth

h is the drop in culvert invert level as shown in the design cases above

The Driving head is the difference between the water levels each side of the culvert.

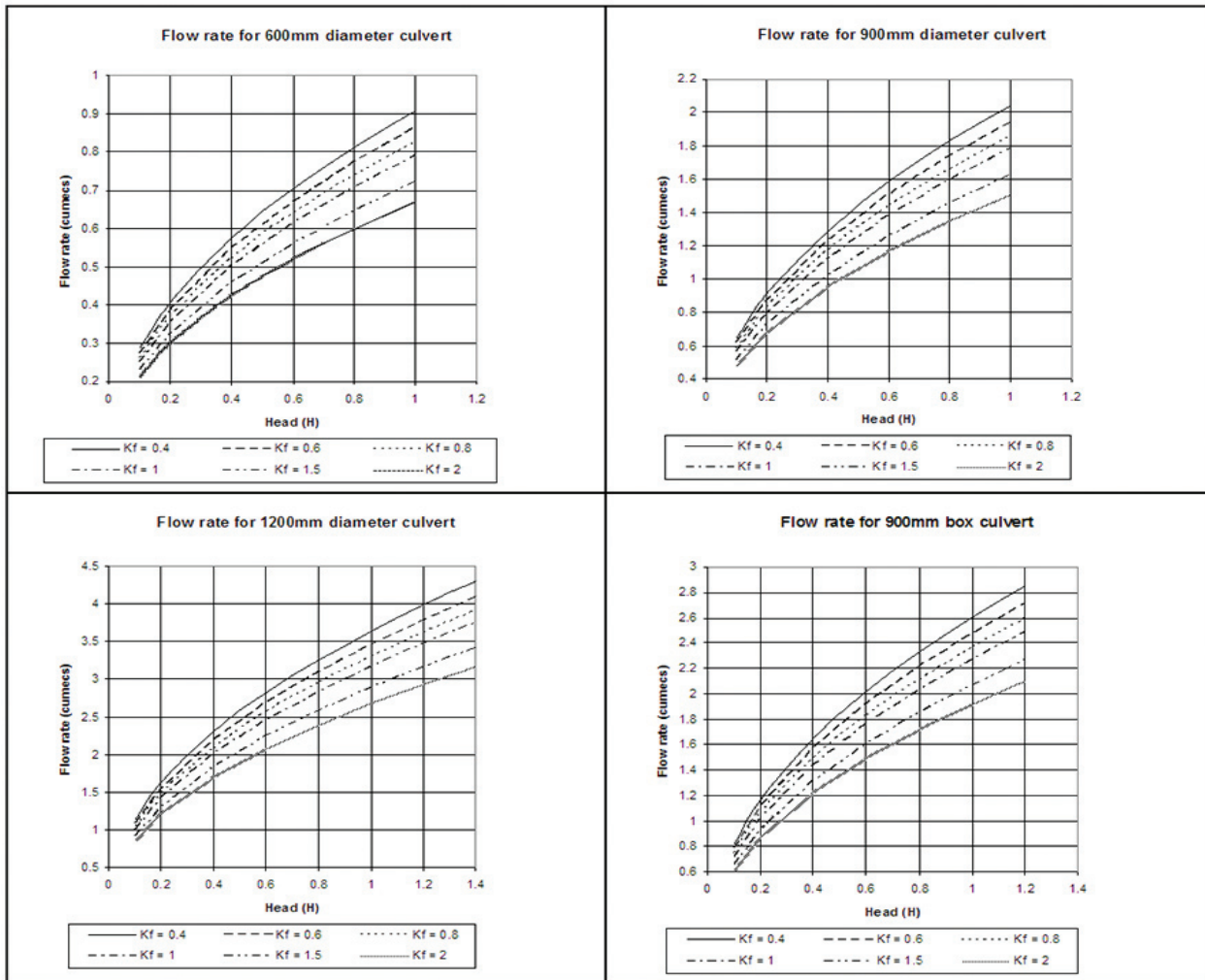
Step 7: Friction factor

The length and roughness of the pipe will affect the flow rate. The friction factor determined from the graph below is an indication of the resistance to flow due to the pipe's characteristics and is required to calculate the maximum flow in the pipe.



Step 8: Check maximum flow rate

Once the friction factor and head are known the maximum flow rate through the pipe can be obtained from the graphs below.

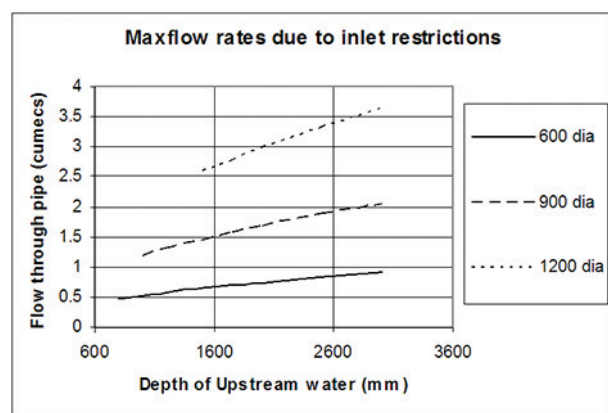


Step 9: Check inlet restriction

For higher flow rates the rate of water flow through the culvert will be restricted by the entrance diameter of the culvert. Check the maximum flow rate for the culverts and compare it with the flow rate obtained from step 8.

Step 10: Check acceptable flow rate

The maximum flow rate obtained in either step 8 or 9 should be compared with the maximum predicted flow rate.



Where the maximum flow rate is larger than the predicted flow rate, the culvert design is acceptable. The next design stages for the culvert should be carried out; selecting appropriate inlet and outlet arrangements and confirming the type of pipe based on the assumptions made in the design steps.

If the maximum flow rate is less than the predicted flow rate the design is unacceptable. If the culvert were to be constructed in this design the flood water would overtop the road causing it to be washed out, or it would flood adjacent fields and properties. The design process must be carried out again from step 3 making one of the following changes:

1. Adding another pipe of the same diameter
2. Increasing the size of the pipe

Pipe options

There are many different options available to the designer for constructing culvert pipes. The pipes can be either precast or constructed in situ, circular or square openings, reinforced or unreinforced and built from a variety of materials. In deciding which type of culvert to construct the designer has to assess the advantages and disadvantages of each construction option. Careful consideration must be given to the skills and resources available, the cost of each option, the prevailing site conditions for the region and the advantages of choosing a few standard designs for the majority of the culverts to be constructed.

1. Precast pipes

Precast pipes are usually manufactured in a central yard and are then transported to site. This method of construction has the advantage that the quality control for the construction of the pipe is likely to be improved, but the two main disadvantages are the increased transportation costs in bringing the pipes to site and the careful transportation and handling required to ensure the pipes are not damaged. Concrete pipes should preferably be transported on end, on a bed of sand, to minimise the risk of damage. Particular care is required in laying and jointing the pipes to ensure good support to the lower third of the pipe circumference.

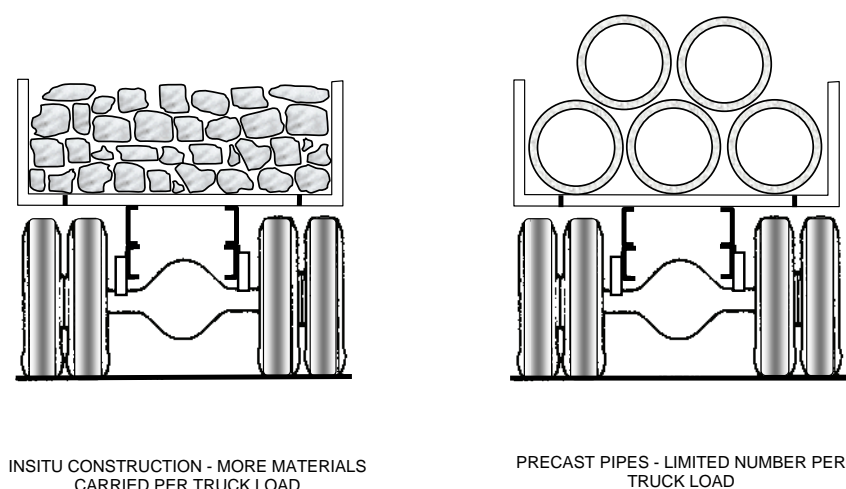


Figure 8.15 Transportation issues

2. In situ construction

Pipes constructed in situ can be made from a variety of materials. Careful supervision will be required on site to ensure that the pipes are manufactured to sufficient quality, but the transportation costs may be reduced when compared with precast pipes if their transport distances are substantial.

a. Masonry culverts (arch and box)

Masonry culverts are generally constructed as box culverts for small sizes and arch culverts for larger sizes. There are three stages to constructing a wall and slab box culvert:

1. Excavation & construction of the base
2. Construction of the walls
3. Laying the roof slab and backfilling the culvert.

The culverts can be constructed with different top slabs depending on the size of the culvert. These slabs may be masonry, timber or precast concrete.

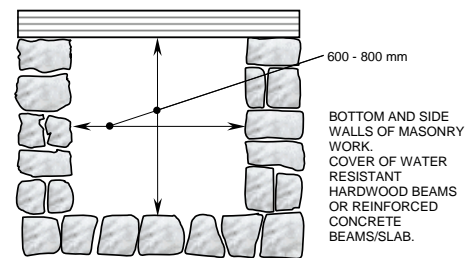
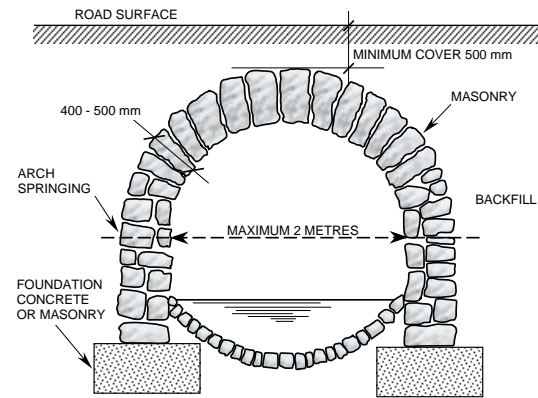


Figure 8.16 Masonry Culverts

Masonry Culverts

Advantages

- The use of locally available material reduces the cost of construction
- Simplicity of construction
- Low level of maintenance required
- Range of options available for the top slab on box culverts

Disadvantages

- Arched culverts require dressed stone bricks, blocks or mortared jointing

b. Concrete arch or box culverts

These can be constructed using the same principles as masonry. Spans larger than 800mm will require reinforcement design and detailing.

c. Timber Culverts

Option 1: Timber barrel

Timber barrel culverts are typically manufactured from shaped, treated wooden planks with tongue and groove joints, held in position by steel bands or wire. Once the culvert is in place and backfilled the steel bands are no longer required as the ground



Figure 8.17 Timber barrel culvert

material holds the pieces of the culvert in position. The bands can therefore rust away after the culvert has been placed without the culvert collapsing.

Timber barrel culverts

Advantages

- Can provide cheap culvert if timber widely available
- Culverts can be assembled at site allowing larger numbers to be transported on a lorry
- Design life is over 25 years with treated wood
- They are light and easy to handle
- Culverts can withstand small ground movements and settlement without losing their structural integrity

Disadvantages

- Professional wood treatment facilities required
- Short working life if wood is badly treated

Option 2: Timber log culverts

A simple and quick method for constructing small relief culverts can be to use timber logs. These culverts will usually be unlined, bare earth and will only accommodate slow flows (up to 1 m/s). The diagram shows the key dimensional requirements for these types of culvert. This type of construction should only be viewed as a temporary culvert unless the timber is properly treated. It can be a useful construction method for emergency maintenance during the rainy season.

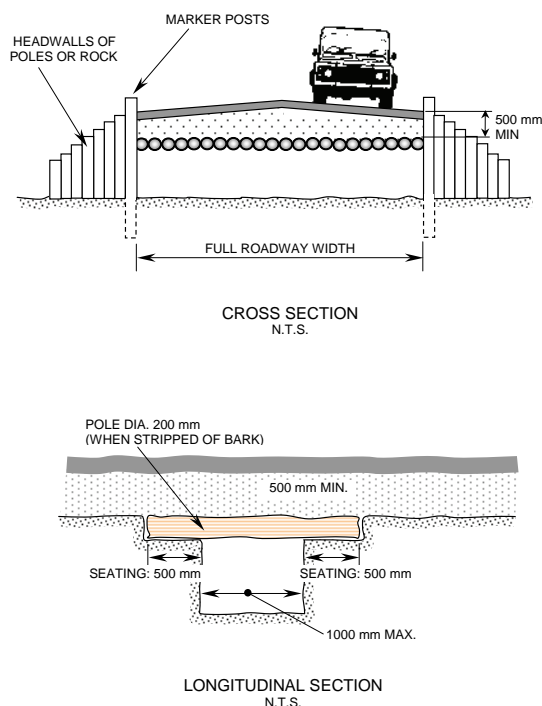


Figure 8.18 Timber log culvert details



Figure 8.19 Timber pole culvert during reconstruction

Timber log culverts

Advantages

- Very quick and cheap to construct
- Minimal skills required for construction

Disadvantages

- Very short life, especially if timber is untreated
- Unlined ditch very susceptible to scour during heavy rains

d. Cast in-situ concrete culverts

These culverts use a timber or steel mould to form the pipe of the culvert. A rubble concrete mixture is used to form the foundation of the pipe. The mould is then placed in position and lean mix concrete poured around the culvert mould. Once the concrete has set the mould is collapsed and removed.



Figure 8.20 Reusable steel mould for cast in situ culvert



Figure 8.21 Cast in situ culvert

Cast in situ concrete culverts

Advantages

- Low cost as mould can be reused many times
- Quick construction methods
- Low cement requirements due to use of rubble concrete

Disadvantages

- Poor life expectancy if rubble concrete is not well placed or compacted



Figure 8.22 Steel mould



Figure 8.23 Precast concrete culvert ring

e Precast unreinforced concrete culverts

These culverts are usually manufactured in a casting yard and brought to site in units. They need to be manufactured under good quality control conditions to ensure that they have sufficient strength. This option is only worth considering for high production numbers where a large number of culverts will be constructed in the same area.

Precast unreinforced concrete culverts

Advantages

- The quality of the pipe can be ensured
- Do not require steel reinforcement
- Very good performance when bedding and backfilling has been carried out well
- Pipes up to 900mm dia. can be manhandled by labour alone
- Economic where a large number of identical pipes are required

Disadvantages

- High cost for small batches
- Careful transportation required to ensure they are not damaged or broken
- Not suitable if site access route is in bad condition
- High transport costs due to their shape
- Diameters greater than 900mm dia. can not be made due to strength and handling problems
- Pipe lengths are restricted to 1m to ensure that they can be handled by labour alone

f. Steel culverts

Steel culverts will usually be constructed from pre-bent corrugated sheets which are bolted together on site. They can be very expensive if a steel manufacturing capability is not available locally in country.



Figure 8.24 Steel culvert

Steel culverts

Advantages

- The steel culverts can withstand small ground movements
- Light sections easy to handle and install
- The components for a number of culverts can be transported on one truck

Disadvantages

- Requires the transport and possible import of expensive steel sheets
- Secure storage of the sheets required to prevent theft

Pipe inlets

The general design of headwalls and wingwalls is discussed in another section of this chapter. However, there are two design cases of pipe inlets that require special attention:

1. Pipes on steep slopes
2. Pipes which are transferring large volumes of storm water from a side drain to the other side of the road

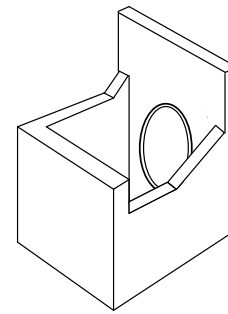


Figure 8.25 Drop inlet on relief culvert

Pipes on steep slopes

The invert of a pipe should be placed on a 2-5% slope to ensure that the flow is not too great to cause extensive scour but fast enough to prevent debris and silt from being deposited in the culvert. If the culvert is located on steeply sloping ground overall height drop across the culvert may need to be much steeper than 5%. If this case occurs the culvert should be designed for the maximum desirable invert slope (5%) and a drop inlet proposed. The drop inlet reduces the energy of the water leaving the culvert, preventing extensive scour. Drop inlets can also be used for relief culverts on long downhill lengths of side drain.



Figure 8.26 Drop inlet on stream culvert

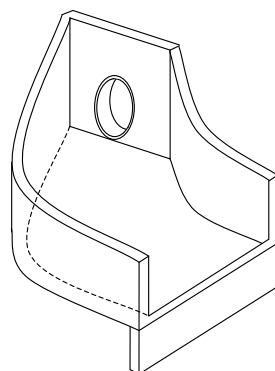


Figure 8.27 L-shaped inlet

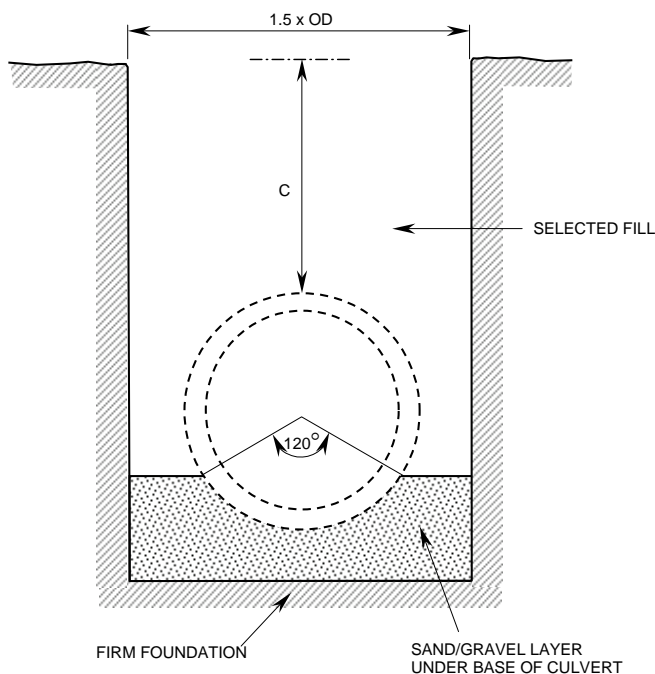
Pipes transferring large water volumes

One of the most important design rules when constructing a road water structure is to disrupt the flow as little as possible. Unfortunately this will not be possible for a culvert that is transferring water from a side drain under the road. The water must make an abrupt right angle change in direction to enter the culvert. For large flows there will therefore be a large amount of turbulence in the water and the potential for scour. The diagram below indicates the key features in the inlet design for large flows.

1. Rounded wingwalls to 'guide' water into pipe
2. Sloping wingwall on inside radius
3. Lined channel sides and base which extend 5m up the channel
4. Cut off wall provided at the edge of the inlet
5. Consider box culvert option as this will cause less restriction and turbulence

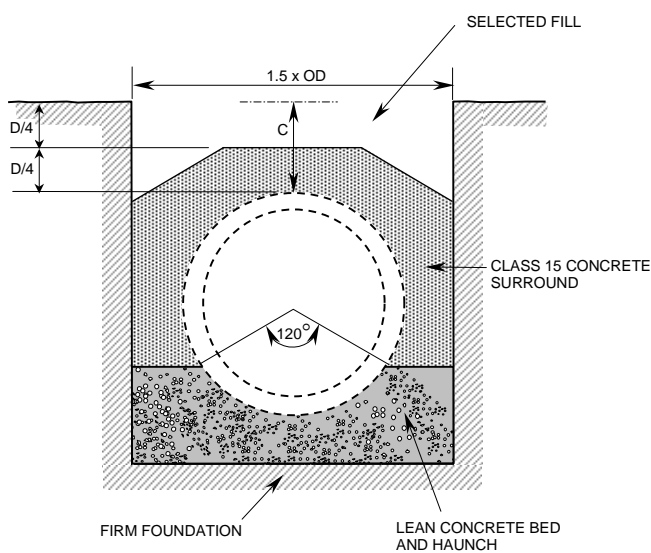
Pipe bedding and cover arrangements

Culverts pipes should be constructed on a firm foundation to ensure that they will not settle and crack. The support for the pipe should be either 250mm of compacted crushed stone, granular material (with a maximum stone size of 30mm) or 150mm concrete slab.



NOTE:
 C = COVER TO FINISHED ROAD LEVEL
 D = INTERNAL DIAMETER OF CULVERT (DESIRABLE)
 = $\frac{3D}{4}$ ABSOLUTE MINIMUM
 OD = OUTSIDE DIAMETER OF CULVERT

Figure 8.28 Pipe granular bedding and cover



NOTE:
 C = COVER TO FINISHED ROAD LEVEL
 = $\frac{D}{2}$ MINIMUM
 D = INTERNAL DIAMETER OF CULVERT
 OD = OUTSIDE DIAMETER OF CULVERT

Figure 8.29 Pipe arrangement with minimum cover

If the culvert is constructed from precast units it will be necessary to place a bedding material, such as sand, on the foundation to remove any irregularities and ensure an even support to the base of the precast units. If the preferred design option is a masonry culvert the foundation for the walls can be extended to form the base of the culvert. Backfilling around the culvert is one of the most important stages in the construction. The quality of the backfilling will determine the strength of a culvert to resist vehicle loads above it. The designer should specify the material to be used to backfill around the culvert, which should be easy to compact and well graded to promote drainage. Stones larger than 30mm should not be included in the backfill as they may damage the culvert. The excavated material from the culvert construction may be used for backfilling if it meets these criteria.

As material is backfilled around the culvert it should be well compacted in layers of 150mm. Particular care should be taken for the lower half of the pipe to ensure:

1. The material under the pipe is compacted with hand rammers
2. Hand rammers do not damage the culvert
3. The pipe is held at the correct level and does not 'rise'
4. Each side of the culvert is backfilled at the same rate to ensure that the culvert is not pushed out of line

The minimum desirable cover from the top of a culvert to the road surface should be the same as the diameter of the culvert. If the conditions do not permit this depth of cover it may be reduced to 75% of the pipe diameter. The cover can be reduced to half the culvert's diameter if the concrete bed, haunch and surround are cast as shown in the diagram. The remaining cover should be good quality standard fill material and the road should be surfaced with gravel or other material as appropriate.

Multiple culverts and vented fords

The design principles for multiple culverts and vented fords are the same as single bore culverts. Where more than one pipe is to be installed the minimum space between the centre line of adjacent pipes should be at least 2 pipe diameters. Where space restrictions require the installation of pipes at closer spacing the following factors should be used to reduce the flow rates through the pipes derived previously in this chapter.

Spacing between pipe centres	Flow reduction factor
More than 2.0 pipe diameters	1.0
1.5 - 2.0 pipe diameters	0.9
Less than 1.5 pipe diameters	Due to difficulties in ensuring adequate compaction under and between pipes, bedding of lean concrete should be used in these circumstances.

The flow capacity of different culvert shapes and diameters should be checked according to the characteristics of the site. The number and size of pipes should then be chosen to ensure that the sum of all the individual pipe flows is greater than the design flow.

The design flow for a multi-bore culvert should be taken to be the maximum flood flow. As vented fords are designed to be overtopped during peak flows the pipes should be designed to pass the normal flow and small floods. Overtopping will only occur for the higher flow rates and the designer will have to decide what level of flow the pipes will pass before overtopping occurs. The overtopping flow will depend on the duration, size and regularity of high flows and the total number of pipes that can be fitted into the structure.

Box Culverts - The design of box culvert options is not covered by this Guideline. Refer to publications such as TRL Overseas Road Note 9.

Headwalls and Wingwalls-Culverts

Headwalls and small wingwalls are required at each end of a culvert and serve a number of different purposes:

1. They direct the water in or out of the culvert
2. They retain the soil around the culvert openings

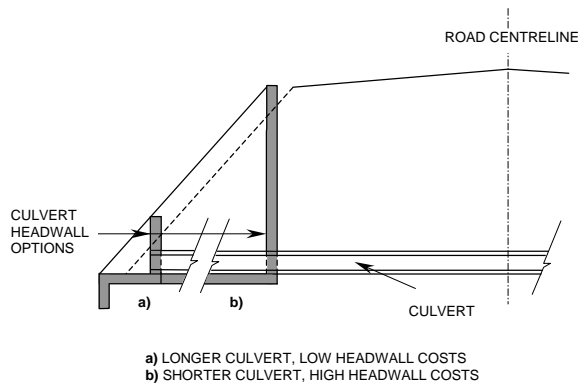


Figure 8.30 Possible culvert headwall positions

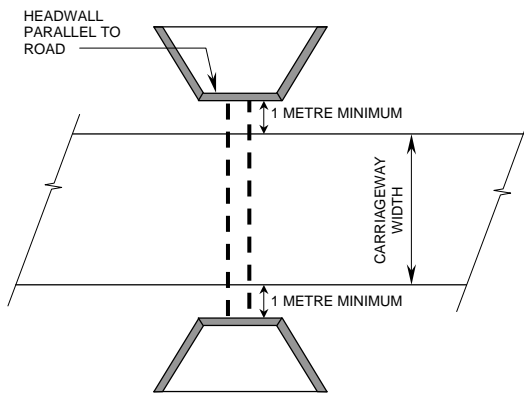
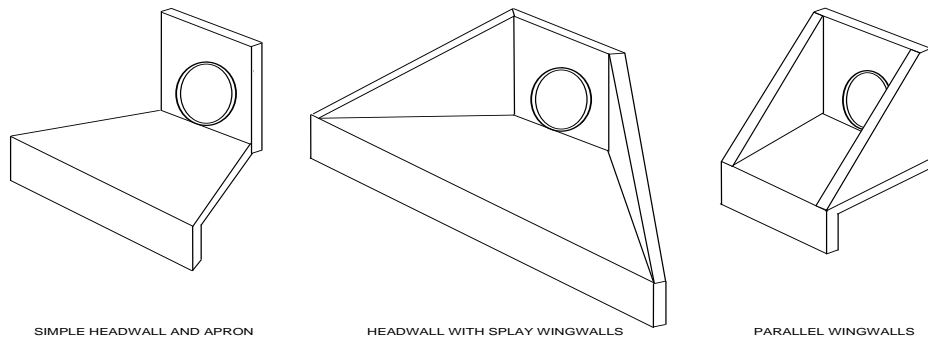


Figure 8.31 Position of culvert headwalls

requirements of national standards. The headwalls should be positioned at least 1 metre beyond the edge of the carriageway width to prevent a restriction in the road and reduce the possibility of vehicle collisions.

Headwalls should project above the road surface by 300mm and be painted white so that they are visible to drivers. There are a number of different layout options for culvert headwalls which are shown in the following diagram.



This arrangement can be used for simple low flow relief culverts. It is the cheapest option but prone to erosion for larger flows.

This arrangement should be used for larger flows instead of the simple arrangement. The wingwalls increase the protection from erosion.

Where the road is on an embankment it is essential that wingwalls are provided to prevent the risk of water seepage and subsidence of the embankment. This arrangement is likely to be the most economical.

Figure 8.31 Headwall and wingwall arrangements

3. They prevent erosion near the culvert and seepage around the pipe which causes settlement

The headwall can be positioned at different places in the road verge or embankment as shown in the diagram.

The closer the headwall is placed to the road on an embankment the larger and more expensive it will be. The most economical solution for headwall design will be to make it as small as possible. Although a small headwall will require a longer culvert, the overall structure cost will normally be smaller. If, due to special circumstances at a proposed culvert site, a large headwall with wingwalls is required it should be designed as a bridge wingwall.

Where a road is not on an embankment the size of the headwall will be small regardless of position. In this case the position of the headwalls will be determined by the road width and any

Headwall with drop inlet - This arrangement should be used when the road is on a steep side slope to reduce the invert slope of the culvert (see previous pipe inlets section).

Headwall with L inlet - This arrangement should be used where the road is on a gradient and water is to be transferred from the carriageway side drain on the high side of the road (see previous pipe inlets section).

Headwall and adjacent works must be designed so that the culverts can be de-silted manually under maintenance arrangements. This can be difficult with a drop inlet arrangement. Refer to chapter 10 on maintenance.

Wingwalls - Larger structures

Wingwalls are used to retain the soil behind the abutments of bridges to help guide flows through the structure in flood conditions and safely retain the backfill material without risk of erosion. There are 2 basic reference layouts for wingwalls, either parallel to the road or parallel to the watercourse. However, wingwalls are usually constructed at an angle between these two arrangements. Wingwalls should always be constructed to the toe (bottom) of the slope and not part way down. Wingwalls that do not extend to the bottom of the slope are likely to suffer from erosion around the ends.

Wingwalls parallel to water course

- Foundations on same level
- Wall more susceptible to erosion from watercourse
- Wall size smaller than wall parallel to road
- Larger amount of fill to be moved, placed and compacted

Wingwalls parallel to road

- Foundations can be stepped but are harder to construct
- Wall mostly away from watercourse
- Wall size longer than wall parallel to watercourse
- Reduced amount of fill required to be moved, placed and compacted



Figure 8.32 Wingwall cascade

The relative availability and cost of fill material and raw materials to construct the wingwalls will determine the most appropriate arrangement. In general, to ensure the cheapest option, the design should ensure the smallest wingwalls are chosen for the structure and its particular location. Where wingwalls are chosen that run parallel to the road it is necessary to take suitable measures to prevent water in the carriageway side drains causing erosion around the wall at their outfall. This usually requires a lined channel or cascade at the base of the wingwall. The two main factors affecting the overall design of a wingwall are the construction material and the bearing capacity of the soil.

Stone, brick and blockwork walls

Stone, brick and blockwork walls should be built with a tapering back face to withstand the pressure exerted by the fill material. The size of the wall will depend on its height, the bearing capacity of the soil and if there is any surcharge (additional fill material above the wall). Any material used in the wall should meet the requirements given in chapter 7.

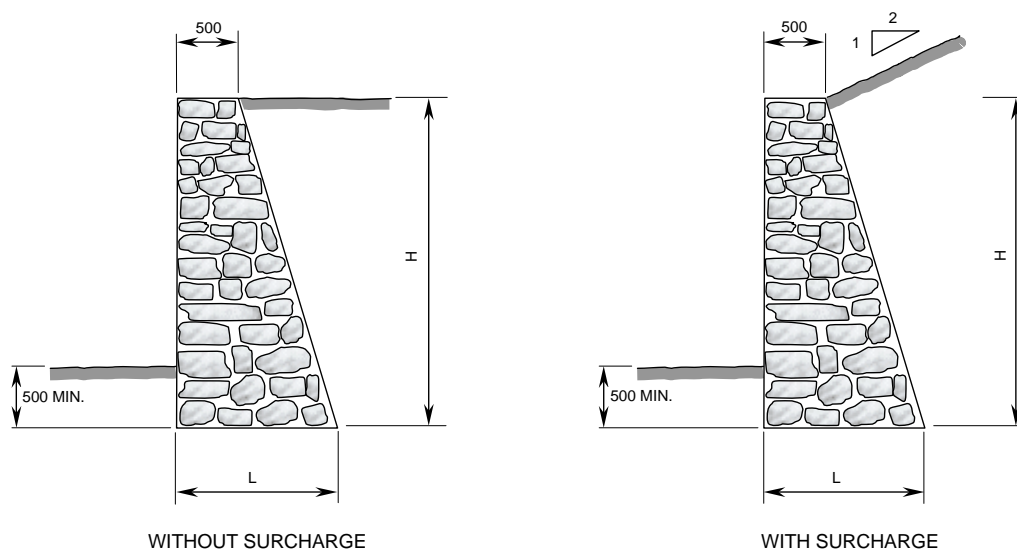


Figure 8.33 Stone, brick or blockwork wall with and without sloping backfill (surcharge)

H- Height of wingwall (without surcharge)	Bearing capacity of the soil		
	Low (75-125kPa)	Medium (125-250kPa)	High (>250kPa)
	L - Width of the base (mm)		
1000	500	500	500
1500	900	800	800
2000	1700	1150	1150
2500	*Construction not possible without ground improvement	1450	1450
3000		1750	1750
3500		2400	2000
4000		3200	2300
4500		4200	2600

H- Height of wingwall (with surcharge)	Bearing capacity of the soil		
	Low (75-125kPa)	Medium (125-250kPa)	High (>250kPa)
	L - Width of the base (mm)		
1000	1000	950	950
1500	1500	1200	1200
2000	2000	1450	1450
2500	*Construction not possible without ground improvement	1750	1750
3000		2350	2000
3500		3200	2250
4000		improvement	2550

* Ground improvement increases the bearing capacity of the soil through the addition of other materials to the ground e.g. gravel or cement – this is outside the scope of this guideline

Note: Where wingwalls are constructed on medium or high bearing capacity soil, parallel to the road, and are only used to retain road fill material to a height of up to 3 metres the wall may be constructed as follows:

1. Top of the wall to be 500mm wide
2. Vertical front face and 1:4 sloping back face (1 horizontal: 4 vertical)

Gabion baskets

Gabion baskets may be used in areas where stones are available. In some areas there may be a problem of persons removing wire from the gabion baskets for other construction purposes. If consultations through community groups cannot resolve this problem then more robust steel mesh gabions may need to be considered. The table below assumes that the gabion baskets have been filled according to the criteria outlined in chapter 7 and have a height and width of 1 metre.

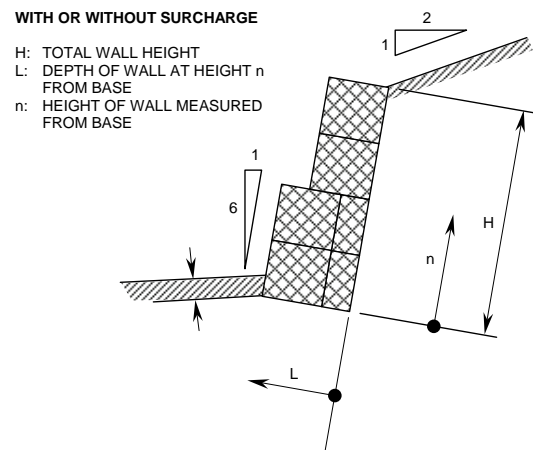


Figure 8.34 Gabion wall

Bearing capacity of soil	Height of wall (m)	Width of gabion wall at height 'n' above base									
		0	0.5	1	1.5	2	2.5	3	3.5	4	
50 - 125 kPa	1.5	1	1	1	1						
	2	1	1	1	1	1					
	2.5	1.5	1.5	1.5	1	1	1				
	3	1.5	1.5	1.5	1.5	1	1	1	1		
>125 kPa	1.5	1	1	1	1						
	2	1	1	1	1	1					
	2.5	1	1	1	1	1	1				
	3	1.5	1.5	1	1	1	1	1			
	3.5	1.5	1.5	1.5	1	1	1	1	1		
	4	2	2	1.5	1.5	1.5	1.5	1	1	1	

Timber walls

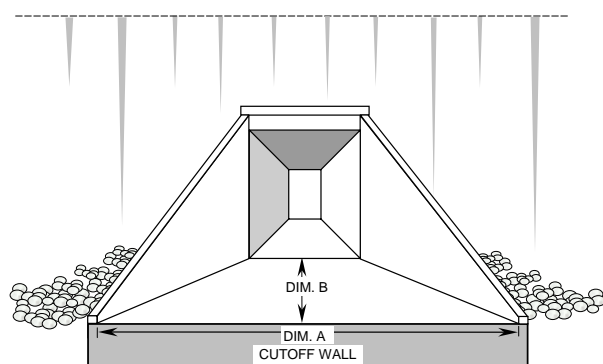
Felled timber tree trucks can be used to form a wingwall (refer to Figure 7.43).

Apron

An apron is required at the inlet and outlet of culverts and downstream of drifts and vented fords to prevent erosion. As the water flows out of or off a structure it will tend to erode the watercourse downstream, causing undercutting of the structure. Refer to the section on cut off walls earlier in this chapter. Aprons should be constructed from a material which is less susceptible to erosion than the natural material in the stream bed.

Drift aprons

Where the discharge velocity across the drift is less than 1.2m/s which may be experienced for relief drifts, a coarse gravel layer (10mm) will provide sufficient protection down stream of the drift. For discharge velocities greater than 1.2m/s more substantial protection will be required which utilises larger stones. This is discussed in the section on downstream protection. The width of the apron should be at least half the width of the drift and extend across the watercourse for the whole length of the drift.



Dim. A = Distance between wingwalls or 2 x culvert dia. for culvert without wingwalls
 DIM. B = 2 x culvert dia.

Figure 8.35 Culvert apron

Culvert aprons

Aprons should be provided at both the inlet and outlet of culverts. They should extend the full width between the headwall and any wingwalls. If the culvert does not have wingwalls the apron should be twice the width of the culvert pipe diameter. The apron should also extend a minimum of 1.5 times the culvert diameter beyond the end of the pipe. Cut off walls should also be provided at the edge of all apron slabs. The choice of apron construction is likely to depend on the type of material used for construction of the culvert. It may be constructed from gabion baskets, cemented masonry or concrete.

Vented ford aprons

The apron for vented fords should extend the whole length of the structure including downstream of the approach ramps to the maximum design level flood. The other design requirements for vented ford aprons are the same as culvert aprons.

Approach ramps

The approaches to vented drifts, large bore culverts and bridges must allow vehicles to cross the structure without losing traction or getting stuck on the crossing. Ideally crossings should not have approaches steeper than 10%. However, steeper approaches can be provided if governed by the local terrain. Approaches steeper than 10% will require the running surface to have a thin concrete or cement bound masonry slab to allow vehicles to maintain traction particularly during wet periods. The slab should be at least 150mm thick and be constructed on a sand or compacted masonry/aggregate base.

The approach way is subjected to similar erosion characteristics as the main structure. It is therefore necessary to surface the approach ways with the same material as the main structure, at least to the height of the maximum flood level, to ensure damage does not occur. If the structure is designed to be overtopped the approach ways must be constructed higher than the maximum flood level to ensure that the water does not erode around the ends of the structure leaving it inaccessible.

It is also necessary to provide cut off walls, described above, along the sides of the approach ways to protect against scour. The sides of the approach ways should be faced to ensure erosion does not occur. They may be constructed from:

1. Masonry walls (most appropriate for higher walls)
2. Gabion baskets
3. Concrete walls (for low walls up to 0.5 metre)
4. Timber logs (high maintenance required)

The design of these walls would be similar to the design of wingwalls described in the previous section.

The fill material in the approach way should be chosen from one of the following three options:

Well compacted sand and gravel	Rubble masonry	Lean concrete mix with plums
<p>Sand and gravel may be readily available in the watercourse around the crossing site. These may be stockpiled during the initial stages of construction by labour. The material to be used as a fill should be well graded and placed in 100mm layers which are well compacted before subsequent layers are placed.</p>	<p>If a well graded mix of sand and gravel is not available it may be more economic to use rubble masonry rather than breaking rocks to create a well graded material. Broken man-made bricks can be used in addition to, or instead of, natural stone provided they meet the requirements outlined in chapter 7. Rubble masonry should be bound together with a 1:8 cement-sand mortar.</p>	<p>A concrete mix of 1:4:8 (cement, sand and aggregate) can be used with large plums up to 200mm in size. This option will have the highest cement requirement, and hence cost. However, it may be the most beneficial fill option if there are small quantities of sand, aggregate and large stone near the bridge site.</p>

The running surface of the approach way should be designed as a structural slab of either concrete or cement bonded stone paving. The slab should also have a 2-3% crossfall in the direction of water flow to ensure that the deck drains quickly after rainfall.

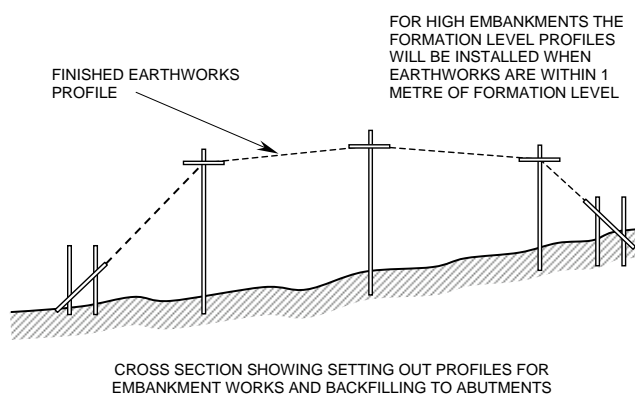


Figure 8.36 Construction of approach ways (a)

Approach ways will be susceptible to scour from water flowing from the carriageway side drains into the water course due to the increased slope. A lined channel should therefore be provided at the edge of the approach way to ensure that erosion does not occur. The approach ways should be constructed separately from the main structure to allow for thermal expansion of the structure and slight ground movements, particularly for the structural slab. If they were constructed integrally with the main structure any slight settlement or thermal effects could cause

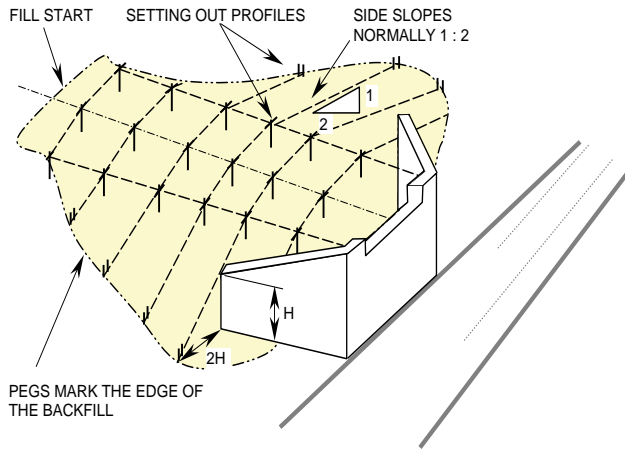


Figure 8.36 Construction of approach ways (b)

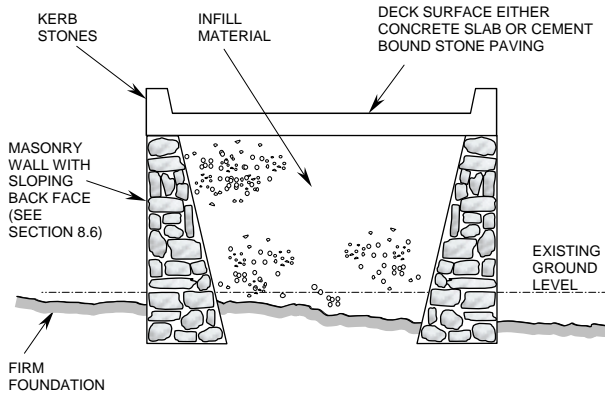


Figure 8.37 Example approach way cross section

cracks in the structure which would weaken it against damage from water. The approach ways therefore require an end wall and cut off wall next to the main structure. The gap between the two structures should be very small (no greater than 10mm). The edges of the approach ways should be marked by guide stones to show drivers the location of the edge of the carriageway. These guides should be 300mm high and painted white.



Figure 8.38 Masonry side drains at the edge of an approach way to prevent erosion

Downstream Protection

A previous section on scour indicated that it is likely that erosion of the watercourse will occur around the structure due to a constriction of the water flow. The constriction causes the water velocity to increase as it passes through/over the structure and this high velocity can be maintained well downstream of the structure. A previous section also discussed the use of aprons downstream of a structure to prevent erosion and undercutting of the structure itself. However, in small constrained channels severe erosion may still occur after the apron, particularly where the watercourse is on a gradient. It is therefore often necessary to provide additional protection to the watercourse, to reduce the velocity of the water and prevent erosion.



Figure 8.39 Severe erosion at outfall

Figure 8.39 shows a gully that has been formed due to water eroding soft material downstream of a culvert as the watercourse was unprotected. For slow flowing water it is unlikely that any protection would be needed, but for faster flowing water the maximum allowable velocity will depend on the bed material and the amount of silt or other material already being carried in the water.

Erosion can occur in any channel regardless of the presence of any structure. It is therefore not possible to state how far downstream of a structure channel protection should extend. However, the following issues should be taken into account:

1. The general erodability of the bed, which will be based on the type of channel material and the gradient.
2. The likelihood of damage to the structure if erosion occurs downstream.
3. The potential effects of erosion on downstream areas (e.g. damage to buildings or farming land).

Bed material	Maximum water velocities without channel protection	
	Clear water	Water carrying silt
Stiff clay	1	1.5
Volcanic ash	0.7	1
Silty soil / sandy clay	0.6	0.9
Fine sand / coarse silt	0.4	0.7
Sandy soil	0.5	0.7
Firm soil / coarse sand	0.7	1
Graded sand and gravel	1.2	1.5
Firm soil with silt and gravel	1	1.5
Gravel (5mm)	1.1	1.2
Gravel (10mm)	1.2	1.5
Course gravel (25mm)	1.5	1.9
Cobbles (50mm)	2	2.4
Cobbles (100mm)	3	3.5
Well established grass in good soil	1.8	2.4
Grass with exposed soil	1	1.8

There are many methods for providing protection to the watercourse. The choice of method will depend on the availability or cost of different materials, the size of the watercourse and level of protection required.

Rip-rap

Rip-rap is the name given to stones placed in the river bed to resist erosion. In order to be effective the stones used should be large or heavy enough that they will not be washed away during floods. Although rip-rap may appear to consist of random rocks it should be well graded and placed as tightly as possible to improve its resistance to erosion. The rocks used should also be strong and not likely to crumble. Angular rocks, in general, have the best performance, due to the interlock that is formed between rocks. Round rocks can be used if they are not to be placed on the sides of the watercourse which have a gradient steeper than 1:4. Flat

slab stones should also be avoided as they can be easily dislodged by the water flow. The table below shows the sizes of stone that should be used for rip-rap. It should be possible for one or two labourers to place the majority of the stones with the few remaining larger stones being placed by a small labour gang.

Stone sizes for rip-rap bed protection				
Water velocity m/s	Rock size dia. m	Rock mass kg	Minimum % of rock meeting specified dimensions	Thickness of rip-rap m
Less than 2.5	0.40	100	0 %	0.5
	0.30	35	50 %	
	0.15	3	90 %	
2.5 - 3	0.55	250	0 %	0.75
	0.40	100	50 %	
	0.20	10	90 %	
3 - 4	0.90	500	0 %	1.0
	0.70	250	50 %	
	0.40	35	90 %	

Masonry slabs

In areas where outlets from culverts are on a steep slope it may not be possible to place rip-rap as it will be washed down the slope. Masonry slabs, cascades or channels may be constructed on the steep section of the outfall to control erosion. As the water velocity will be high it will be necessary to use mortar in the slab as hand pitched stones are likely to be washed out. It will not be necessary to make the slab smooth as a rough slab will help to reduce the energy in the water. Large stones may be fixed in the slab which project above the standard level to create more turbulence to slow the water speed. Masonry cascades or step structures can incorporate a series of 'ponds' or sumps to help dissipate energy.

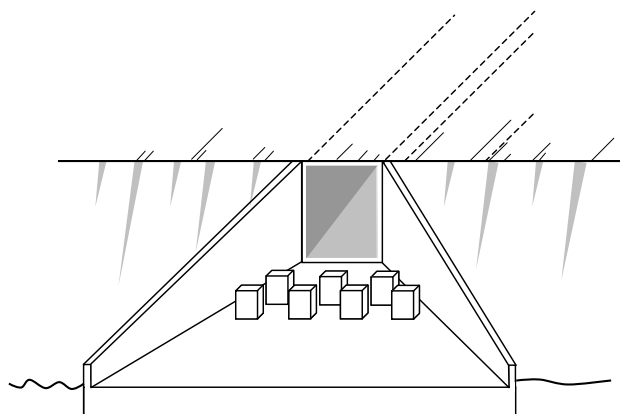


Figure 8.40 Energy dissipating apron

In flatter areas, up to a 5% gradient, it should be possible for small watercourses to use hand pitched masonry, providing it is well placed with any large flat stones bedded on their edges.

Gabions

Gabions can be used to protect the bottom or banks of a watercourse. As the stones are confined by the wire cages much smaller stones than those used for rip-rap can be put in the cages. The disadvantage of