

## 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	✓	✓	✓	✓	✓
Structural slabs	✓		✓	✓	
Cut off walls	✓	✓	✓	✓	✓
Pipes		✓	✓		
Headwalls & wingwalls		✓	✓	✓	✓
Apron	✓	✓	✓		
Approach ramps			✓	✓	✓
Downstream protection	✓	✓	✓	✓	✓
Arches				✓	
Bridge design ◆ general ◆ deck ◆ abutments ◆ piers ◆ bearings & joints				✓ (arch bridges)	✓

### Scour

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.

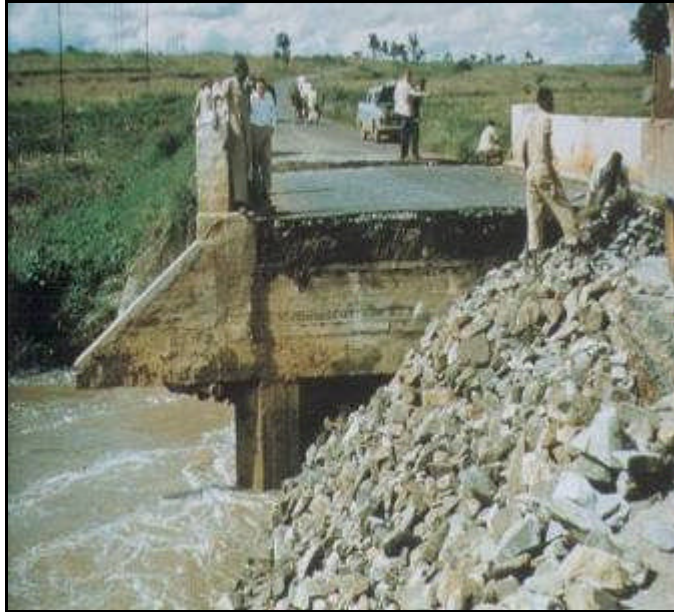


Figure 8.1 Bridge damage due to scour of abutment

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

## 8. STRUCTURE DESIGN

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

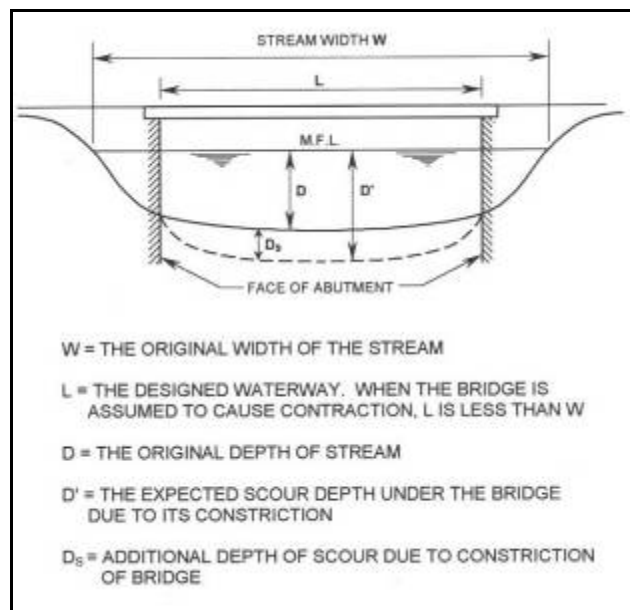
### Rule 2 - Create a minimal constriction to the water flow

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.

<b>Peak flood flow rate</b>	0.5	1	2	4	6	8	10	15	20	25	30	m <sup>3</sup> /s
<b>Minimum width (W)</b>	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.



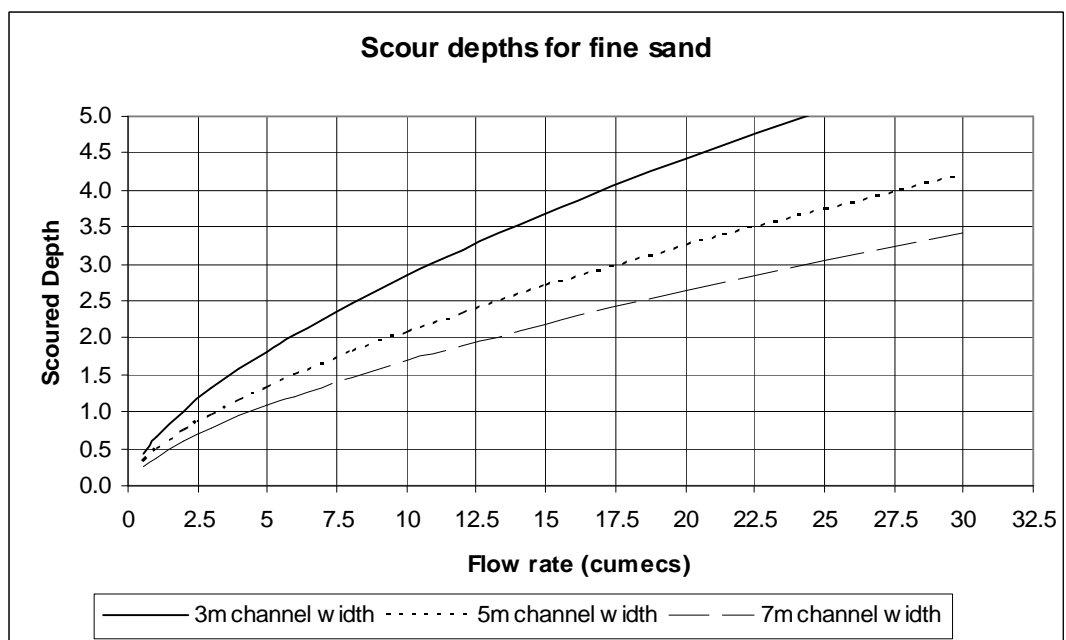
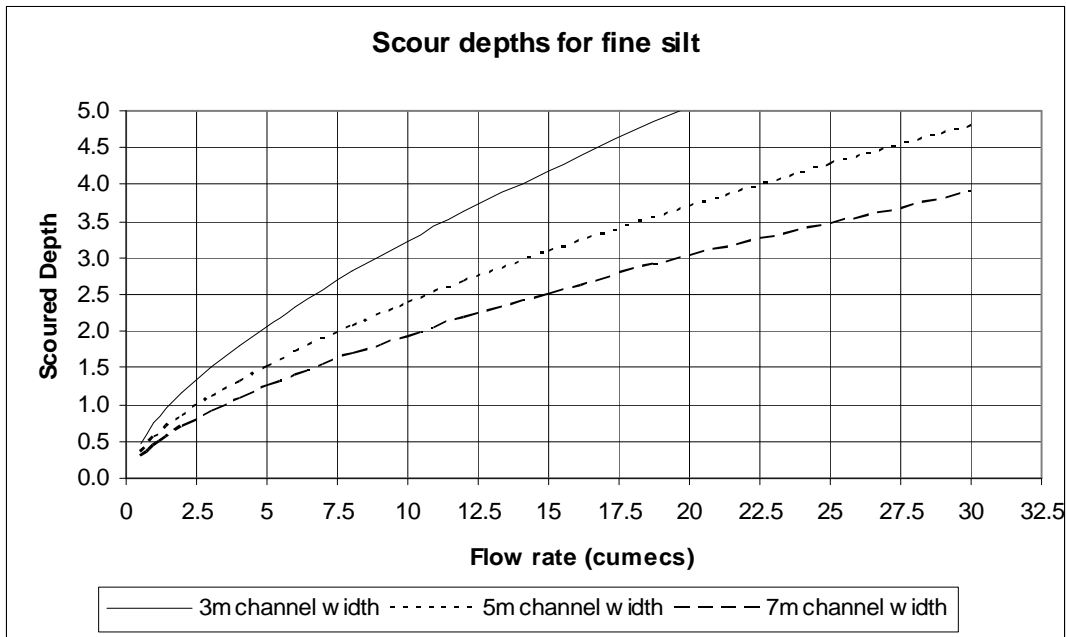
## 8. STRUCTURE DESIGN

The depth of scour is therefore:

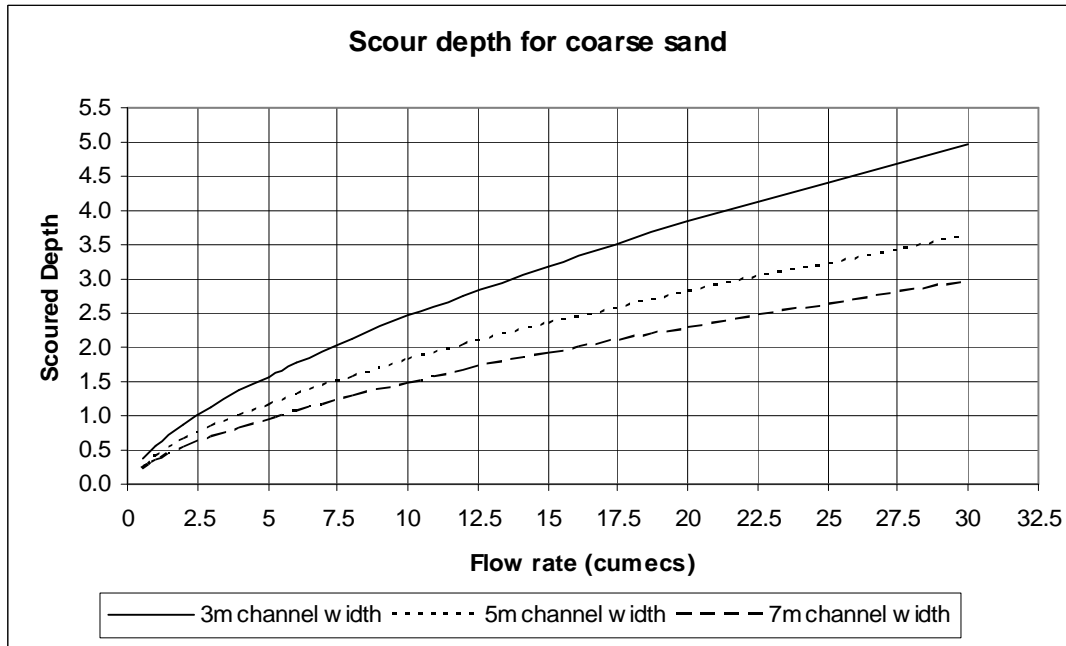
Depth of scour = flood water depth at structure - original unconstrained watercourse depth

$$D_s = D^1 - D$$

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



## 8. STRUCTURE DESIGN



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 table below 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.

## 8. STRUCTURE DESIGN

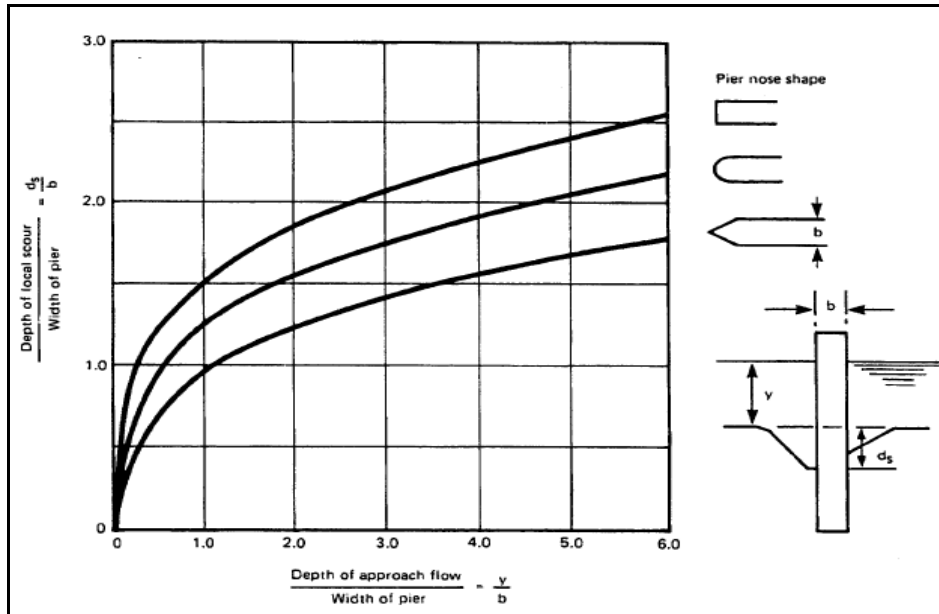


Figure 8.2 From TRL ORN9



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.

## 8. STRUCTURE DESIGN

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:  $2 \times 20 \times 1.5 = 60 \text{ kN/m}^2$

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

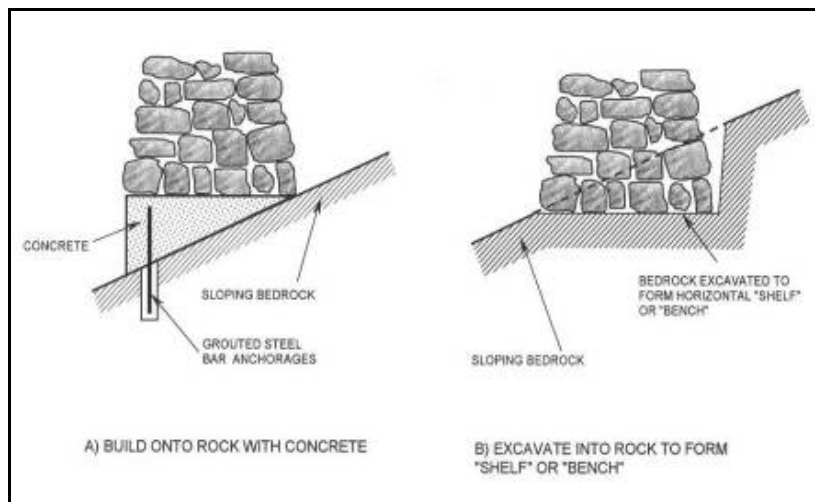


Figure 8.4 Construction on sloping bedrock

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.

## 8. STRUCTURE DESIGN

### 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. 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.



Figure 8.5 Guide stones at the edge of a 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

## 8. STRUCTURE DESIGN

### 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.

#### ◆ 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



Figure 8.6 Concrete slab drift

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.

## 8. STRUCTURE DESIGN

### ◆ 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



Figure 8.7 Hand pitched stone drift

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.

### ◆ 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



Figure 8.8 Gabion drift

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 down stream 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

## 8. STRUCTURE DESIGN

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.



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.

### 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

## 8. STRUCTURE DESIGN

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.

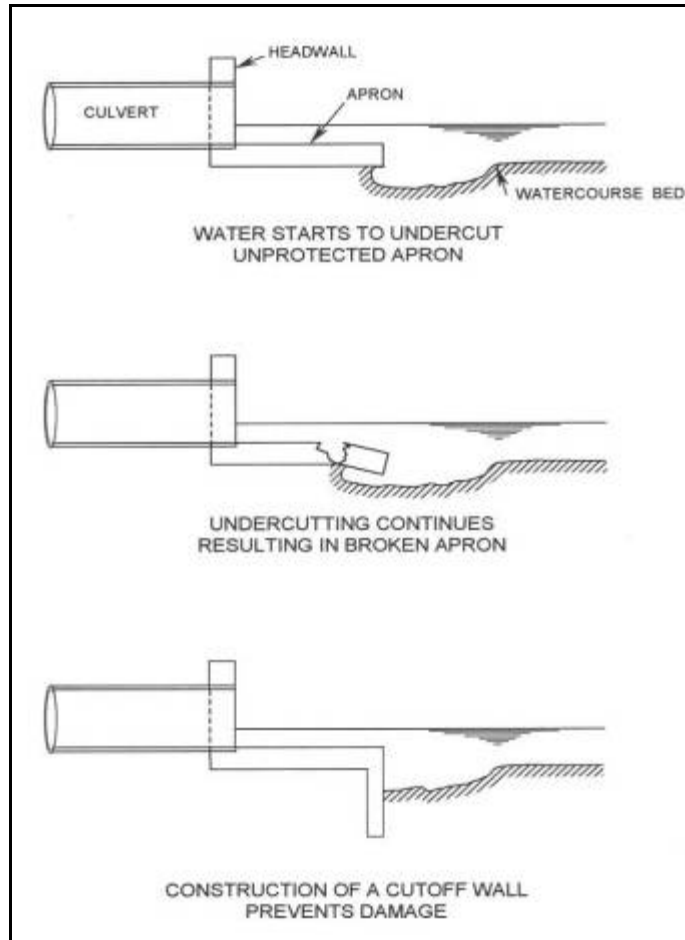


Figure 8.10 Cut off wall

### 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 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

## 8. STRUCTURE DESIGN

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.

### 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.

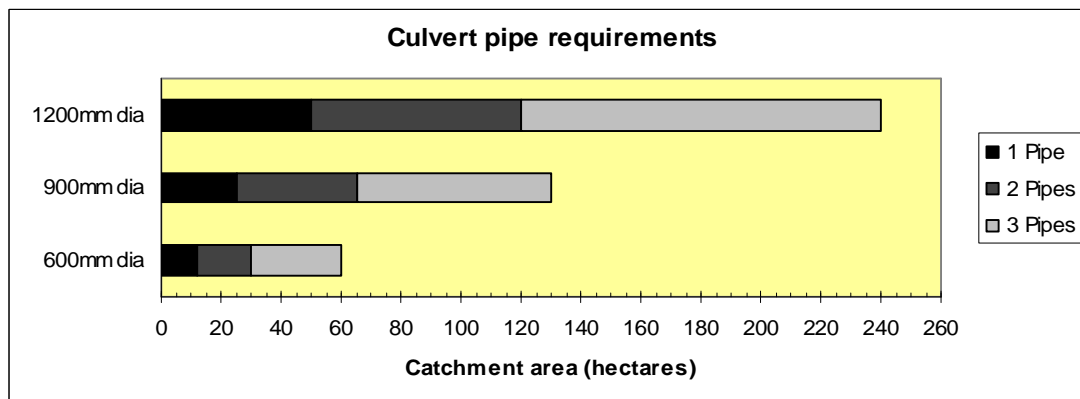


Figure 8.11 Culvert pipe requirements

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.

#### 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.

#### Maximum flow rates for 600mm diameter case 3 culverts

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

## 8. STRUCTURE DESIGN

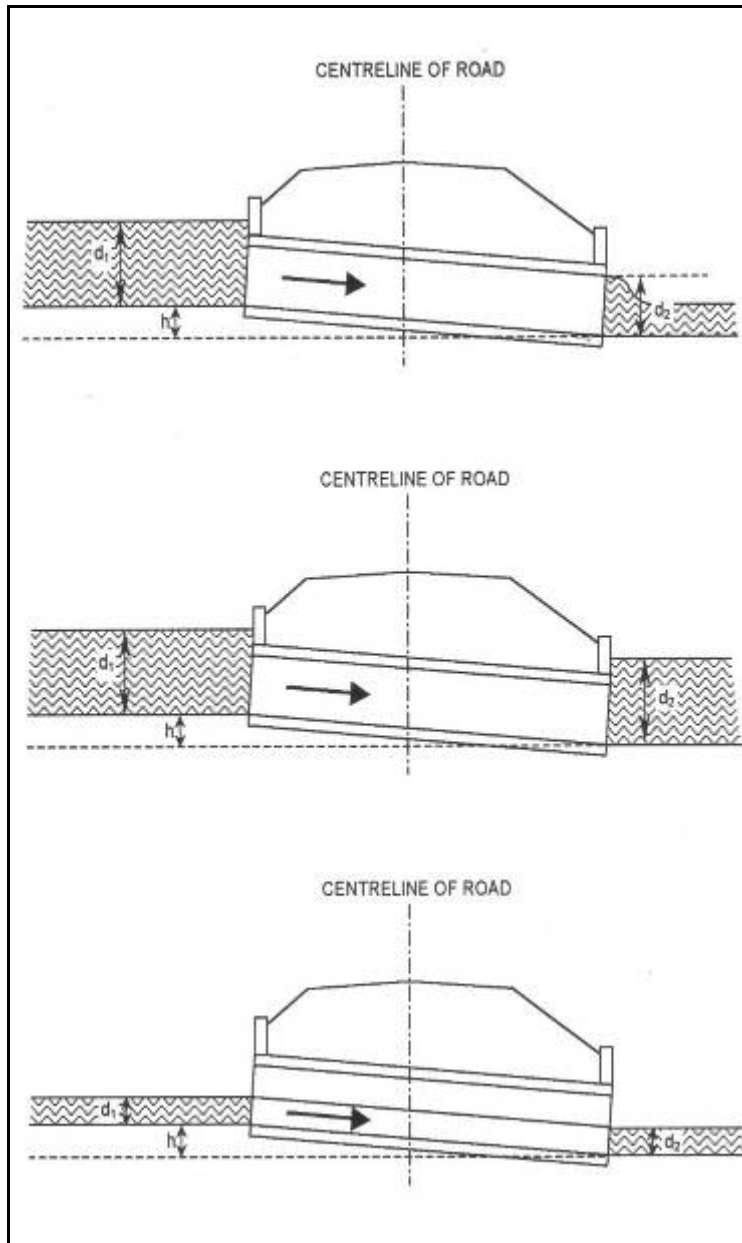


Figure 8.12 Pipe design cases

### 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**

#### ◆ 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.

## 8. STRUCTURE DESIGN

### 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.

**Driving head = H**

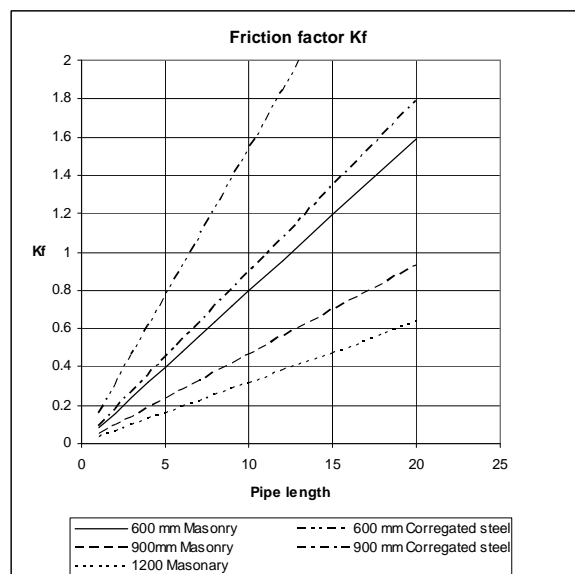
$$H = d_1 + h - d_2$$

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

It is the difference between the water levels each side of the culvert.

### Step 7: Friction factor

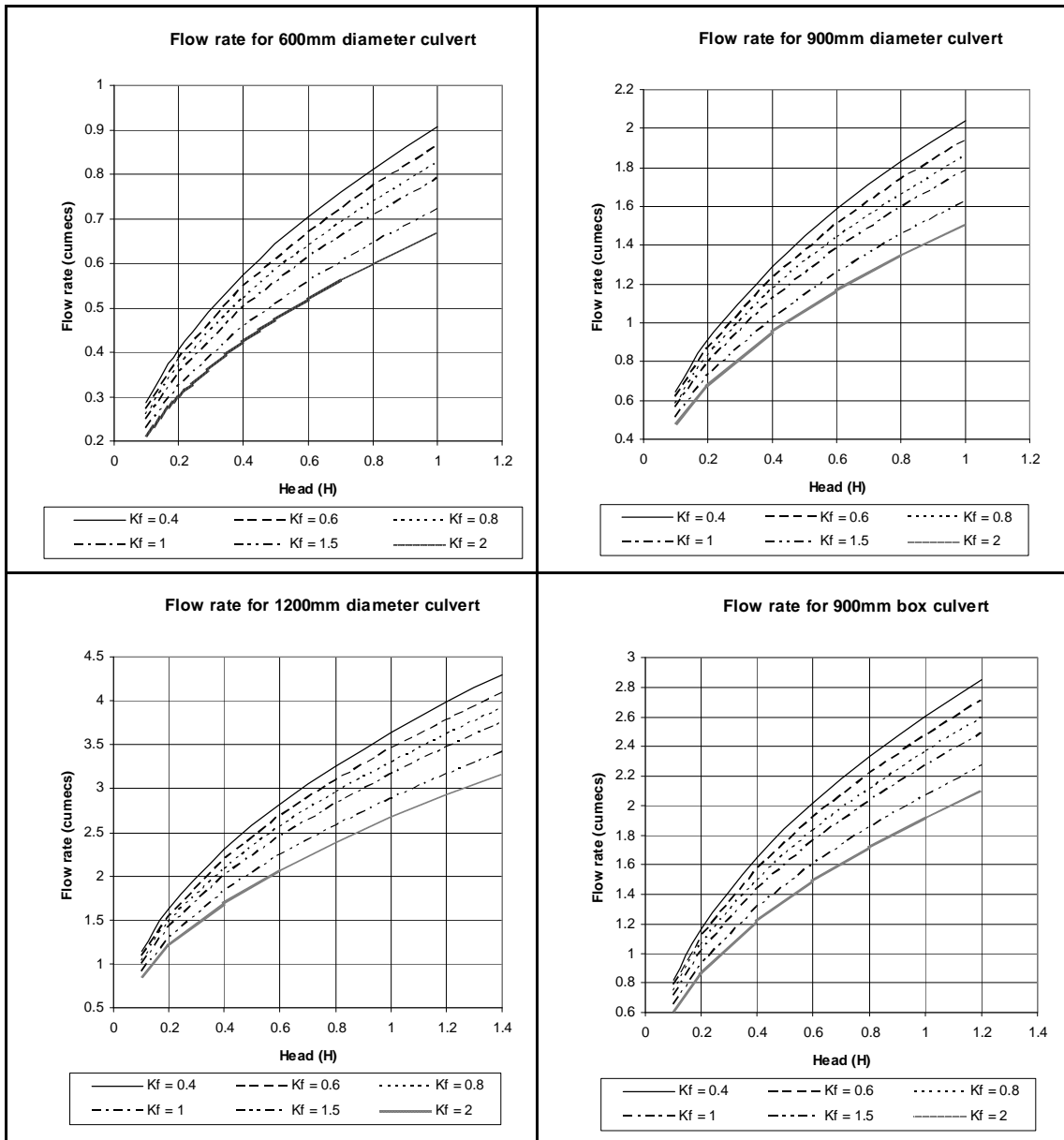
The length and roughness of the pipe will affect the flow rate. The friction factor determined from the graph below is an indication of the resistance to flow due to the pipe's characteristics and is required to calculate the maximum flow in the pipe.



## 8. STRUCTURE DESIGN

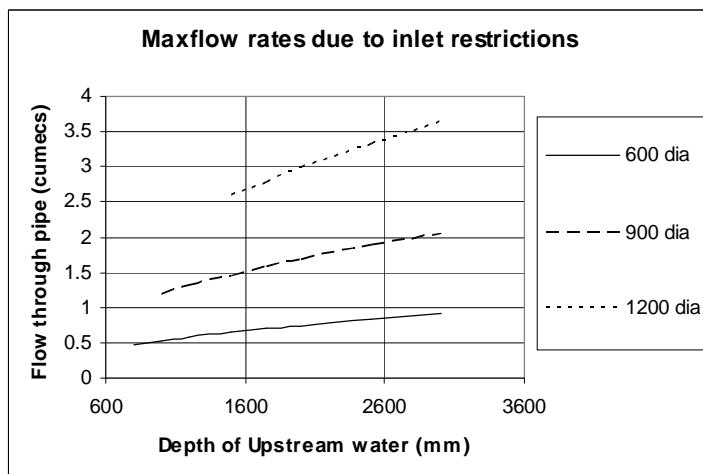
Step 8: Check maximum flow rate

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.



## 8. STRUCTURE DESIGN

### 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.

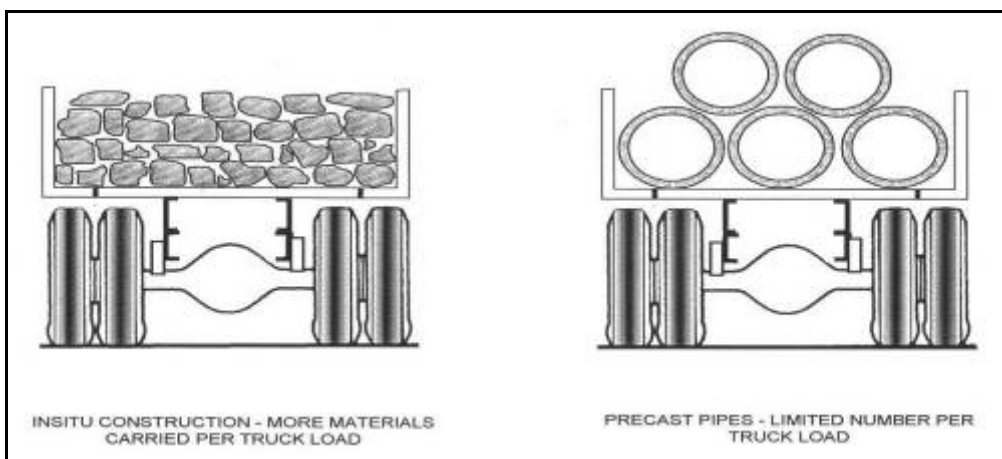


Figure 8.15 Transportation issues

#### 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

## 8. STRUCTURE DESIGN

transportation costs may be reduced when compared with precast pipes if their transport distances are substantial.

### ◆ 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.

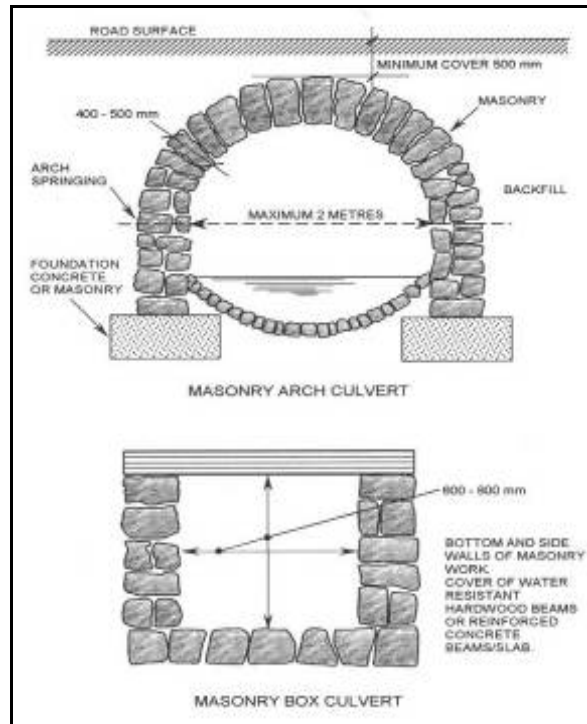


Figure 8.16 Masonry Culverts

### 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

### ◆ 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.

### ◆ 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 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.



Figure 8.17 Timber barrel culvert

## 8. STRUCTURE DESIGN

### 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.

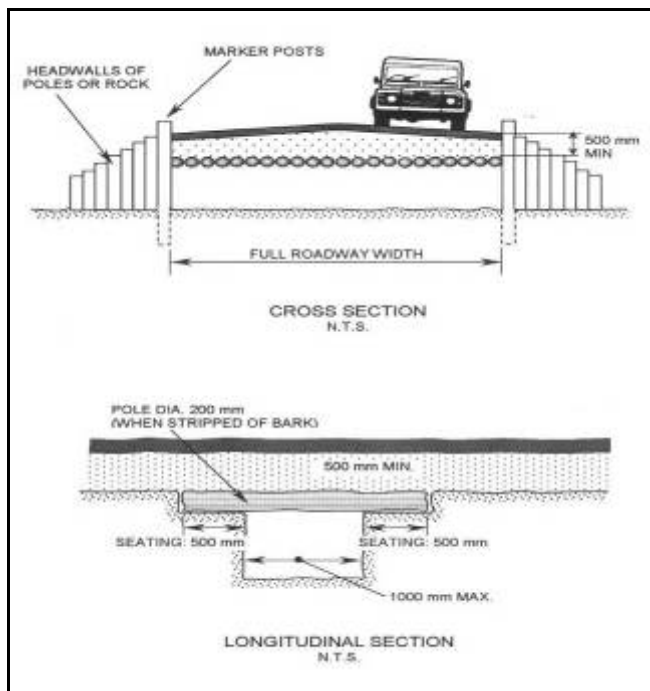


Figure 8.18 Timber log culvert details



Figure 8.19 Timber pole culvert during reconstruction

## 8. STRUCTURE DESIGN

<b>Timber log culverts</b>	
<b>Advantages</b>	<b>Disadvantages</b>
Very quick and cheap to construct	Very short life, especially if timber is untreated
Minimal skills required for construction	Unlined ditch very susceptible to scour during heavy rains

### ◆ 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

<b>Cast in situ concrete culverts</b>	
<b>Advantages</b>	<b>Disadvantages</b>
Low cost as mould can be reused many times	Poor life expectancy if rubble concrete is not well placed or compacted
Quick construction methods	
Low cement requirements due to use of rubble concrete	

### ◆ 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.

## 8. STRUCTURE DESIGN



Figure 8.22 Steel mould



Figure 8.23 Precast concrete culvert ring

### 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

#### ◆ Steel culverts



Figure 8.24 Steel culvert

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.

## 8. STRUCTURE DESIGN

<b>Steel culverts</b>	
<b>Advantages</b> 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	<b>Disadvantages</b> 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

### 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.

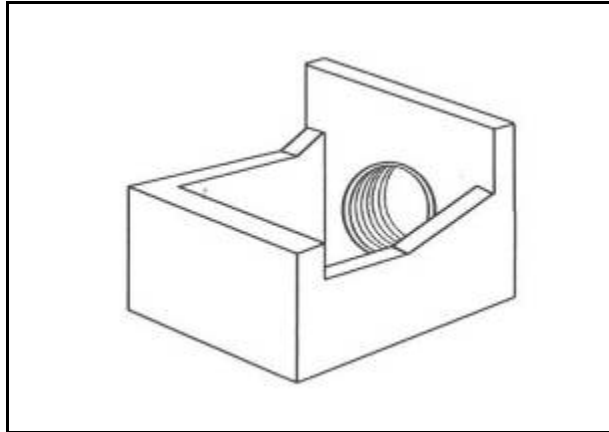


Figure 8.25 Drop inlet on relief culvert

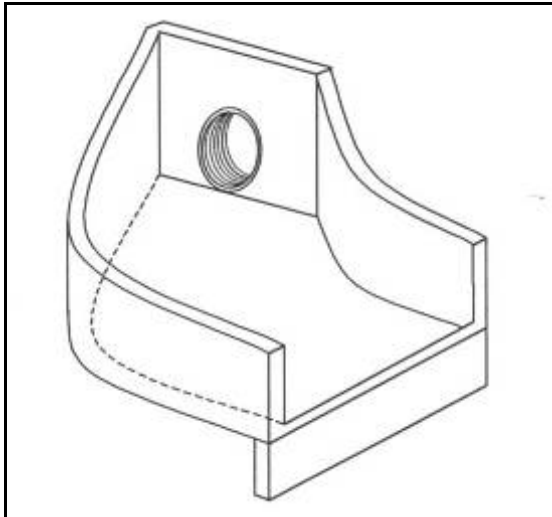
### Pipes transferring large water volumes



Figure 8.26 Drop inlet on stream culvert

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.

## 8. STRUCTURE DESIGN



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

Figure 8.27 L-shaped inlet

### 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.

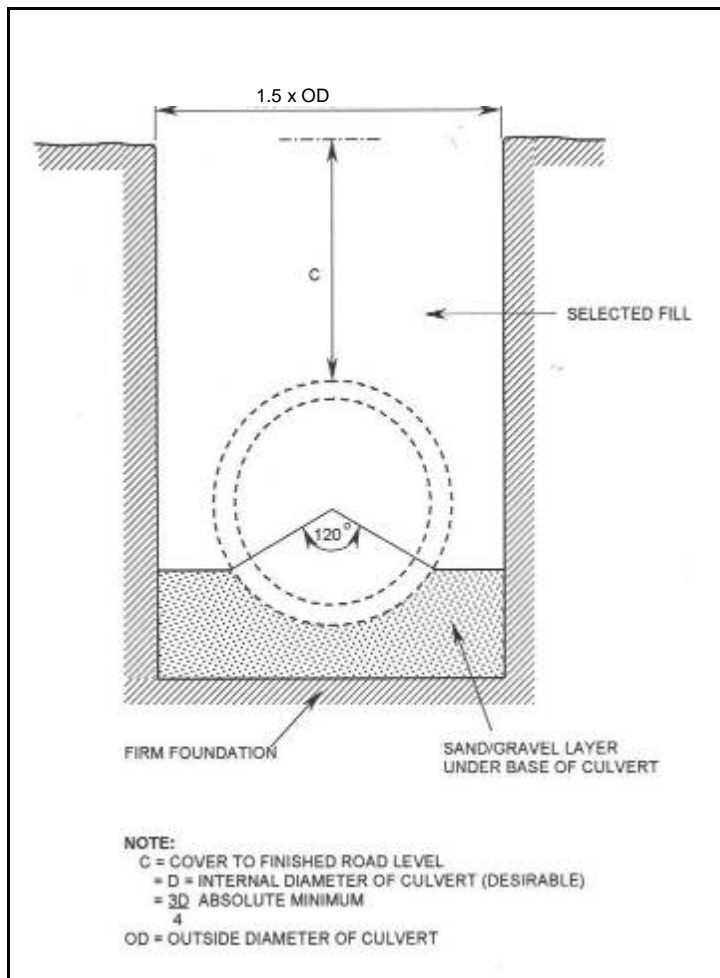


Figure 8.28 Pipe granular bedding and cover

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.

## 8. STRUCTURE DESIGN

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.

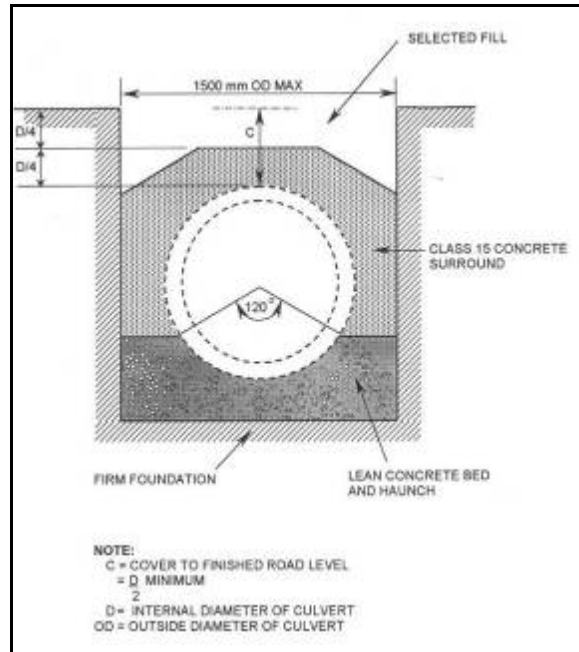


Figure 8.29 Pipe arrangement with minimum cover

### 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.

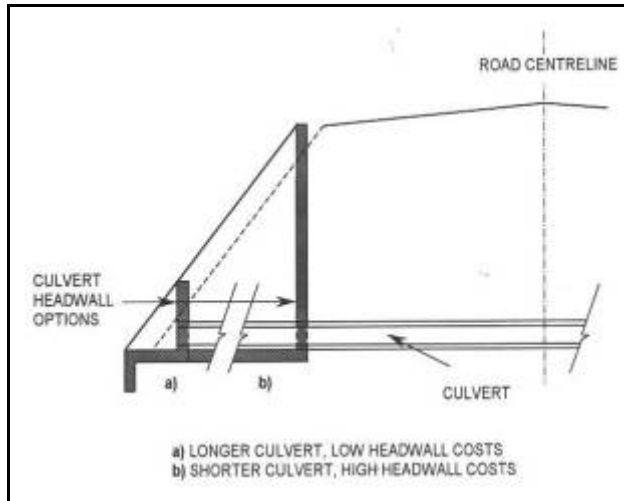
## 8. STRUCTURE DESIGN

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
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.

Figure 8.30 Possible culvert headwall positions

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 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.

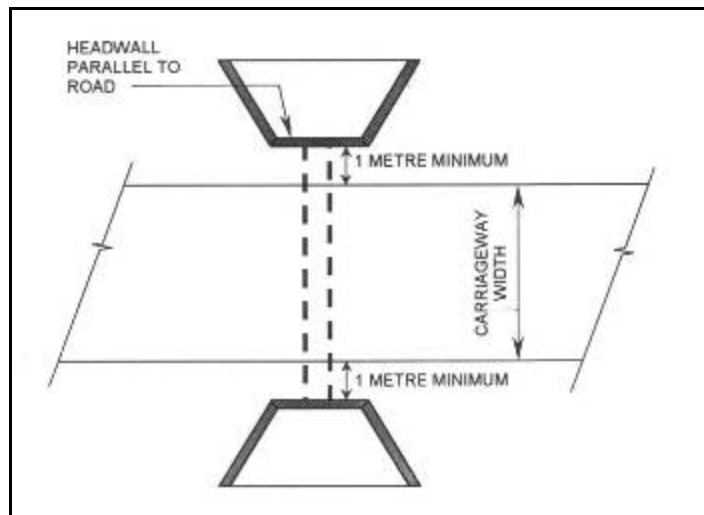


Figure 8.31 Position of culvert headwalls

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.

## 8. STRUCTURE DESIGN

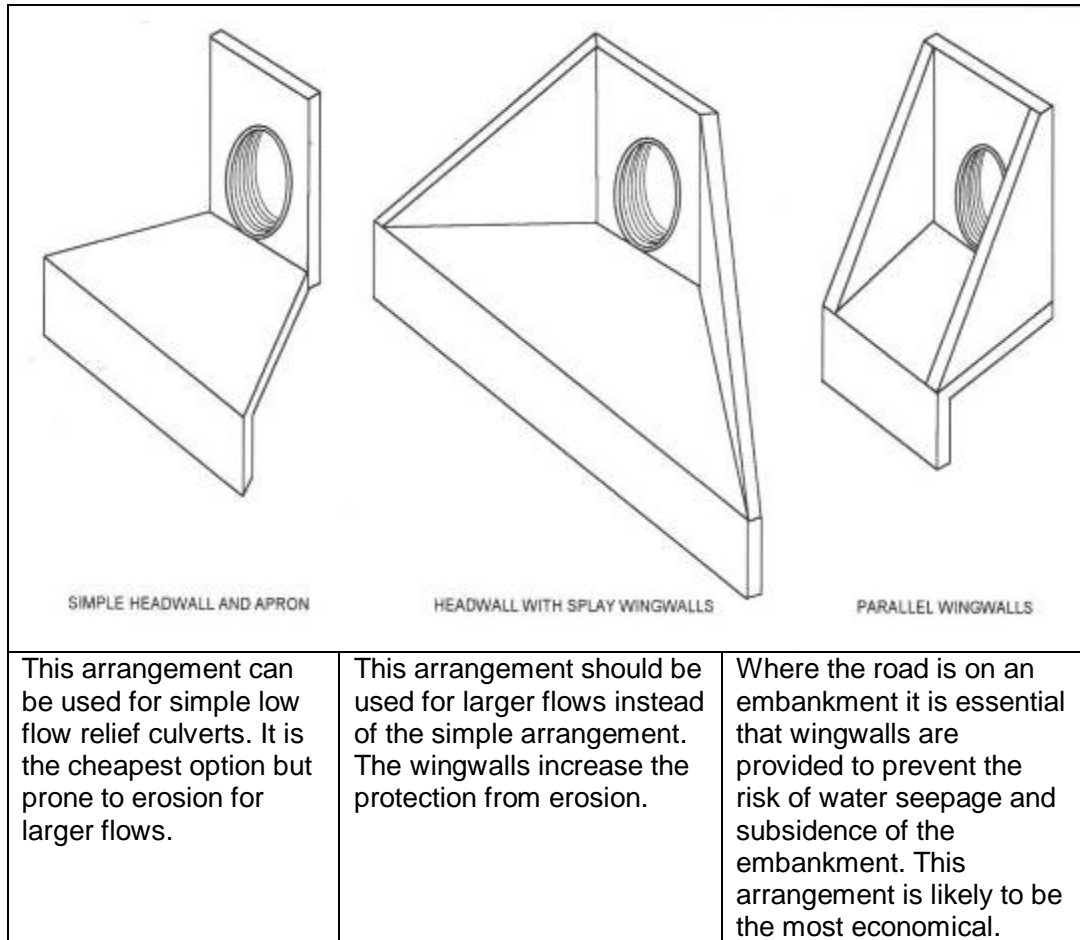


Figure 8.31 Headwall and wingwall arrangements

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.

## 8. STRUCTURE DESIGN

<b>Wingwalls parallel to water course</b>	<b>Wingwalls parallel to road</b>
Foundations on same level	Foundations can be stepped but are harder to construct
Wall more susceptible to erosion from watercourse	Wall mostly away from watercourse
Wall size smaller than wall parallel to road	Wall size longer than wall parallel to watercourse
Larger amount of fill to be moved, placed and compacted	Reduced amount of fill required to be moved, placed and compacted

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.



Figure 8.32 Wingwall cascade

### ◆ 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.

## 8. STRUCTURE DESIGN

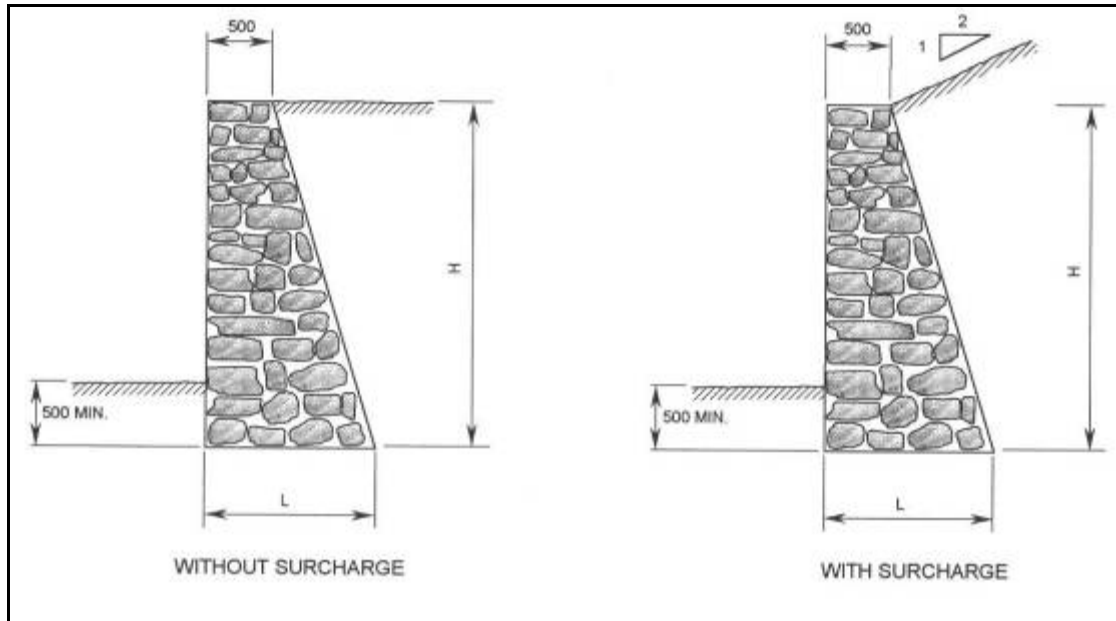


Figure 8.33 Stone, brick or blockwork wall with and without sloping backfill (surcharge)

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:

## 8. STRUCTURE DESIGN

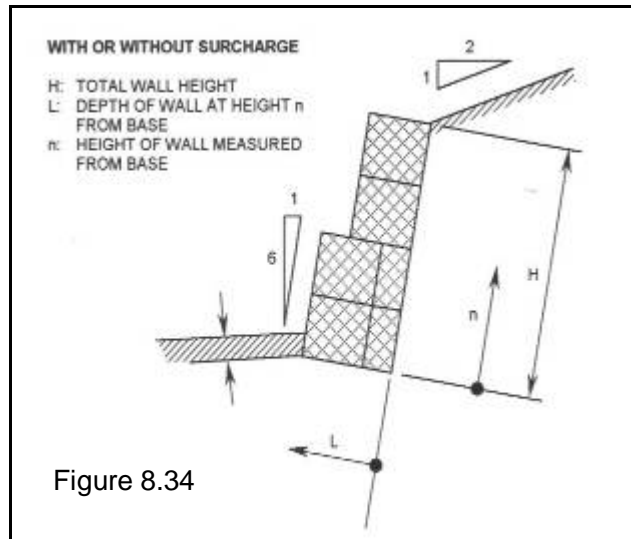
1. Top of the wall to be 500mm wide
2. Vertical front face and 1:4 sloping back face (1 horizontal: 4 vertical)

### ◆ 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.



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

## 8. STRUCTURE DESIGN

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.

### ◆ 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.

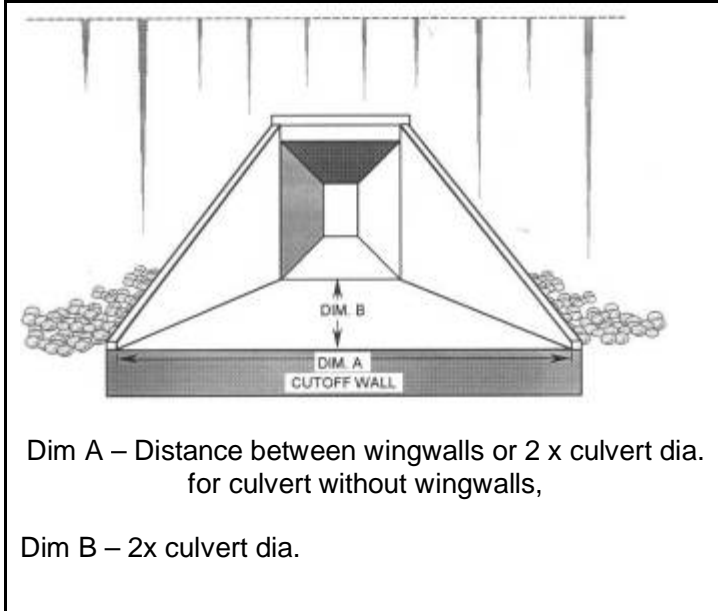


Figure 8.35 Culvert apron

### ◆ 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)

## 8. STRUCTURE DESIGN

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.

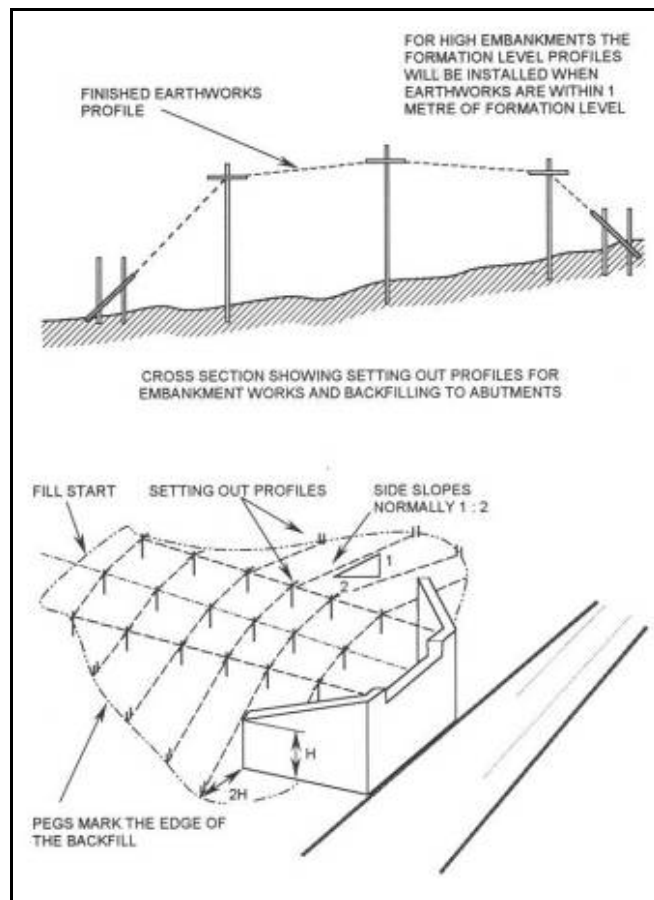


Figure 8.36 Construction of approach ways

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 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

## 8. STRUCTURE DESIGN

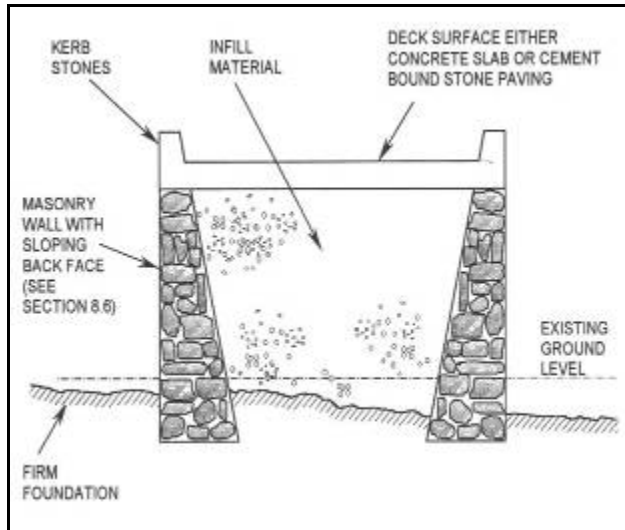


Figure 8.37 Example approach way cross section

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



Figure 8.39

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 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 (eg. damage to buildings or farming land).

## 8. STRUCTURE DESIGN

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 %	

## 8. STRUCTURE DESIGN

### ◆ 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.

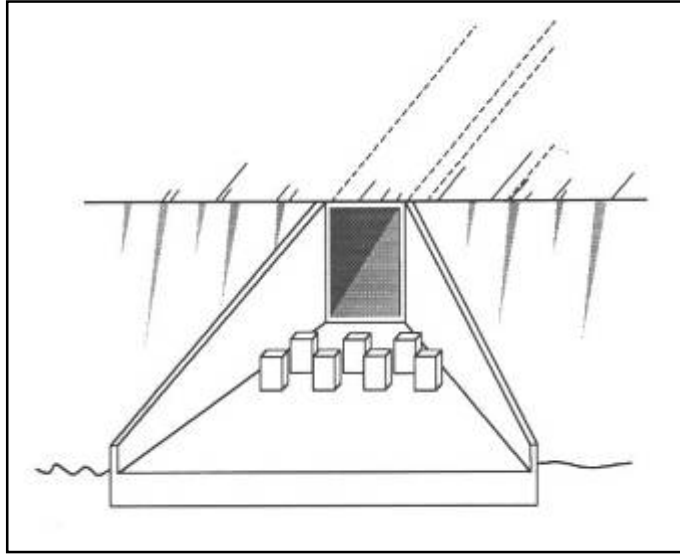


Figure 8.40 Energy dissipating apron

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 gabions is that they have the additional cost of the wire for the cages when compared with rip-rap. However, the ability of single labourers to move and place the stones may outweigh the cost of the wire. As gabions can be made in different sizes they can be used for a wide range of different shaped watercourses. They can also withstand limited ground movements and therefore accommodate any small changes in the river bed. If the bottom of the watercourse requires protection it would be possible to make a gabion that is only 200 or 500mm thick to form a mattress

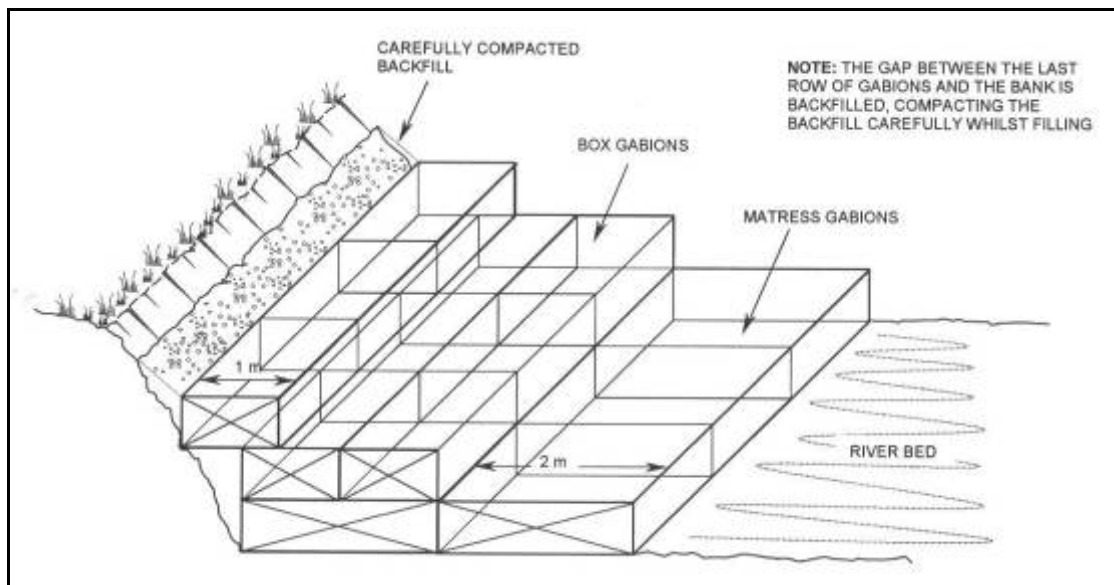


Figure 8.41 Gabion protection on steep banks

## 8. STRUCTURE DESIGN

over the watercourse bed. The diagrams show two methods for using gabions and mattresses for protecting the water course.

The size of the gabions will depend on the velocity of the water flow. For all flow velocities the smallest gabion used is 0.5 x 0.5 x 1 m.

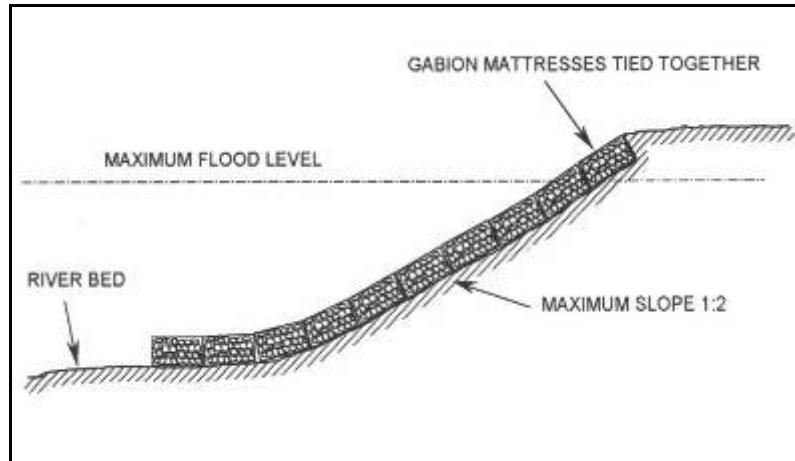


Figure 8.42 Gabion protection on shallow banks

Any mattresses in the bottom of the water course should be 200-300mm thick for water velocities up to 3m/s and 500mm thick for velocities over 3m/s. It is very important that they are securely wired together to ensure that they do not slide down the bank and cause the water to erode the watercourse banks behind them.

The minimum size of the gabion baskets makes this option suitable only for larger watercourses.

### ◆ Vegetation

Vegetation is likely to be the best option for small watercourses as once established it slows down the speed of the water flow and holds erodible soil together. It can also be a cost effective protection method where suitable local plants are available. The use of vegetation to control erosion is sometimes called bio-engineering. Bio-engineering covers a wide range of techniques that use vegetation, which include the control of erosion and stabilisation of engineering structures. This guideline discusses the use of bio-engineering to control erosion downstream of water crossings. It is not sufficient to randomly plant any vegetation, as the conditions must be correct for the plants to grow and they must produce the desired anti-erosion effect.

The most basic form of vegetation erosion control will be to allow the region's natural grasses to grow in the water channel. They may grow naturally without any assistance if they are already well established in the channel. However, if some erosion has occurred in the channel it may not be possible for the grass to establish itself without assistance. In these cases it will be necessary to cultivate the grass in a nursery or near the site at the road side if it will not be damaged by vehicles or cattle. Once the grass is established it can then be transplanted into the water channel. The replanting may be by individual plants or by turfing techniques. Natural fibre matting may also help to establish plant growth. The timing of the planting will be dependent on the rainy season. Plants need to get established in the watercourse while there is moisture in the soil. It may be necessary to regularly water the plants until they are established in their final situation. However, they are not able to grow during periods when the channel is full of water. It is unlikely that the grass will grow in the base of the watercourse if water is flowing throughout the year. In these cases it may be possible to plant the grass on the edges of the channel and an aquatic plant in the base of the channel. The choice of plant will again be based on local knowledge, but it is likely that plants found in other watercourses with similar conditions nearby would be the most appropriate. The local agricultural or botanical institutions should be able to provide guidance on plant selection.

In areas where hand pitched stone is proposed to protect the channel downstream from a culvert it may be reinforced with plants rather than cement or mortar, to bind the stones together.

## 8. STRUCTURE DESIGN

Stones should be placed in the river bed in the same manner as for standard hand pitched stone slabs. Any small gaps that remain between the stones should then be filled with soil and grass planted approximately 150mm apart. The exact distance will depend on the shapes and gaps between the stones. When the grass is planted the workers should ensure that the roots are deep enough to enter the soil beneath the stone pitching. In channels with a permanent water flow the grass should only be planted towards the sides of the channel, as it will be unable to grow under water in the centre of the channel.

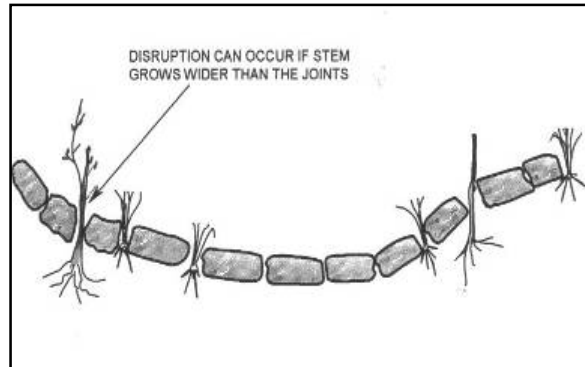


Figure 8.43 Care required with roots

A number of countries throughout the world have adopted a wide scale use of bio-engineering to stabilise slopes and prevent erosion. In these countries nurseries have been set up in each region to cultivate and grow special grasses that are particularly good at resisting erosion. These nurseries are usually managed by government or NGO organisations and supply grasses and other plants to work sites in the area. Vetiver grass is the most commonly used as it can grow in a wide variety of soil conditions including those of very poor quality. It also develops a fibrous and deep root system which is ideal for holding weak soil together and preventing erosion. Vetiver grass has successfully been used to prevent erosion on steep roadside banks and at the edges of engineering structures. The cultivated grass shoots are planted out in the area prone to erosion. The spacing of each shoot will depend on the perceived erosion risk and will vary between 100mm for high erosion areas and 200mm for lower risk areas.

### ◆ Steep channels

In areas where water is flowing down steep hillsides and crossing a road through a culvert, it is necessary to provide protection to the slope above and below the road. This is particularly important when a road is winding up a hill and a watercourse crosses the road a number of times, where it is not possible to channel all the water down steep inclines at the hairpins. Water flowing downhill has a large amount of energy which must be 'lost' if erosion is to be prevented. The most appropriate method in these cases is to construct a step waterfall or cascade to dissipate the energy.

The photograph and diagram show a step waterfall made from gabion baskets, but it would also be possible to construct the structure from masonry if available. Regardless of the material chosen the structure should be built into the hillside by excavating the necessary material. Care must be taken to ensure that the sides of

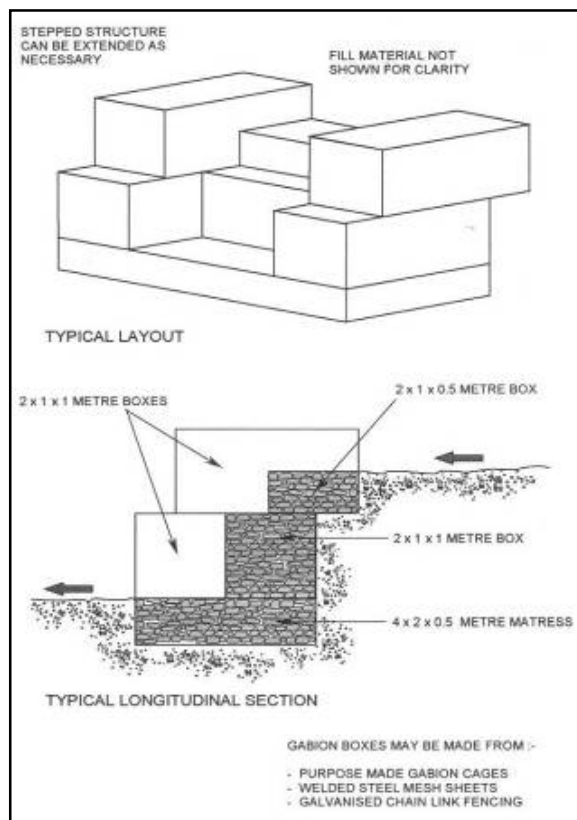


Figure 8.44 Gabion step-waterfall

## 8. STRUCTURE DESIGN



Figure 8.45 Gabion basket step waterfall

the channel extend outwards far enough to ensure that the water is contained in the channel.

### ◆ Drain protection

Along each side of a road there should be a drain to assist in removing water from the carriageway and transferring it into the nearest watercourse. In flat terrain these drains can be earth or gravel lined however, where gradients are greater than 2% they will require protection to prevent fast flowing water eroding the ditch. The most effective method of preventing erosion is to use scour checks, which are mini dams constructed in the drain. These scour checks form barriers to the water flow, causing silt to be collected behind each scour check and hence forming a series of steps in the drain which help to dissipate the water energy.

Scour checks can be built from either wooden stakes or stones. Where stakes are used stones should be placed below the stakes to prevent erosion as water falls over the step.

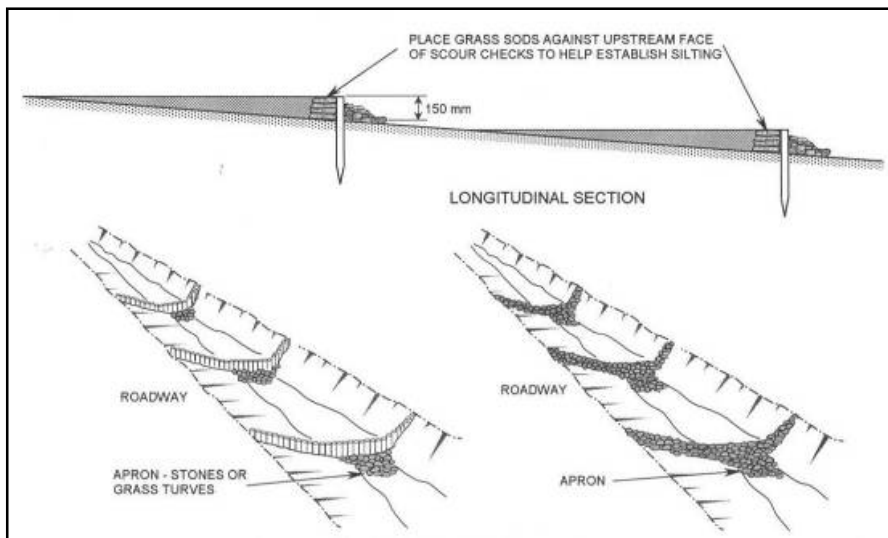


Figure 8.46 Scour checks

The distance between scour checks will depend on the drain gradient as shown in the table below.

Road gradient	Distance between scour checks
2 - 3 %	20m
3 - 5 %	15m
5 - 7 %	10m
> 7 %	5m
> 10 %	Ditch should be lined with masonry, stones or concrete to prevent erosion

**Arches**

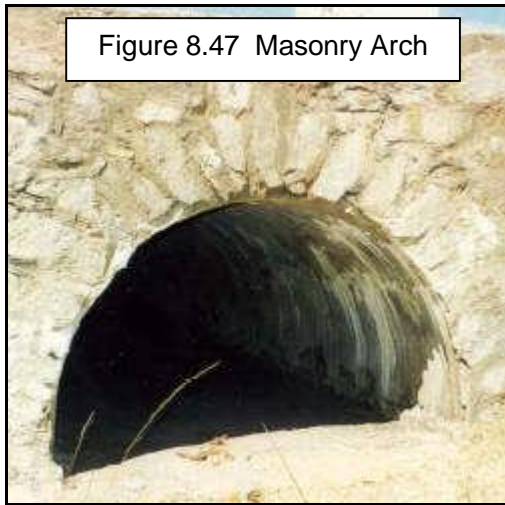


Figure 8.47 Masonry Arch

It is often difficult to define the difference between large bore culverts and arch bridges. Regardless of the name given to the structure, it will normally only be required where a road crosses a well defined watercourse and/or large flows are expected. This guideline defines a large bore culvert as a structure with arches up to 2.5 metre diameter. There are 2 design issues to be resolved if this type of structure is to be constructed.

1. Some form of permanent wall will be required on the upstream and downstream sides of the structure and on the base of the archway to retain the enclosed fill.

2. A large amount of fill material will be required to complete the construction.

**General design issues**

If a large opening culvert or arch bridge is to be constructed there are a number of issues that should be initially addressed.

◆ Arch shape

An arch resists the dead weight and traffic loads by compressive forces in the arch ring. This results in very large forces at each end of the arch which must be resisted by the foundations. If the arch is not semicircular these forces will have a horizontal component which is harder for the foundations to resist than vertical forces alone. It is therefore recommended that only semicircular arches are used unless specialist engineering support is available for the design.

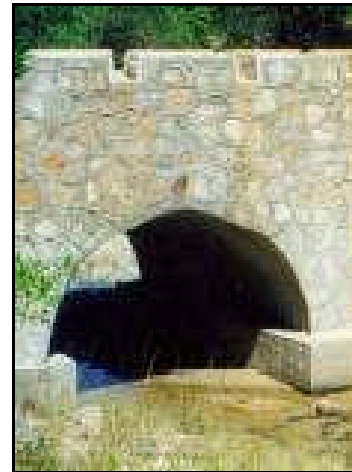


Figure 8.48 Arch bridge

The size of the forces at the end of the semi circular arch shown in Figure 8.49 will be equal to half the total weight of the arch and fill material, plus the weight of any traffic. The design of semi-circular arches should allow for an element of horizontal loading particularly during construction and placing of fill material. As the arch load will be concentrated in the foundations at each end of the arch these structures should only be built on ground which has a good bearing capacity.

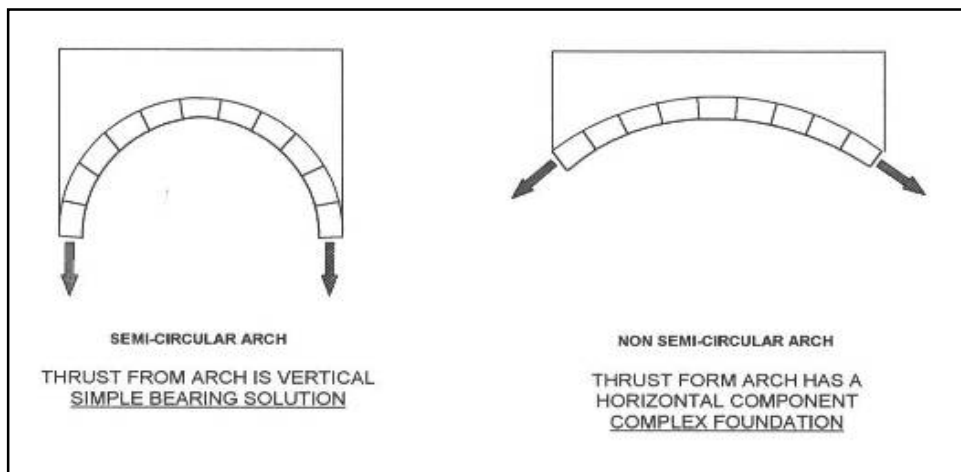


Figure 8.49 Arch forces

## 8. STRUCTURE DESIGN

### ◆ Formwork reuse

Depending on the type of materials used to build the arch, formwork may be required during construction. Temporary formwork can be very expensive when compared with the cost of the construction materials. Where possible it should therefore be designed to be reused on future bridges in order to reduce the overall cost and unnecessary resource use.

### ◆ Bridge/culvert layout

Once the designer has chosen to construct an arch bridge/culvert he will have to decide on the size of the arch or arches for the structure. The choice will depend on the particular characteristics of each potential site but the table below highlights the different options. If the designer wishes to use piers then reference should be made to a later section in this chapter which discusses the design of piers.

<b>Small Versus Large arches?</b>	
<b>Small arches</b>	<b>Large arches</b>
Easier to construct using labour based techniques	Formwork may require cranes to manoeuvre components into place
Piers will be required to be constructed in the water course	It may be possible to span the whole watercourse with one arch and avoid the need for piers in the watercourse (reducing scour problems)
The bearing pressures exerted by the piers will be lower than for large arches	The load exerted by a large arch will require ground conditions that can withstand very high bearing pressures

### ◆ Construction Sequence

The first stage of building an arch structure is to construct the foundations and any piers that may be required. The arch formwork can then be put in place and the arch constructed. The side wall construction should only commence once the ring is fully completed. The placing of fill material above the arch can proceed as the side walls are built. The placing of fill in layers about 1m below the constructed fill height would serve as a platform for the artisans who are laying the stonework for the side walls. Guide stones should be included on each side of the deck to mark the edge of the carriageway. These could be integral with the side walls or be formed with the deck surface. The options for the design of the deck surface will be the same as for the approach ways discussed previously.

### **Arch materials**

There are a number of different material options available for the construction of walls and temporary or permanent shutters for an arched bridge. Some of these options can be used in both the walls and arch, while others are only suitable for forming the arch.

Stone, bricks and blockwork can be used to form the walls of the structure. The choice of material should be made based on the cost and availability of each material. Any material that is used should conform to the specifications given in chapter 7. If part of the wall is in the water flow the material should be hard enough to resist erosion. The walls should be constructed with a tapered back face, similar to the characteristics of wingwalls discussed in a previous section.

Stone, bricks or blocks can also be used to construct the arch of the structure. Some form of temporary framework will be required during construction. This temporary

## 8. STRUCTURE DESIGN

formwork is likely to cost as much as the stonework used in the bridge itself. This option is therefore only likely to be viable if the formwork will be reused for additional spans or on other structures. The most appropriate formwork will usually be a wooden frame covered in wooden planks or sheets, although large truck tyres may be used to hold timber sheets in place for smaller arches. Reusable steel formwork may also be used, especially if a large number of culverts of the same diameter are to be constructed. Once constructed the arch gets its strength from its uniform shape with all components in compression on the arch face. It is therefore important that the formwork used is good quality and rigid, to ensure that the arch does not deform during construction.

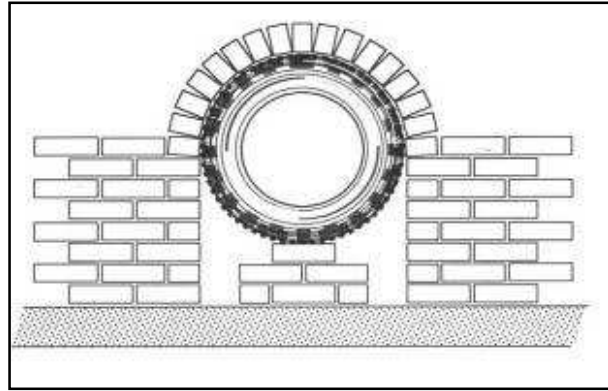


Figure 8.50 Use of tyre in formwork

All stonework used in an arch should be placed as shown in the diagram. The arch should consist of a minimum of 2 courses of masonry which should be interlocking where possible. In addition the minimum thickness of a semi circular arch ring is shown in the table below.

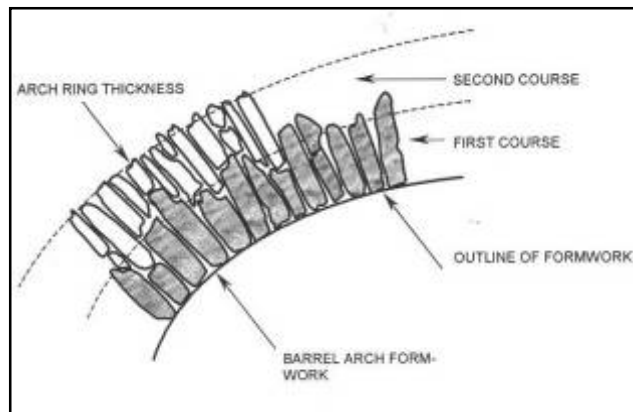


Figure 8.51 Two course arch

It is not possible to get the level of interleave shown in Figure 8.51 if using bricks. The strength of brick arches can only be ensured if a good bond is achieved between the brick and mortar. As the arch will be very strong and rigid once it has been completed there should be a simple method for releasing the formwork without damage in order that it can be used again.

Minimum arch ring thickness						
Arch span (m)	1	2	3	4	5	6
Ring thickness (m)	0.2	0.3	0.35	0.40	0.45	0.5

An alternative to stone or brickwork for the construction of the arch is to use corrugated metal sheets. The advantage of these sheets is that they act as permanent formwork to be left in place, becoming part of the finished structure, and preventing the need to use expensive temporary formwork. Although corrugated metal sheets are likely to have a higher purchase and transport cost than stonework this additional cost may be offset by the elimination of temporary formwork and the possibility to use lower grade fill, lean concrete or stonework and skills in the construction of the arch over the corrugated sheets.

## 8. STRUCTURE DESIGN

Corrugated metal sheets will need to be pre-bent to the correct radius for the arch by the supplier. They can then be bolted together at the bridge site to form the arch. To ensure that the arch does not distort when the fill is placed and compacted, the foundations or piers should restrain the corrugated metal, preventing it from flattening out. This requires a ledge to be constructed to hold the sheets in place.

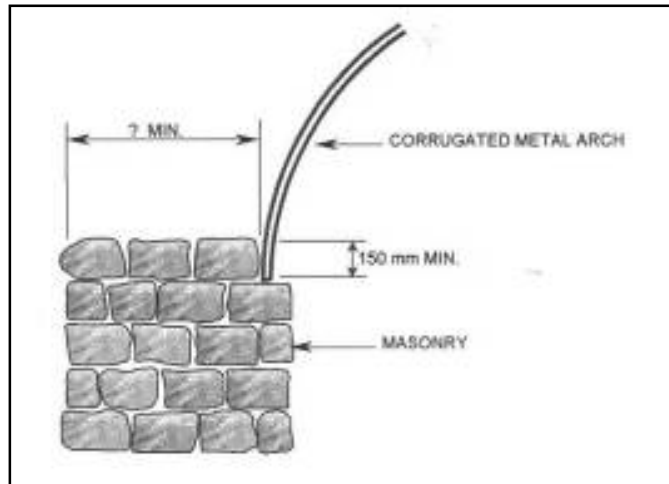


Figure 8.52 Corrugated metal sheet arch

### Fill options

There are 3 fill options that can be used in arch bridges which were discussed in the fills for approach ways in the section above:

1. Well compacted gravel
2. Weak concrete mix with plums
3. Rubble masonry

### Bridge design

This section covers the design of bridge decks appropriate for use on low-volume (traffic) roads in rural, often remote, areas. It includes guidelines for the design and construction of support abutments and piers. A bridge is basically an extension of a road, albeit a more sophisticated and expensive part. At a cost of up to 100 times or more than that of an equivalent length of road, however, it is important that careful attention be paid to its design and construction. Bridges are critical elements of the road system. A bridge collapse not only disrupts the serviceability of the whole of the road network but it can also endanger life to a much greater extent than other components of the road. The possible consequences of structural failure must be taken into account and given due emphasis in the design process.

In this section, as in the rest of this guideline, emphasis is placed on low-technology, labour based solutions, as these tend to be the most economic and socially beneficial in rural areas in developing regions. The previous text in this guideline is generally applicable to both single and two lane traffic small structures. The following pages generally cover bridges spanning less than 10m and carrying a single lane of low volume traffic. For single lane bridges, an appropriate deck width between kerbs or width limiting obstacles is 4m which is sufficient for most commercial farm and public transport vehicles. This can be reduced where certain vehicles are physically prevented from using the bridge and use is confined to motorcycles, bicycles, pedestrians and animals. Extrapolation of the contents of this guideline to larger bridge spans or for heavier traffic is not advisable. In these situations, a full engineered solution is required and reference should be made to Overseas Road Note 9 (TRL 2000) or other appropriate documents.

#### ◆ Choice of bridge site

An appropriate choice of location is important if an effective bridge solution is to be obtained, in terms of cost of construction, maintenance and service life. The ideal site would have low flood levels, high solid banks (preferably rock), a non-skewed crossing and straight approach roads. Normally, however, some compromise is required.

## 8. STRUCTURE DESIGN

### ◆ Loading

Careful consideration must be given to the type, volume and weight of vehicles which will use the road. It is often stated that “if a heavy truck can physically use the road, then at some stage it will”. Generally, bridges must also be designed to carry the heaviest load expected. This is particularly important for decks, less so for abutments and piers. Modern bridge loading specifications are generally applicable to structures which experience high volumes of traffic (>10,000 vehicles per day). The economics are such that bridges built to these specifications cannot be justified for the majority of low cost roads used to service rural areas. Note that many low-volume rural roads in developing countries rarely experience vehicles greater than 6 tonnes: this limit covers cars, light buses, pick-up trucks, cattle wagons, etc. In particular circumstances this may not be sufficient, for example, near stone or gravel sources or factories which produce heavy goods. Where heavier traffic (>10 tonnes gross vehicle weight) is likely to be a regular occurrence proper engineering design by suitably qualified engineers is required. This is beyond the scope of this guideline and reference should be made to documents such as Overseas Road Note 9 (TRL 2000).

### ◆ Scour

The site of bridges must be carefully chosen to take local conditions into account to ensure durability and functionality, including alignment. Chapter 5 gives details of the general principles involved in site selection and appraisal. For bridges, this is crucial if future problems and maintenance costs are to be minimised. The type of site investigation required to take the watercourse into account is outlined in chapter 6. The detrimental effects of scour on bridges and support systems must be recognised; in fact this is the most likely cause of structural failure in bridges around the world.

In most cases problems can be minimised, and often avoided completely, by appropriate choice of form and location for the crossing.

### ◆ Drainage

Every form of bridge requires some water management to ensure that water does not pond on the deck, which could cause a traffic safety hazard, rotting of timber, corrosion of reinforcement or deterioration of masonry. For solid decks a transverse camber of 1 in 40 and a 1 in 100 longitudinal fall is sufficient to prevent ponding. Where kerbs are present some means of disposing of water from the deck is required. For timber decks, a 20mm gap between planks is sufficient to allow adequate drainage. For solid decks, scuppers should be considered and should be carefully located and detailed to discharge excess water through the deck without causing erosion, staining or maintenance problems. The careful detailing of road side drainage outfalls at the bridge site is essential to avoid erosion problems.

### ◆ Maintenance

In bridge design, there is a trade-off between initial construction cost and on-going maintenance costs, and bridges which are cheapest to build can end up being the most expensive when whole life costs are considered. Maintenance of a bridge must be considered at the design and construction phase. The designer should make allowances for access for inspection and should recommend a maintenance plan which includes extent and frequency of inspection, and any routine works required. These maintenance costs should always be considered when selecting the preferred design solution.

In general, it is a good idea to design bridges to minimise future maintenance actions and costs. This is because maintenance is often neglected, particularly in rural areas where traffic levels are low and financial/physical resources and logistics may be severely constrained or challenging. It should be remembered that routine maintenance will ALWAYS be required. This involves regular brief inspections, including preventative maintenance such as clearing of drains and removal of debris or garbage, on an annual basis. This gives a clear indication of the performance of the bridge and the progress of

## 8. STRUCTURE DESIGN

any deterioration. Provided adequate guidance and a means of recording the results of the inspection are provided, these inspections do not require qualified engineers. However, a more detailed inspection at intervals of about seven years by a qualified engineer is recommended. The detailed cost of the bridge structure options should include the expected costs of the maintenance regime inspections over the design life of the structure in present day costs, and also an estimate of the likely routine maintenance activities. These should be estimated from maintenance records for existing similar structures.

Abutments and piers are often constructed within the watercourse. These should be designed and constructed to keep to an absolute minimum their effect on water flow. This minimises the possibility of scour and helps to avoid expensive maintenance work. In general and where possible deck soffits should be constructed a minimum of 300mm above the highest expected waterline. For timber decks this should be increased to 1000mm. For further guidance see table on page 154. Structure design and flood return period considerations are addressed in chapter 3.

In some cases, the construction of a low level bridge or vented ford might be appropriate where normal water depth exceeds fordable depth, and where dry access is not required all of the time. These are bridges which allow flooding approximately once a year for up to three days at a time. Most modern vehicles can drive through 150mm of water and this may be an acceptable economic solution for very low volume (traffic) roads. Scour protection should be provided to cope with the 50-year flood level where practical. This should be sufficient to prevent scour or even complete washout of both the deck and support system. Construction materials must be carefully chosen to prevent deterioration with time. In particular, the flood water must be prevented from flowing around the structure or flowing down the road. This can best be ensured by proper location of the bridge; retrospective work to keep flood water within the original channel can be very expensive, if not impossible.

- ◆ Choice of structure

The selection of structure type is discussed in Chapter 4.

- ◆ Choice of materials and form of construction

The general properties of construction materials and how to identify and evaluate them are outlined in chapter 7. For bridges as for other road structures, the choice depends primarily on local conditions and on the availability of materials and labour and the costs of the feasible options. However, greater care is required in the selection of appropriate materials for bridge structures as the materials will be called upon to take greater loads, and local weaknesses or defects may lead to total collapse of the bridge. It is probable



Figure 8.53 Reinforced concrete deck on masonry abutments and pier

that in order to minimise the total cost of the structure, maximum use should be made of local materials and labour. Any choice of materials and form of construction may have maintenance implications and these should be included in the overall assessment of the options.

Reinforced concrete is generally considered to be the most economic material for construction of bridge spans up to 30m or so. This is because of the long life

## 8. STRUCTURE DESIGN

expectancy, good durability characteristics and low maintenance costs. However, while well-constructed concrete is very durable and requires very little maintenance, construction requires a high level of technical skill as well as the availability of good quality materials. The guidelines in chapter 7 must be followed if good quality structural concrete is required. Bad site practice and poor workmanship can lead to a very poor structure which can cause loss of stability and early collapse. Typical faults include use of dirty water, sand and aggregate, inadequate mixing, placing and compacting of concrete, inaccurate fixing and positioning of reinforcement or formwork, storing of cement in humid conditions, etc. Mix design, i.e. the proportions of cement, sand, coarse aggregate and materials to be used, is very sensitive to mistakes. Labourers often do not realise the consequences of poor practice and close supervision should always be carried out when structural grade concrete is required. If there are local shortages of formwork, steel fixing and structural concreting skills (which often have to be imported into a rural area), it may be more appropriate to adopt designs that utilise locally available building skills such as carpentry and masonry.

Each region tends to have its own local construction artisans (blacksmiths, carpenters, stonemasons, etc) and materials (stone, brick, wood, gravel). These will affect the economics and local resources should be used where possible, although other factors may also influence the final choice, for example a local policy may influence preferences. The construction of stone or brick masonry arch bridges is labour intensive but these are the most durable and, arguably, the most aesthetically pleasing bridge forms. Simple arches are also technically the simplest form of bridge structure to construct with relatively limited supervision requirements. If suitable materials and stonemasons are available, this may be the most effective long-term solution.

Timber as a primary structural material has its advantages. Its low weight, low cost, general availability, and ease of construction make it attractive in many remote situations where it is grown locally. Timber can be assembled using non-skilled labour and in adverse weather conditions. It requires some protection against deterioration and insects, particularly in hot humid climates. Timber requires deeper sections than steel or concrete mainly because of its lower stiffness. Experience in North America, where there are many timber bridges, suggests an average life of 50 years, although with good maintenance, the life can be considerably greater.

Timber as a structural material has some major disadvantages which should be considered. All timber can rot and be eaten by insects. Some degree of protection such as creosote is required and this should be re-applied periodically through the life of the structure as required to ensure maximum life. Immersion in creosote or other preservative for several days prior to assembly provides long-lasting preservation. As timber is light it can easily be washed or blown away. All timber decks should be tied down at supports and these fixings should be inspected at regular intervals. Timber is easily set on fire, either by accident or maliciously. Garbage, driftwood, weeds, etc. should not be allowed to accumulate under the structure. When timber, either in the form of sawn sections or logs, is used for structural purposes it is very important to have a clear understanding of the strength and durability obtained from the particular material available. Seasoned timber free of defects and properly preserved should always be used. See Chapter 7 for more details including tests to evaluate prospective timber sources.

Durable local stone in compression is the most economical material of construction when whole life maintenance costs are included. General properties of different stone are given in chapter 7. Alternatively bricks can be used but for bridge structures it is important that they are consistent in strength and quality. Chapter 7 gives some background on the expected properties of locally produced bricks.

### ◆ Foundations

## 8. STRUCTURE DESIGN

Foundations for piers and abutments are discussed earlier in this chapter. Bridges are usually constructed on sub-soil with an allowable bearing capacity greater than  $300\text{kN/mm}^2$ . This is easily achieved in gravel, compact sand and strong clay. A simple check to indicate this minimum capacity is:

1. A man's weight bearing on a 30mm diameter bar only penetrates 100mm;
2. A 2m rod driven into the ground with a 3kg hammer experiences increasing resistance.

On softer soils, a bridge may not be appropriate and another site or form of structure should be considered. Bridges can be constructed on very soft soils using piles. Timber piles can be driven using fairly rudimentary equipment and manual or animal power. Where piles are used, design and supervision should always be carried out by a suitably qualified engineer. Where bearing capacity is limited, it should be noted that gabion abutments are lighter than concrete and spread the load well.

### Arch bridges

Arch bridges usually provide the best solution in consideration of the level of maintenance required. Spans greater than 10m require a properly engineered solution and reference should be made to Overseas Road Note 9 (TRL 2000) or other appropriate documents for design and construction. This guideline is appropriate only for spans less than 10m. The previous section deals with large bore culverts and provides general information on the construction of masonry arch structures. The following paragraphs refer to arch bridges appropriate for low volume roads suitable for pedestrians and vehicles less than 6 tonnes.

Arch bridges can be built in different forms and shapes. The key elements of an arch bridge are shown below. The wedge shaped blocks, stones or bricks which form the barrel or ring of the arch are called voussoirs. These are usually placed symmetrically around a centre stone or key-stone. In fact, the key-stone has no special function and is an aesthetic rather than a structural requirement. The block in the abutment on which the arch barrel sits is called a skewback and the surface between the skewback and the end of the arch barrel is called the springing. The highest point of the arch is called the crown and the lower sections are the haunches. The upper and lower boundary lines of the arch ring are called the extrados and intrados respectively. The outer walls which retain the fill are the spandrel walls and they become the wingwalls at either side of the arch.

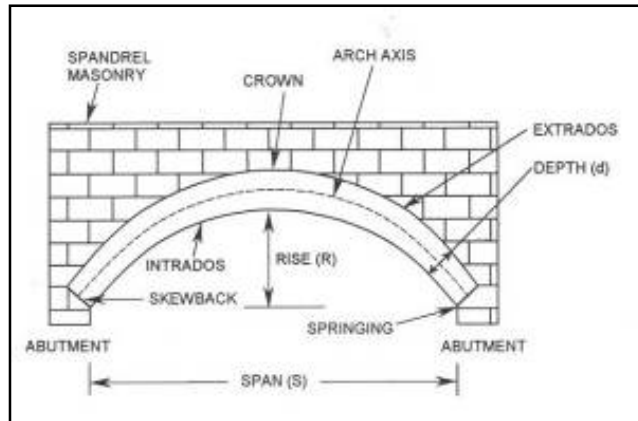


Figure 8.54 Arch bridge details

Arches can be constructed using any good quality stone or brick. Wedge shaped stone can be used without mortar but it is more common to use regular shaped rectangular stone or brick placed with a good quality mortar forming the slightly wedge shaped joints between each unit. The use of mortar can reduce the stresses in the stone by as much as 30% and should always be used if possible. If bricks are used, a high standard is required; they must be fired to a good engineering quality and be consistent in shape and strength.

Arch bridges are heavy structures and care should be taken to ensure that the foundation has sufficient bearing capacity. Foundations are usually relatively shallow spread footings

## 8. STRUCTURE DESIGN

or onto solid rock where this exists at the springing. It is essential that there is sufficient resistance in the abutments to resist the substantial horizontal spreading forces inherent in an arch design. Excavation must be taken down to firm material. In soft soils, timber, concrete or steel piles may be required beyond the scope of this guideline. A cofferdam can be used to provide a temporary dry working area.

Piers in multi-span arch structures are usually thick structural components with widths about 25% of the arch span. These are massive enough so that individual arches of multi-arch bridges are self-supporting. Piers can be made using a double outer layer of bricks or blocks and the cavity filled with clay or rubble. However, it is good practice to make the piers of solid masonry where possible, particularly for smaller bridges.

For the arch barrel, extensive support is required during construction and it is likely that supporting falsework will be placed in the river bed. There are obvious related seasonal storm or flood risk considerations. Formwork would normally be made from timber of sufficient strength, fixed to give the correct shape to the arch. As the section on arches suggests, other material can be used, eg. corrugated iron sheets. The formwork and supporting falsework must be firmly positioned and able to take the weight of the masonry and workmen. It must be devised in such a way that it can easily be removed once the arch has been constructed.

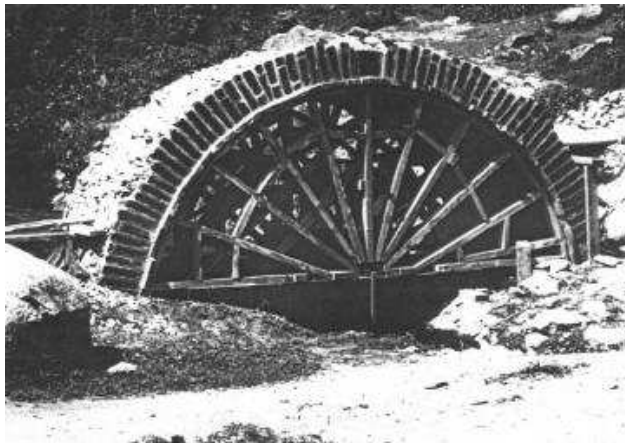


Figure 8.55 Masonry arch under construction with wooden formwork

Distortion of the arch during construction must be avoided as this can have serious implications on the strength and stability of the completed bridge. The formwork should not distort or move noticeably due to workmen moving over it. It is economical to reuse the formwork and this should be kept in mind when devising the installation and method of removal after construction. To avoid having supports in the river bed, formwork arching between the abutments can be used but this would not usually be required for small span arches of normal height.

As access to the river bed may be required for a long period of time, arches may not be suitable where floods occur frequently.

Arch bridges are suitable where high clearances are required. As the section above suggests, the simplest arch shape is a semi-circle which avoids horizontal thrust forces at the springings. It also provides maximum headroom and simplifies the geometric layout. Other shapes such as ellipses are used to reduce the height of large span bridges; these are considered to have a potential weakness at the quarter points. Any arch form where the ring is not vertical at the support will induce horizontal forces in the abutments or piers which must be resisted.

The thickness of the ring or barrel of the arch is the main factor affecting the strength of a well constructed bridge. Small arches may be built using a single layer of bricks laid radially providing a ring thickness of 215mm for a standard brick size. For larger arches the ring thicknesses shown in the table on page 140 should be followed. Because of the arch shape, the thickness of the mortar will vary through the depth of the ring. Most arches are made using two or more concentric rings with mortar providing the only bond. A header or stretcher bond may also be used, ie. a brick laid radially to provide a key

## 8. STRUCTURE DESIGN

between the rings. For larger spans, the number of rings can be increased towards the springings. It is recommended that skewed arches are avoided.

Once the arch ring has been completed the fill material is put in place. A large amount of fill is required. Any local material of consistent quality can be used, for example the material excavated during the construction of the foundations. Strength is not a requirement, its only function being to distribute the load uniformly to the arch barrel. However, well compacted fill can add considerably to the strength of an arch bridge. Refer to the section on approach ways for appropriate materials and compaction requirements. A well drained granular fill is the best material, being flexible enough to allow the bridge to tolerate some degree of movement. It is recommended that the arch formwork is only removed once all the fill material is in place.



For brick arches, it is also recommended that the formwork be removed after the mortar has fully hardened, about seven days, to avoid distortion of the arch while the mortar is still soft. For stone arches, this period can be reduced.

Figure 8.56 Completed masonry arch bridge with splayed wing walls on hard rock foundations

Spandrel and wingwalls retain the fill material and stiffen the arch ring at its edges. They should be thickened at the base to provide better stability. For larger spans it may be helpful to have wingwalls sloped outwards in plan for extra stability.

### Deck

The deck, or superstructure, is that part of a bridge which carries the roadway. Its function is to transmit the load safely to the abutments and piers, without damage to the bridge structure or undue distortion of the deck. For bridges with spans less than 10m, the only loads that need to be considered are the dead load of the deck itself, including parapets and any other bridge “furniture”, and the live load due to traffic or pedestrians.

It is always a good idea to carry out a design check if possible. A simple analysis can be carried out, assuming the deck is a simply supported beam. The loading to be used should consist of the heaviest vehicle likely to use the bridge and a uniformly distributed load of  $5\text{kN/m}^2$  of deck area to represent pedestrian loading (including cycles and animals). The maximum expected stresses can be obtained and compared with the strength of the material used. Maximum deflections can also be calculated once the deck details have been established. In general, it is a good idea to limit the maximum expected deflection to  $1/100^{\text{th}}$  of the span to avoid damage at the deck joints.

The deck can take many structural forms depending on local conditions and availability of materials and labour. Arch bridges have been described in the previous section; other types of bridges include reinforced concrete slab bridges, beam bridges (reinforced concrete, timber, steel), and truss bridges (timber or steel). The following gives general information on how different materials can be used to provide low cost bridge decks.

#### ◆ Material - Concrete

Precast concrete beams are likely to be the most economical construction material, however for small spans (<6m), simple cast in situ reinforced concrete slabs are likely to be the most economical solution. For larger spans, beams will generally be required. A span to depth ratio of about 12 will generally be sufficient, although decks should not be constructed less than 300mm thick. As previously mentioned, reinforced concrete is a

## 8. STRUCTURE DESIGN

material requiring certain technical expertise and requires care in construction if an effective structural material is to be produced. Best practice as described above should always be followed and supervision of unskilled workers is necessary if structural grade concrete is to be produced. Reference should be made to Overseas Road Note 9 (TRL 2000) for further information.

### ◆ Material – Timber

The weight of timber is about 25% that of concrete and timber is therefore quite an effective construction material. All timber should be obtained from suitable hardwood which is generally available in tropical forest areas, and should be treated using creosote etc. to prolong life. There are three basic elements to a timber girder deck:

1. Road bearers: These support the surface of the deck and are often called beams, girders or stringers, although trusses can also be used. The road bearers form the main structural elements of the deck and are described in more detail below.
2. Floor planking: These are the boards which are nailed to the stringers to form the surface of the deck. These boards spread the wheel load to the girders. As the girders are generally spaced at less than 1m the individual pieces of floor planking do not need to be too long. A depth of 75-100mm is normally sufficient.
3. Wheel tracks or running boards: These are boards which are fixed to the 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. The geometry of the tracks must be such as to accommodate the wheel base of all vehicles likely to use the bridge. For most cases, tracks 1200mm wide with a gap of 800mm between inside edges should be sufficient. In some cases, a cover of asphalt or sand can be applied to prevent damage from heavy vehicles. Worn out or damaged running boards, floor planks and girders should be replaced to avoid progressive damage and injury to bridge users. A beneficial additional detail is to fix a 'threshold' plank laterally across the road at each end of the running boards. This detail will help to reduce the vehicle impact loadings on the ends of the running boards (this location is particularly susceptible to loosening of the running board fixings).

The design and suitability of the final product is very dependent on the type and grade of timber available. General advice is difficult because of the wide range of timber available



Figure 8.57 Timber deck with floor planking and edge beams in need of repair

around the world. Most codes refer to sawn timber of consistent quality. In the following, it is assumed that a supply of well-seasoned hardwood timber is available, which is free of rot or insect infestation. It also assumes that, in the worst case, the bridge will be loaded with light vehicles (< 6 tonnes in weight). Where heavier vehicles are expected, more attention should be paid to structural details and reference

should be made to Overseas Road Note 9 (TRL 2000) or similar documents to define the size and spacing of main structural elements.

## 8. STRUCTURE DESIGN

The road bearers can consist of either a number of girders spanning between supports or a pair of trusses along the edges of the bridge with transverse stringers carrying the deck. Simple girder bridges are easier to construct and require less skilled labour but are only suitable for short spans. For longer span bridges trusses provide a more efficient use of timber but these require specialist skills for design and construction. In particular the joints and connections require careful attention. Design of timber truss bridges should only be carried out by a suitably qualified engineer.

Timber girders can be constructed from either sawn timber sections or from the original logs depending on the source of timber available. The factors affecting the strength of girder decks are:

1. type of timber (quality, strength)
2. depth of member
3. width of member
4. spacing

It is possible to design the timber deck for a particular type of timber but this will require detailed knowledge of its properties. Where sawn timber is available commercially, this information may be obtainable from the supplier. Chapter 7 presents the general properties of different timber broadly classified into soft, medium, hard and very hard wood and gives samples of the tree species. This highlights the fact that strength is closely related to timber density.

Generally sawn timber is easier to use and fix in place because of the regular shape and flat surfaces. It is also easier to examine for defects such as knots or insect damage which can seriously reduce strength. Where minor flaws exist, the timber can be used provided the flaw is placed as close to the top of the girder as possible to reduce its effect on strength. Where sawn timber is not available, logs can be used. These require more care in selection for quality and size, positioning and fixing in place.

<b>Sawn timber girder bridge deck for 6 ton vehicles</b>		
Span (m)	Timber size* (width x depth - mm)	Girder spacing (m)
5	150 x 300	0.5
8	200 x 400	0.8
10	200 x 400	0.5
12	250 x 500	1.0
*All timber to have a density greater than 450kg/m <sup>3</sup>		

The table provides the size and spacing of sawn timber girders required for various spans. These are appropriate for pedestrians and light vehicles only (up to 6 tonnes). For heavier vehicles, the tables in Overseas Road Note 9 should be used. Note that wide spacing makes

fixing of deck planks more difficult.

Logs are best used round but with the top shaven to carry the deck. The bark should be stripped and each log checked for soundness and defects. Properly seasoned logs should be used. Particular care should be taken to ensure that the timber has not been attacked by insects. As with all timber, logs should be treated with creosote or other preservative agent preferably by immersion for several days. Painting is not sufficient protection. The ends of the logs are particularly vulnerable as they are often in contact with soil. Moisture and garbage often collect at supports and can cause rotting. The logs should be closely matched for size and positioned with the top surfaces in the same plane and to accommodate any variations in log diameter with the large diameter at alternate ends on adjacent logs (refer to chapter 9).

## 8. STRUCTURE DESIGN



Figure 8.58 Log stringers from underside of bridge deck

Running boards can be placed directly on top of the logs although deck planking is recommended if pedestrians and animals are to use the bridge regularly. In general, three or four logs of about 300mm diameter are sufficient to span up to 10m to carry a single lane of light traffic. Again, for heavier traffic, the tables in TRL Overseas Road Note 9 should be used.

One common problem with timber decks is excessive spacing of the longitudinal stringers. Excessive deflection of the stringers under vehicle loading can cause surface damage to the timber at the supports which can lead to rotting and early deterioration of the deck. The deflection can also cause the deck planks to work loose leading to damage, rot or even complete loss. A general recommendation for heavily trafficked bridges is that the stringers be placed as close as is reasonable for the available timber sizes to avoid excessive differential movement across the deck. This can be relaxed for low-volume roads. Stringers should be placed so that the tops are at the same level; this ensures that deck planks bear evenly across the deck. If one stringer is higher than the rest, the underside should be trimmed where it bears on the support or the seating for that stringer should be lowered. This avoids having to trim the whole top length of the timber. Floor planks 50x100mm make a very effective deck. These can be laid on edge and nailed to the preceding one to make a very stiff solid slab 100mm thick.

Where joints are made using nails or screws, the following minimum spacing distances should be used (in terms of the nail diameter) to minimise the chance of damage to the timber and premature failure of the joint.

Location of nail	Number of nail diameters
Edge distance parallel to grain	20 diameters
Edge distance perpendicular to grain	5 diameters
Distance between lines of nails	10 diameters
Distance between adjacent nails in a line	20 diameters

### ◆ Material – Steel

Steel beams with a concrete or timber deck make a very effective bridge. Steel beams are expensive and may be difficult to transport. However, they may be available from demolished steel truss bridges or buildings. A concrete deck can be cast on top of the beams. This must be made integral with the steel beams either by encasing the beams in concrete or using shear keys fixed to the top of the beam at 100mm spacing and penetrating 50mm into the concrete deck. The deck can also be constructed using soil, rubble or lean concrete provided a method of supporting and retaining the fill is devised. This could consist of transverse arches supported by the bottom flange over which fill material is compacted. The arches can consist of brick or stone masonry, metal plates or concrete.

## 8. STRUCTURE DESIGN

Steel beam decks tend to rattle and vibrate excessively due to inadequate fixing at the supports. Beams can be fixed to timber abutments using screws or nails driven through holes in the bottom flange. If a timber deck is used the planks should be fixed securely to the beams.

If available and of suitable length, old railway lines can be used to form a bridge deck. Because of difficulty of fixing to abutments and attaching deck planks, the rails can be encased in concrete so that the rails act as reinforcement. This also protects the rails from corrosion.

### Abutments

Abutments provide the support system for the deck and retain the soil under the approach road and can be built using various forms and materials. The main function is to transfer the loads from the deck to the supporting foundations. They are also located at the transition between the approach embankment and the bridge deck. Effective abutments should provide good performance and stability to the bridge structure as a whole. The form of the abutment will depend on foundation material and on the deck type. The bearing capacity of typical soils and rock are given in Chapter 6; this will dictate the size of the abutment and the bearing area required.

The material used for abutment construction depends primarily on the availability of local material. It is recommended that concrete or masonry be used to make abutments where possible. Mass concrete can be used provided the concrete is of sufficient quality and the abutment is of sufficient size.

Timber abutments may be considered acceptable for low volume road structures but their vulnerability to deterioration and short service life should be recognised. Gabions can also be used providing fill material of suitable size and resistance to water damage is available. They have the advantage of providing natural drainage to the approach road. However, they are susceptible to damage and settlement due to scour and should be checked regularly to ensure that the wire has not corroded. Gabion abutments are not suitable for situations of paved road surfaces due to the settlement risks.

Abutments should be built away from the watercourse if possible to avoid scour problems, even if it means an increase in length of bridge. High abutments are expensive and it may be more cost effective to increase the span if smaller abutments can be constructed further back from the watercourse.. Further information about the options for filling behind abutments is provided in the section on approach ways.

Abutments experience lateral loads resulting from the action of the backfill material. The most critical loading situation is often when the abutment has been constructed to full

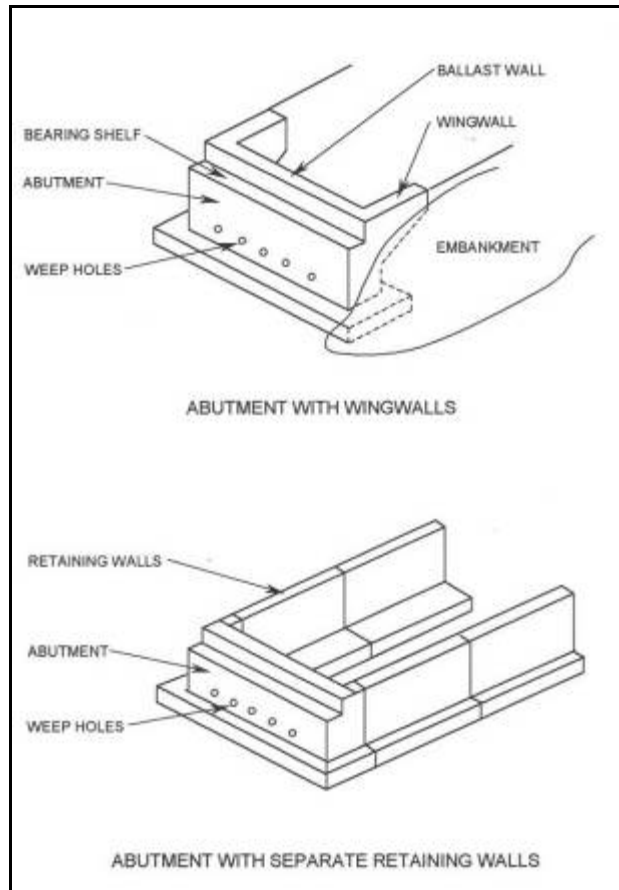


Figure 8.59 Abutment details

## 8. STRUCTURE DESIGN

height but before the deck is constructed to provide propping support. To achieve this it may be convenient to delay completion of the backfilling operation until after the deck has been placed.

### Piers

Piers can be the weakest parts of bridges and are most susceptible to damage by scour. The number of intermediate piers should be minimised and they should be omitted completely if possible. If it is necessary to include piers they should be oriented exactly in the direction of the water flow to minimise the obstruction and water turbulence.

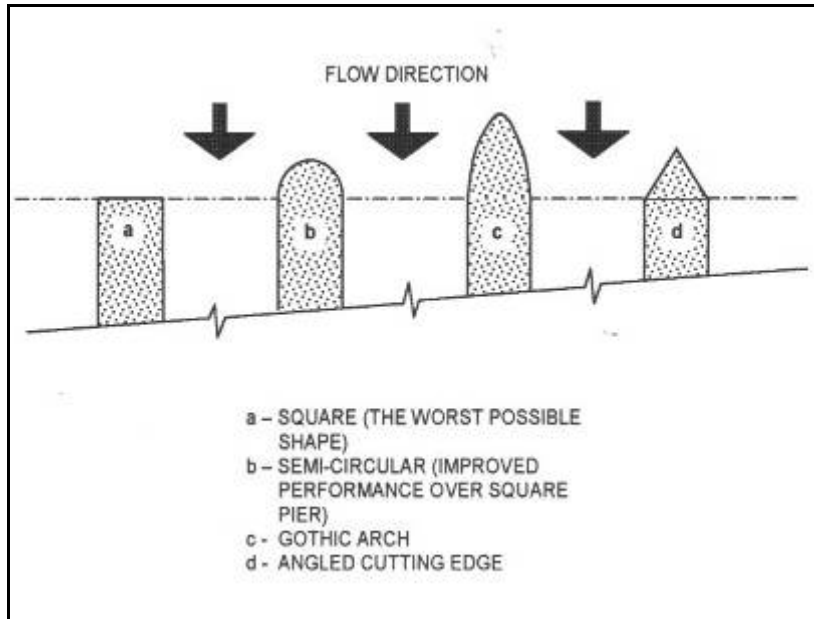


Figure 8.60 Pier shapes (Plan view)

The section on scour above presents a simple estimation of the potential scour depth that may be expected around a pier. The footing should be placed well below this depth unless a firm rock foundation is encountered. The shape of the pier will affect the amount of scour and designers should always aim to construct piers with cross-sections which will minimise their effect on the water flow.

Design procedures are similar to those for abutments and the guidelines given above should be followed however, performance and stability requires more attention.

Piers are required to support the deck of a bridge or the base of an arch. They may therefore be called upon to carry large vertical loads to the foundations through footings. Footings may be considerably larger than the piers if the ground conditions are poor. The form and shape of the pier will depend on the bearing capacity of the foundation material. The bearing capacity of typical soils is given in Chapter 6. Stonework or brick masonry is the most suitable for pier construction due to its ease of construction, durability and resistance to scour. It can also be used to create permanent formwork for the pier and allow the use of other fill material in the middle (refer to the section on fill material in approach ways). Reinforced concrete piers will tend to be more expensive than masonry due to the increased temporary works required and the probable need to import the steel, and the shuttering and steel fixing skills. Timber would be a third choice although it requires frequent inspection and maintenance. Timber must be braced due to its lower strength capabilities; this will ensure lateral forces due to the water flow can be resisted. Gabions are not recommended for use as piers due to scour and settlement risks.



Figure 8.61 Brick pier

## 8. STRUCTURE DESIGN

### Bearings and joints

On major bridge spans (>20m) bearings and joints are required to allow movement of the structure due to temperature or imposed loading without causing structural damage. For bridges of less than 10m spans, these movements are small enough to be catered for by simple bearings, such as a sheet of felt or rubber placed between the beams and the abutment, or can be resisted by stresses in the structural elements. Nevertheless, bridge movements cannot be ignored and should be considered as part of the design and construction of the bridge.

Movements arise from vehicle loading, pedestrians, temperature, wind and earthquakes. Wind and earthquake loading are major considerations for long span bridges and are not normally considered for bridges with spans less than 50m. Where high winds and earthquakes are expected, however, detailing should be such that lateral and lifting forces are resisted by suitably tying down the deck and structural elements. Vibrations from pedestrians, and particularly from vandalism, can cause problems on “lively” structures, and decks should be prevented from jumping off their supports. Simple upstands at the supports on either side of the deck would be sufficient to prevent lateral movements in most cases. Steel or timber dowels can also be used where appropriate.

It is difficult to construct a road continuously over a bridge and the construction joints cause many problems even in well-designed structures and paved roads. The ingress of moisture and differential movements between the bridge structure and the backfill material invariably causes progressive damage which adversely affects vehicles as well as the bridge. On low volume roads where vehicle speeds are low, the effect of this is not serious and routine maintenance is sufficient to maintain a smooth ride. In some cases, however, it may be a serious problem and a proper drainage system may be required to prevent major damage.

### Parapets

Generally, bridges are constructed with parapets to prevent people from falling over the edge or to provide containment for vehicles in the case of accidents. For low volume roads, however, these are often not necessary. Some form of kerb to prevent vehicles from slipping over the edge or to provide some degree of protection to pedestrians should always be considered.

Where significant flows of pedestrians or animals use the bridge regularly, handrails are required, particularly where a hazard such as a dangerous drop (greater than 2m) exists. Handrails should be 1m high and are most conveniently made from timber. Where children are expected to use the bridge regularly, a mesh type of barrier may also be necessary to prevent them climbing or falling through the parapet.



Figure 8.62 Raised kerbs on a vented causeway allow water to pass over the structure with minimum disturbance, but provide protection from vehicles driving off the structure.

## 8. STRUCTURE DESIGN



Figure 8.63 Timber bridge with handrails

### Other design issues

#### ◆ Debris Control

During a flood vegetation and other debris will be carried in the water. The designer must make sure that this debris will not either damage the structure itself or cause a blockage in the water flow which then damages the structure. In the case of bridges it is particularly important that the water does not overtop the deck, as it is not designed to withstand the water flow. The table below provides minimum clearances that should be provided between the maximum water level and the bottom of the bridge deck.

Discharge ( $\text{m}^3/\text{s}$ )	Minimum clearance (mm)
< 0.3	150
0.3 - 3.0	450
3.0 - 30	600
> 30	1000

#### ◆ Road signage

Bridges, drifts and any other structures causing a restriction in the road width should be well marked by signs to warn approaching drivers. Depending on the visibility along the road the sign should be placed between 50 and 100m back from the obstruction and about 1.5m from the edge of the road. Fixings should be robust and tamper proof. If theft of metal signs/components is a problem at the structure location, then signs should be painted on a masonry backing. On surfaced roads, surface markings may be an option.



## 9. Construction

The purpose of this chapter is to provide guidance on the actual construction of structures, from the preparatory work, through the various site activities to the completion of site works. It includes aspects of programming, construction, supervision and monitoring of works, whether the structure is built by a contractor, a road authority work force or a work group set up specifically for the task.

Not all issues dealt with in this chapter will arise during the construction of a structure, especially a small one. Checklists are provided and where appropriate the text refers to other documents for further reference and information.

### Preparatory work

#### ◆ Culverts

The limited resources and costs involved, and usually standardised nature of culverts, will often mean that the amount of preparatory work may be limited. However some aspects of the preparatory work in the following sections for larger structures may be relevant.

#### ◆ Bridges, drifts and large culverts

The size, resources and funding required for larger structures will usually necessitate considerable preparatory work before the actual site works can begin.

It is assumed that structural survey and design will be carried out in accordance with the guidelines elsewhere in this document and with any locally established standards. It is also assumed that cost estimates, detailed drawings and bills of quantities will be prepared for the works.

If the work is contracted, appropriate contract documentation should be prepared in accordance with local standards and procedures. When a contractor will be appointed, local contractor classification, tendering, selection and award procedures should also be complied with. Arrangements should be in place for resolution of any disputes that may arise through the contract.

Arrangements for management, supervision, testing, approval and audit of the works should be established. All of these issues should be clearly documented and known to the parties involved in the construction process. If there is any doubt about the responsibilities, adequacy or arrangements for any of these issues, then professional advice should be sought to rectify the situation.

The construction of any structure for a public road involves risks and responsibilities which must be appreciated and should be assigned to the most appropriate parties.

#### **Contract Documentation**

Inappropriate contract documentation has often been used in the past for relatively simple structures. Fortunately, simplified model documentation and guidelines are now available from organisations such as FIDIC and ICE, which are more appropriate for small structures contracts. Contract documentation should be appropriate, equitable and acceptable in the local legal environment.

## 9. CONSTRUCTION

Inadequate attention to some aspects of the work can result in a structure not fit for its purpose, waste of resources, or even serious damage or eventual loss of the structure.

### ◆ Structure costing

It will usually be necessary to prepare a detailed costing of the structure, either for internal budgeting and funding purposes, or for contracting out the work. This will normally be achieved through preparation of a Bill of Quantities which can be priced by the client/promoter and by a contractor.

Sample bills of quantities are provided in Volume 3. The following checklist indicates the components which should be included in any complete costing of a structure.

The table below (checklist for preparing a construction programme) may be used as the basis for developing a Bill of Quantities. Bills of Quantities in a national standardised format, with activity related items, will assist clients and contractors in pricing works and assessing value for money.

<b>Checklist of cost components for detailed costing of a structure</b>	
<p><b>Direct costs</b></p> <ul style="list-style-type: none"> <li>Materials</li> <li>Unskilled labour</li> <li>Skilled labour</li> <li>Equipment purchase</li> <li>Equipment operating costs</li> <li>Equipment hire</li> <li>Tools</li> <li>Temporary works</li> <li>Services hired in</li> </ul>	<p><b>Overheads</b></p> <ul style="list-style-type: none"> <li>Supervisory and technical staff</li> <li>Survey and setting out</li> <li>Main office, workshop costs</li> <li>Supervision vehicles</li> <li>Transport to and from site</li> <li>Site camp and stores</li> <li>Security measures and facilities</li> <li>Communications (telephone, mail)</li> <li>Insurances, bonds</li> <li>Banking and other charges</li> <li>Training</li> <li>Protective clothing and safety</li> <li>Traffic control/signs</li> <li>Testing</li> <li>Welfare, pensions, social costs</li> </ul>
<p><b>Contingency/risks</b> (e.g. unforeseen additional work, late payment, delays)</p>	
<p><b>Profit</b> The contractor should normally be expecting to make up to 10% profit on his work. This percentage will be affected by local competition and risks</p>	

### **Planning of Site Works**

Good planning of the site works is essential, particularly as many structures sites are remote from organisational bases, sources of materials and skilled manpower, and communications can be difficult. Poor planning can lead to serious delays and increased costs.

## 9. CONSTRUCTION

### Checklist for planning site works

1. List all construction and support activities and prepare a construction programme (using a bar chart) based on the Bill of Quantities, expected productivities and logical sequence of activities.
2. Prepare resource plan and cash flow requirements.
3. Plan in recognition of the seasonal watercourse conditions and expected flood conditions. Plan adequate arrangements for damming, diverting or control of water.
4. Ensure compliance with all laws and regulations regarding recruitment, labour, (permanent/casual) employment, gender and disadvantaged groups opportunities, payment, security for payment to labourers, conditions of work.
5. Plan compliance with environmental requirements, particularly with regard to materials exploitation, replacement of felled timber, watercourse pollution and waste disposal.
6. Inspect site. Check site survey. Review designs and documentation for compatibility and with the actual site conditions. Clarify any inconsistencies
7. Plan and arrange land (acquisition/lease/use) and setting up site, camp and stores. Cement to be stored in a secure, dry and well ventilated place.
8. Ensure adequate site access arrangements, particularly if the structure is being built in advance of the road works.
9. Plan water supply, other services requirements and sanitation arrangements
10. Plan site security (particularly against theft of handtools & materials; cement is particularly susceptible)
11. Ensure availability and accessibility of funds and contingency finance.
12. Ensure payment arrangements for (sub)contractors, and suppliers are in place.
13. Plan staffing, identify skills locally available or required to be imported to the site area, accommodation, logistics, transport to site, recruitment and training of workforce.
14. Arrange for supplies of materials to site.
15. Plan safe and adequate temporary arrangements for traffic and pedestrians where replacing an existing structure or facility.
16. Plan actual/contingency arrangements for de-watering and shoring of foundations.

### Checklist for preparing a construction programme

The construction programme will involve some or all of the following activities:

1. Clear trees, bush, and scrub, dispose of safely.
2. Primary setting out and establishment of reference points.
3. Remove topsoil, stockpile for re-use or disposal.
4. Dig catchwater drains to protect site, and any side drains.
5. Remove/bury nearby/break surface boulders (see below).
6. Detailed setting out and establishment of levels and profile boards.
7. Excavate foundations and any cut-off trenches.
8. Temporary shoring, watercourse diversions, piling, cofferdams, de-watering/drainage.
9. Drill and blast any solid rock.
10. Replace "soft spots" in ground, clean and prepare foundation area.

## 9. CONSTRUCTION

<ol style="list-style-type: none"> <li>11. Construct foundations.</li> <li>12. Construct temporary works for superstructure.</li> <li>13. Erect abutments, piers, deck, wingwalls.</li> <li>14. Fix deck timbers and running boards where applicable.</li> <li>15. Erect kerbs, parapets barriers and safety structures.</li> <li>16. Install drainage layers and features against structure.</li> <li>17. Backfill against and adjacent to the structure, compacting each layer according to the specifications. Particular attention to be paid to all compaction within 5 metres of the structure.</li> <li>18. Construct road pavement/surfacing and markings, road shoulders.</li> <li>19. Construct road drainage features.</li> <li>20. Construct gabions and erosion control measures.</li> <li>21. Lay topsoil/turves and planting.</li> <li>22. Install traffic warning signs if necessary.</li> <li>23. Clear site, remove surplus materials and leave tidy.</li> </ol>
--

◆ Simple method for breaking large boulders

Build a fire with the brushwood or other combustible materials around a large boulder and keep it well fuelled through the day. In the late afternoon dowse it with containers of water to achieve rapid cooling of the outer surface. This will create surface and internal cracking to allow the boulder to be broken up with crowbars and sledge hammers. Larger boulders may require several attempts.

The following productivity standards may be useful in estimating the resources and time required for each activity.

<b>Recommended productivity standards</b>	
Site clearance (bush clearing, tree felling, etc.)	100 – 350m <sup>2</sup> / worker day
Removal of tree stumps	1 / worker day
Soil excavation (and stockpiling alongside)	2 - 5m <sup>3</sup> / worker day
Rock (fractured) excavation (solid rock will require drilling and blasting/splitting)	0.8m <sup>3</sup> / worker day
Loading	8.5m <sup>3</sup> / worker day
Haulage by wheelbarrow	
0 - 20m	8.5m <sup>3</sup> / worker day
20 - 40m	7.0m <sup>3</sup> / worker day
40 - 60m	6.5m <sup>3</sup> / worker day
60 - 80m	5.5m <sup>3</sup> / worker day
80 - 100m	5.0m <sup>3</sup> / worker day
100 - 150m	4.5m <sup>3</sup> / worker day
Install only 600 or 900mm diameter culvert lines (including excavation and backfill)	0.8 - 1.2 lin.m / worker day
Mix and place concrete	1.0m <sup>3</sup> / worker day
Erect masonry work	1.0m <sup>3</sup> / worker day

Productivity depends on a number of factors, including worker nutrition, fitness, experience and motivation, site organisation, tool quality and condition, and climate. Individual small structures sites do not allow much scope for improvement of performance with experience due to the short time spans involved for individual activities.

## 9. CONSTRUCTION

New workers under training will also be less productive. Poor quality and condition of handtools can affect productivity by up to 25%.

The following checklist includes the range of skills which may be required on a structures site. The more specialist skills may need to be imported into the project area. Some skills may be taught through on-the-job training. This will involve costs and loss of productivity. Workers not from the area of the structure site may require temporary accommodation and incur costs relating to travel and allowances.

Potential skills requirements for a structures work site:

1. Surveying and setting out
2. Drilling and blasting
3. Piling/cofferdam
4. Carpentry
5. Masonry
6. Temporary works
7. Steel bending and fixing
8. Concreting
9. Equipment maintenance

<b>Checklist of handtools and site equipment</b>		
◆ Handtools		◆ Equipment
Ranging rods	Hand drills	Culvert moulds
Spirit level /Abney level / water tube level	Plugs and feathers	Plate compacter
Stringlines, pegs	Masons trowels	Pedestrian vibrating roller
Profile boards & travellers	Masons hammers	Water bowser
Plumb bob	Spirit levels	Water pump
Tape measures	Straight edges	Concrete mixer
	Lifting tackle	Batching boxes
Felling axes	Buckets	Vibrating poker
Tree felling saws	Mortar pans	Piling equipment
Bush knives	Mixing boards	Hydraulic excavator
Brush hooks	Water	Compressor and air tools
Ropes	containers/drums	Craneage
	Screeding boards	Aggregate crushing eqp.
Pick axes	Pointing tool	Aggregate screens
Mattocks		Supply and site transport
Hoes	Hand rammers	Formwork/moulds
Crowbars	Rakes/spreaders	
Shovels		Traffic signs and barriers
Sledge hammers	Slump test equipment	
Wheelbarrows	Concrete cube moulds	Safety helmets and
Head pans/baskets	and curing tank	equipment
Earth 'stretchers'	Soil density testing	
	equipment	
Carpenters tool kits		
	Sandbags for water	
	control	

## 9. CONSTRUCTION

### Site Works

The works will be organised according to the activities in the construction programme. Guidance on the individual activities is provided elsewhere in this document. However some specific aspects warrant further explanation.

Temporary works should be designed to withstand the watercourse (e.g. flood or debris) conditions expected and temporary loading situations.

Works must be carried out according to the specifications and drawings. Quality control arrangements should ensure compliance in accordance with specifications. The control of cement requires particular attention; this is a valuable commodity and it is difficult to detect reduced inputs until after construction. Batching should be carefully controlled and the making and curing of cubes should be closely supervised. It will normally be necessary to arrange for cubes to be crushed at a reliable laboratory remote from the site. The laboratory must be consulted to ensure that the testing can be carried out according to the standards specified. It is advisable to visit the laboratory to assess the standard of service provided.

The slump test (see chapter 7) should be used to control concrete workability and check the water: cement ratio. Treatment of permanent timbers should be closely supervised or guaranteed.

### Simple setting out techniques

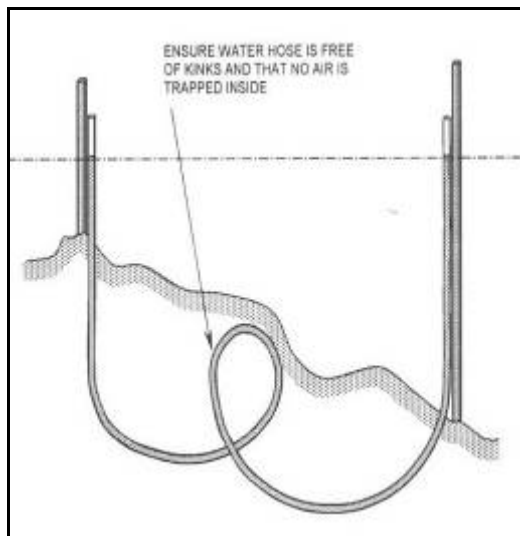


Figure 9.2 Levelling with a water hose

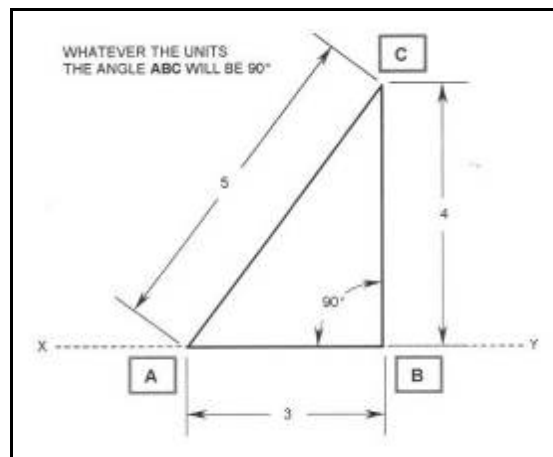


Figure 9.1 Setting out a right angle

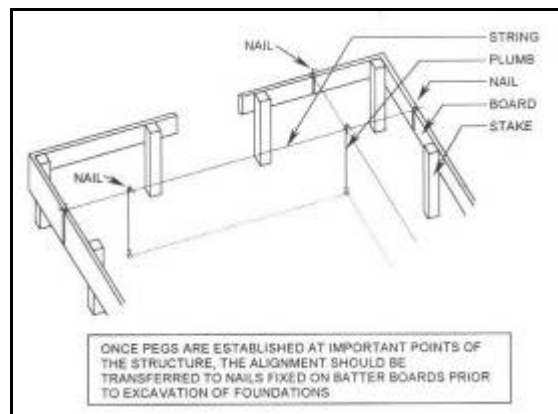


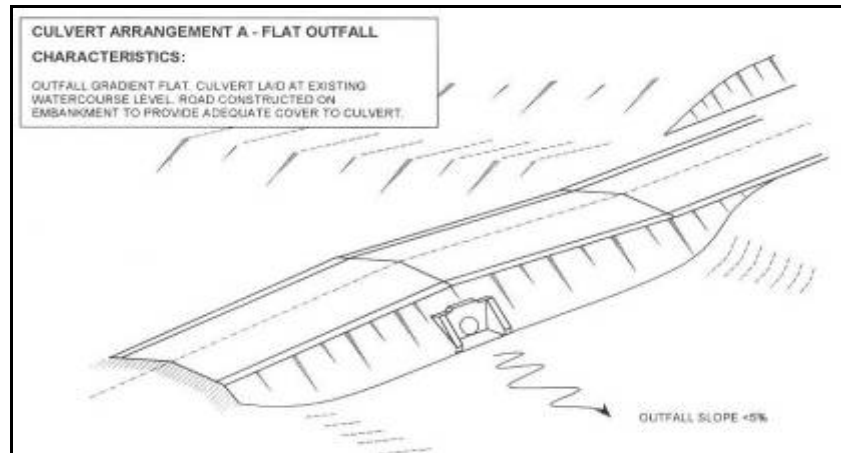
Figure 9.3 Use of batter boards

## 9. CONSTRUCTION

### Setting out culverts and drifts

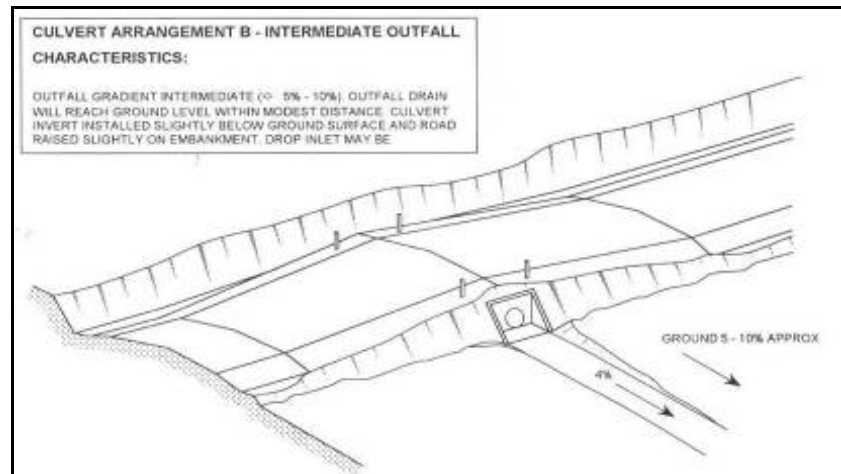
The setting out should be according to the design. The principal setting out requirements are the establishment of the centreline of the barrels (for culverts), the extent of the structure (ends and corners) and the inlet/upstream and outlet/downstream invert/slab levels.

Figure 9.4



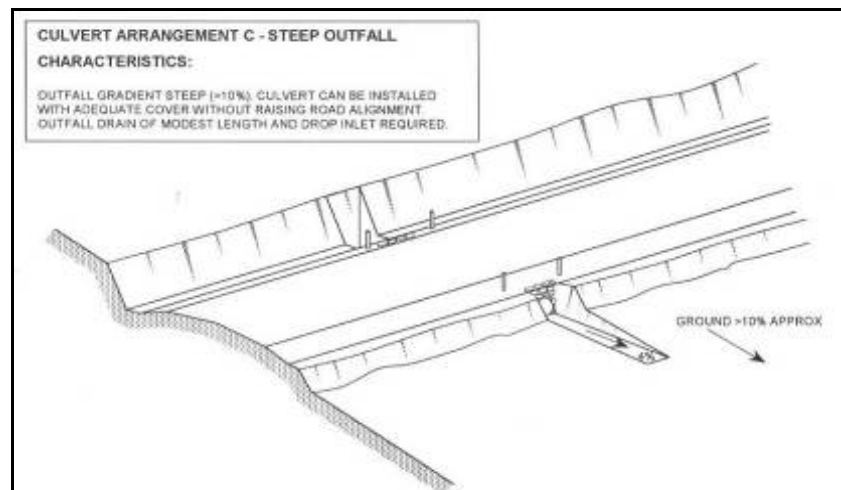
Wooden pegs should be used to establish key positions and levels. For minor culverts and drifts where no levels are provided, the invert of the culvert or drift slab should

Figure 9.5



follow the level of the existing watercourse as closely as possible. The following guidance will minimise the possibility of silting or erosion of a culvert due to installation at an incorrect level.

Figure 9.6



## 9. CONSTRUCTION

### Procedure for setting out a culvert

If the culvert site is flat, check the watercourse gradient for 20 metres downstream from the location of the culvert outlet. Use boning rods and Abney Level, or line and level, for this purpose. If the gradient is less than 5% (1 metre fall in 20 metres), then construct the culvert in **Arrangement A** with the culvert inverts as close to existing ground/water course level as possible. Also construct **Arrangement A**, if the height of embankment fill (measured from ground level to edge of road running surface) at culvert site is at least 1.1 metres. Otherwise proceed with the following steps to install **Arrangement B** or **C**.

#### SETTING OUT OF 600 mm $\varnothing$ CULVERT - ARRANGEMENT B OR C

MAIN DIMENSIONS ARE FOR ROADWAY WIDTH OF 5.5 m. (DIMENSIONS IN BRACKETS ARE FOR CROSS SECTION WITH ROADWAY WITH OF 'w' METRES)

PROCEDURE STEP BY STEP	EXAMPLE/EXPLANATION												
<p><b>STEP 1</b></p> <p>Fix the centreline of the culvert. Establish two pegs (peg A and peg B) at the location of both roadway edges and at proposed finished roadway level. Make sure that pegs are on the same level (use line and level or Abney level).</p>													
<p><b>STEP 2</b></p> <p>Measure distance between peg A and B (5.50 m, or 'w' for other cross sections).</p>													
<p><b>STEP 3</b></p> <p>Calculate the minimum depth (d) to be excavated from proposed road level to underside of culvert pipe at the inlet to ensure adequate cover (at peg a).</p>	<table style="width: 100%; border-collapse: collapse;"> <tr> <td style="padding: 2px;">OUTSIDE DIAMETER OF CULVERT <math>\varnothing</math> 600 mm</td> <td style="text-align: right; padding: 2px;">0.72 m</td> </tr> <tr> <td style="padding: 2px;">OVERFILL (MINIMUM COVER)</td> <td style="text-align: right; padding: 2px;">+ 0.45 m</td> </tr> <tr> <td style="padding: 2px;"><b>TOTAL DEPTH (d)</b></td> <td style="text-align: right; padding: 2px;"><b>1.17 m</b></td> </tr> </table>	OUTSIDE DIAMETER OF CULVERT $\varnothing$ 600 mm	0.72 m	OVERFILL (MINIMUM COVER)	+ 0.45 m	<b>TOTAL DEPTH (d)</b>	<b>1.17 m</b>						
OUTSIDE DIAMETER OF CULVERT $\varnothing$ 600 mm	0.72 m												
OVERFILL (MINIMUM COVER)	+ 0.45 m												
<b>TOTAL DEPTH (d)</b>	<b>1.17 m</b>												
<p><b>STEP 4</b></p> <p>Calculate the difference in culvert level between peg a and b with the chosen culvert gradient (4% is normally selected as the ideal gradient).</p>	<table style="width: 100%; border-collapse: collapse;"> <tr> <td style="padding: 2px;">GRADIENT:</td> <td style="text-align: right; padding: 2px;">4%</td> </tr> <tr> <td style="padding: 2px;">DIFFERENCE IN LEVEL:</td> <td style="text-align: right; padding: 2px;">= 0.22 m</td> </tr> <tr> <td style="padding: 2px;"><math>\frac{4\% \times 5.50 \text{ m}}{100\%}</math></td> <td style="text-align: right; padding: 2px;">(FOR ROAD WIDTH w, = 0.04 w)</td> </tr> </table>	GRADIENT:	4%	DIFFERENCE IN LEVEL:	= 0.22 m	$\frac{4\% \times 5.50 \text{ m}}{100\%}$	(FOR ROAD WIDTH w, = 0.04 w)						
GRADIENT:	4%												
DIFFERENCE IN LEVEL:	= 0.22 m												
$\frac{4\% \times 5.50 \text{ m}}{100\%}$	(FOR ROAD WIDTH w, = 0.04 w)												
<p><b>STEP 5</b></p> <p>Calculate the depth to be excavated from proposed road level to the underside of culvert pipe at the outlet (at peg b).</p>	<table style="width: 100%; border-collapse: collapse;"> <tr> <td style="padding: 2px;">ROAD WIDTH (m)</td> <td style="text-align: right; padding: 2px;">5.50</td> <td style="text-align: right; padding: 2px;">(w)</td> </tr> <tr> <td style="padding: 2px;">INLET DEPTH</td> <td style="text-align: right; padding: 2px;">1.17 m</td> <td style="text-align: right; padding: 2px;">1.17 m</td> </tr> <tr> <td style="padding: 2px;">DIFFERENCE IN LEVEL +</td> <td style="text-align: right; padding: 2px;">0.22 m</td> <td style="text-align: right; padding: 2px;">0.04 w</td> </tr> <tr> <td style="padding: 2px;"><b>DEPTH AT OUTLET</b></td> <td style="text-align: right; padding: 2px;"><b>1.39 m</b></td> <td style="text-align: right; padding: 2px;"><b>y = (1.17 + 0.04 w)</b></td> </tr> </table>	ROAD WIDTH (m)	5.50	(w)	INLET DEPTH	1.17 m	1.17 m	DIFFERENCE IN LEVEL +	0.22 m	0.04 w	<b>DEPTH AT OUTLET</b>	<b>1.39 m</b>	<b>y = (1.17 + 0.04 w)</b>
ROAD WIDTH (m)	5.50	(w)											
INLET DEPTH	1.17 m	1.17 m											
DIFFERENCE IN LEVEL +	0.22 m	0.04 w											
<b>DEPTH AT OUTLET</b>	<b>1.39 m</b>	<b>y = (1.17 + 0.04 w)</b>											

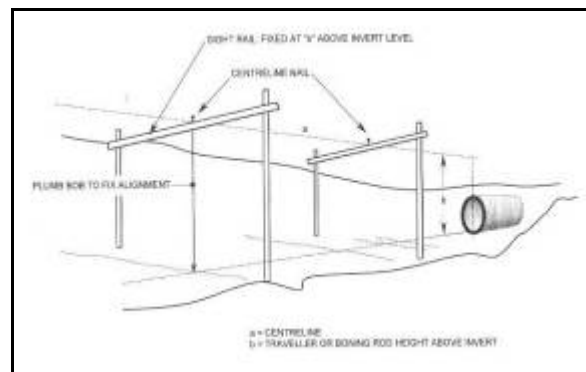
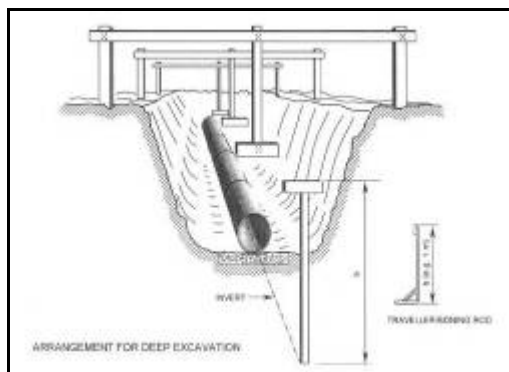
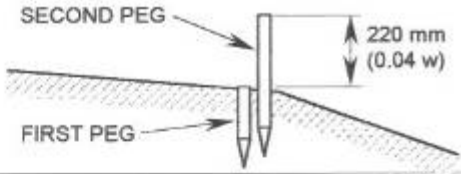
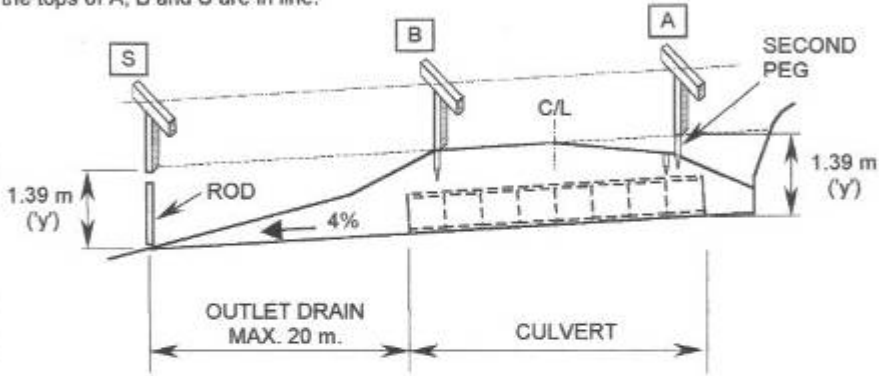


Figure 9.7 Setting out culvert profiles

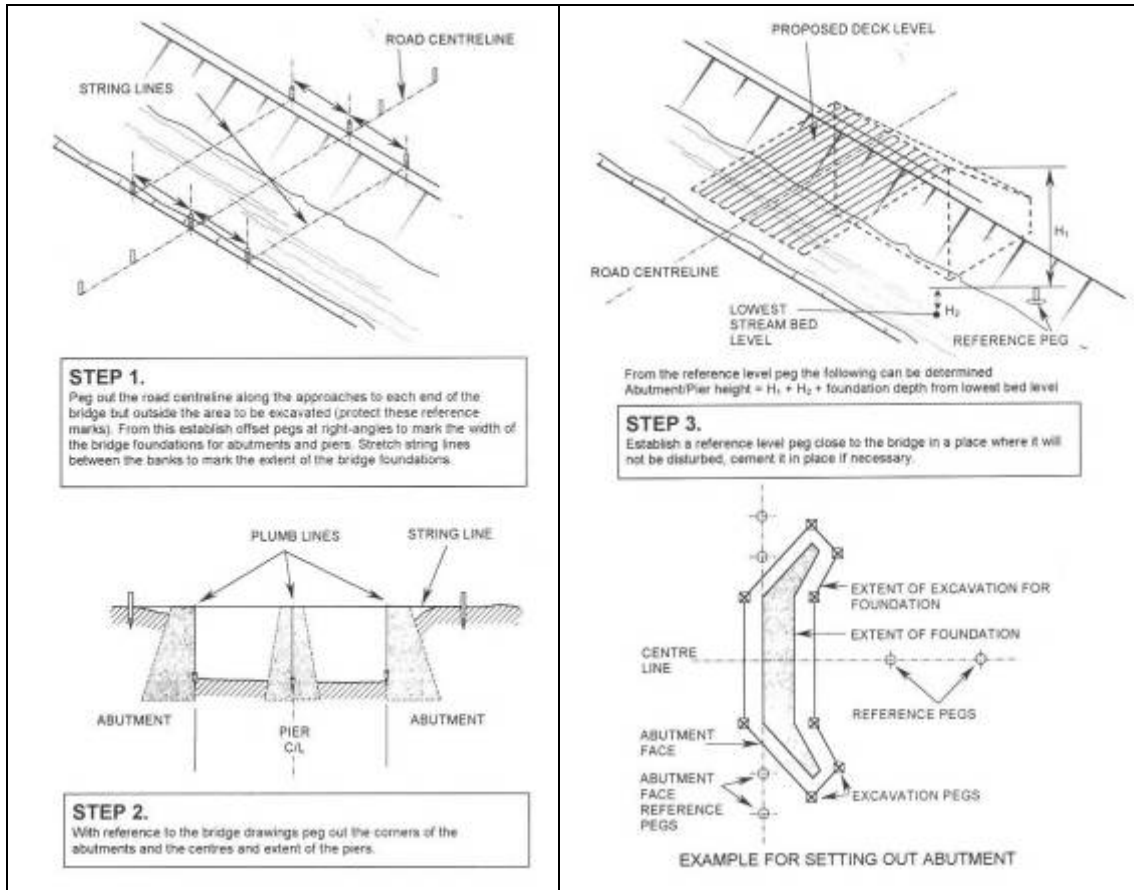
## 9. CONSTRUCTION

PROCEDURE STEP BY STEP	EXAMPLE/EXPLANATION
<p><b>STEP 6</b></p> <p>Raise level peg A by the same measurement that you have calculated under step 4 by establishing a second peg (difference in level).</p>	
<p><b>STEP 7</b></p> <p>Find the end of the outlet-drain by using boning rods and a stick or rod of length 1.39 m ('y' for other cross section road widths) (see sketch below): Walk S and rod away from B until the tops of A, B and S are in line.</p>	
<p>If the length of the outlet drain SB is less than 20 metres then establish the drain outlet peg at ground level at point S. Construct the culvert in <b>Arrangement C</b>. (i.e. the road alignment will not need to be raised). Establish the excavation level for the underside of the culvert pipe by measuring vertically down 1.39 m ('y') from peg B and the top of the second peg at point A. The excavation pegs should be 5.50 m apart ('w' for other cross section road width).</p>	
<p><b>STEP 8</b></p> <p>If the drain outlet cannot be found within 20 metres of the culvert outlet then place a peg at ground level at point S, 20 metres away from the culvert outlet point B. Adjust the boning rod at point S until the tops of the 3 boning rods A, B and S are in line. Measure the distance from the bottom of the boning rod S to the ground level: z metres. The road level at A and B will have to be raised by 1.39 - z metres (y - z for other cross sections). To fix the culvert inlet excavation level, measure (1.39 - z) metres (y - z for other cross sections) down from the top of the second peg at point A. To fix the culvert outlet excavation level, measure (1.39 - z) metres (y - z for other cross sections) down from the peg at point B (these pegs should be 5.50 m apart, or w for other cross sections). This is <b>Arrangement B</b>. The road will need to be raised as indicated above and the vertical alignment raised or a suitable ramp constructed either side of the culvert.</p>	
<p><b>NOTE:</b></p> <ol style="list-style-type: none"> <li>Where pipes will be bedded on imported material, excavation levels will have to be lowered by the thickness of bedding material.</li> <li>For 900 mm <math>\varnothing</math> culverts the dimension in step 3 is increased to <math>1.05 + 0.70 = 1.75</math> m. In step 5 the depth at outlet will be 1.97 m (<math>1.75 + 0.04 w</math>).</li> </ol>	

### Setting out bridges and large structures

Benchmarks and reference points must be established. They should be well marked and protected. The structure centreline should be set out. Front faces of abutments and centrelines of piers should be set out. All setting out pegs should be located well back from the main working areas and be protected by (preferably brightly painted) timber markers. Two pegs established in a line both sides of a structure will mean that lines can be re-established if one of the pegs is accidentally disturbed. Right angles can be set out using the '3:4:5 triangle' rule (see Fig. 9.1 for simple setting out techniques).

## 9. CONSTRUCTION



### Excavations

Foundations (if not on bedrock) are usually the most risky stage of the construction process. Whatever site surveys were carried out beforehand, the actual foundation conditions cannot be determined until full excavation takes place. Unforeseen problems may occur. If problems are not adequately tackled at the foundation stage, they can be particularly difficult or expensive to rectify later.

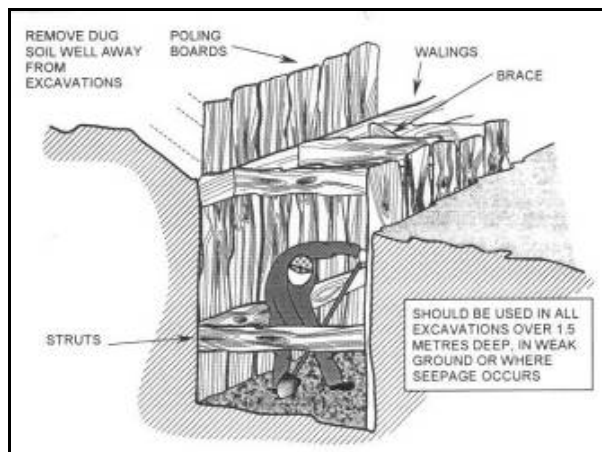


Figure 9.8 Safety issues

Particular care must be taken to ensure the safety of workers. Excavations can collapse particularly in weak ground or where groundwater seeps into the excavation. Temporary shoring should be used if there is any risk of this.

Foundations should be kept as dry as feasible and covered as soon as possible. If weak or soft spots are uncovered then they should be replaced with imported suitable material such as clean gravel or crushed stone.

The bearing capacity of the actual foundation soil can be checked using simple apparatus such as the DCP (Dynamic Cone Penetrometer).

## 9. CONSTRUCTION

A sump and drainage channels may be necessary to keep the foundation dry. Buckets or a water pump may be used to remove the water from the sump.

If the ground conditions are worse than expected then the design engineer should be consulted (his availability at this critical stage should be ensured during the construction planning process).

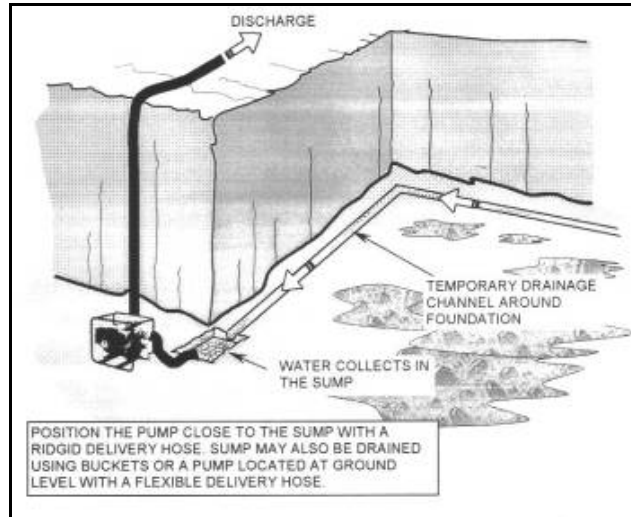


Figure 9.9 Pumping arrangements

If steel reinforcement is incorporated in the foundations it is advisable to use a blinding of lean mix concrete directly on to the trimmed soil to form a clean working platform for arranging and fixing the reinforcement. For other works compacted gravel or crushed stone can be used for a clean working surface.

If the foundation is on bedrock a good key must be ensured. This can be achieved by chipping the complete rock surface and exposing a rough clean rock face. The drilling of holes and insertion of dowels may be necessary to ensure a good key. Sloping bedrock should be excavated in steps (benched) to provide a stable foundation.

Culverts on busy existing roads may be built in two halves with adequate traffic control and safety measures. Otherwise a diversion must be arranged with adequate warning signs and traffic control measures.

### Supervision check box - Excavation

- ◆ Inspection and approval by engineer/senior technician
- ◆ Keep as dry as possible
- ◆ Trim to correct levels (and falls for a culvert or drift)
- ◆ Ensure firm foundation - remove soft spots and replace with good material
- ◆ Culvert excavations should be no wider than necessary to install culvert

### Temporary works

Scaffolding, shuttering and temporary works should be constructed by skilled artisans to designs prepared taking account of the local materials and loadings expected.

### Shuttering/formwork and steel reinforcement for concrete work

Formwork and steel reinforcement (where specified) for concrete should be constructed in accordance with current standards and guidelines. Each stage of the work should be thoroughly checked before concreting is permitted. Checks should include cleanliness, soundness and quality of formwork and to ensure that it will not move or leak under the loading of fresh wet concrete and workers.

## 9. CONSTRUCTION

Timber chamfer fillets (e.g. 20mm x 20mm timber sawn at 45°) should be fixed on all external 90° angles to ensure smooth finished edges to the concrete.

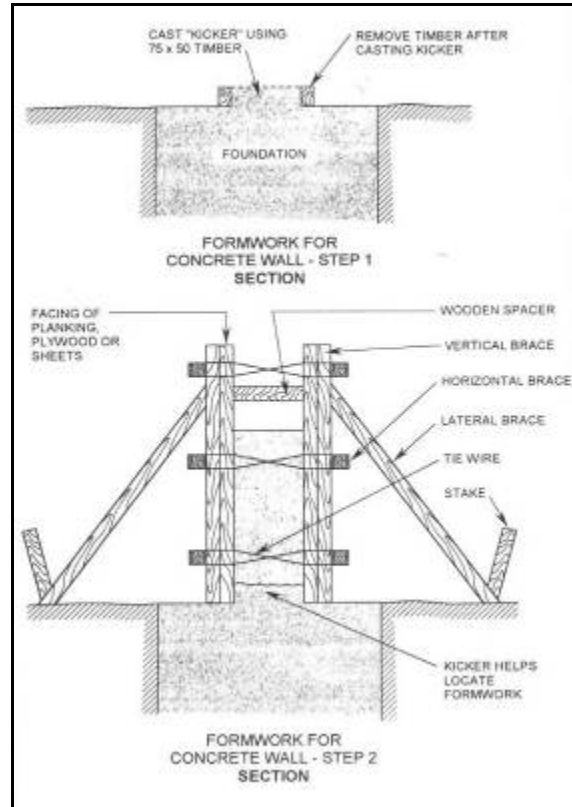
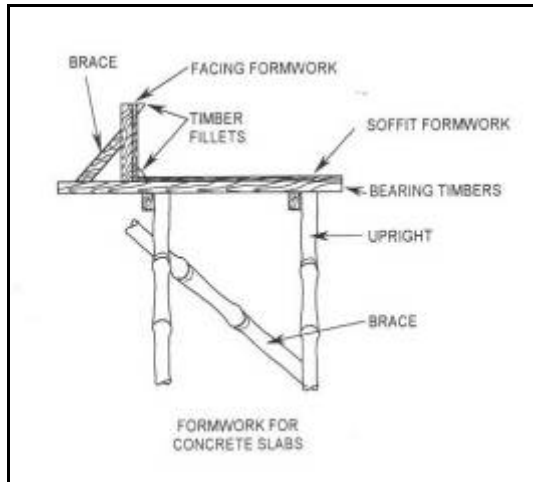


Figure 9.9 Formwork should be coated with mould oil to allow easy striking of formwork after the concrete has set. Linseed oil, old engine oil or other cheaply available oils may be suitable for this.

### Supervision Check Box - Shuttering/formwork

- ◆ Faces of sawn timber/plywood/sheet steel securely fixed and supported on a timber/bamboo/steel framework
- ◆ Erected to the correct levels, alignment and tolerances, strong enough to support the weight of wet concrete and operations without distorting/settling
- ◆ No gaps or holes in faces for wet concrete to escape
- ◆ Oiled to assist with striking/removal
- ◆ Weep holes/scuppers/fixings/joints etc. in correct locations
- ◆ Clean with all debris removed prior to concreting

## 9. CONSTRUCTION

### Supervision check box - Reinforcement steel fixing

- ◆ Ensure steel bar grades, sizes, numbers, spacing and shapes according to design drawings
- ◆ Ensure minimum cover to steel from soffits, walls and top surfaces (50 - 100mm)
- ◆ Ensure minimum overlaps between bars
- ◆ Ensure steel and shuttering is clean with no loose rust or contamination (slight corrosion assists bonding of concrete to reinforcement)
- ◆ Reinforcement should be cut to the specified lengths, bent cold and provided with the minimum laps specified. Overlapping and lapped bars should be bound tightly with binding wire at ALL points.

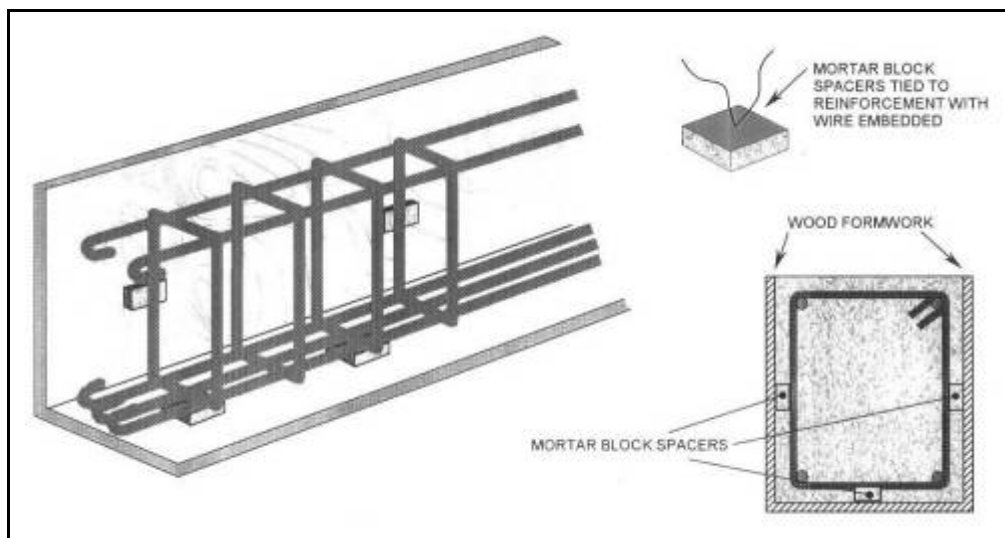


Figure 9.10 Reinforcement spacers

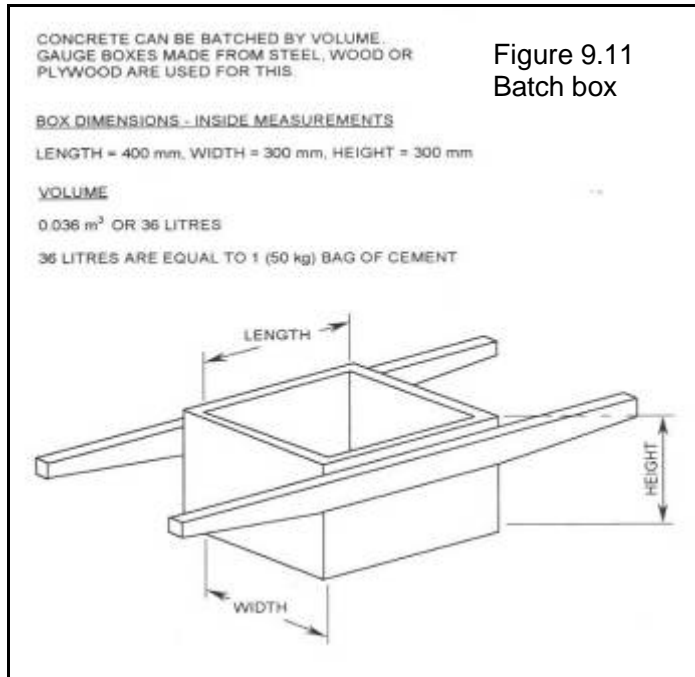
The spacers supporting reinforcement should be securely fixed so that they will not move during concreting. Spacers can be made from mortar cubes with binding wire cast in. The amount of cover to the reinforcement (usually 50 mm in moderate conditions to 100 mm in extreme exposure conditions) is important for reinforced concrete durability.

### Concrete work

The requirements of the specifications and guidelines elsewhere in this guideline should be followed. Water for concrete should be clean and free from contaminants such as salt, silt etc. Water with solids in suspension should be allowed to stand in barrels so that the sediments settle out. Water that is drinkable is usually fit for concrete works.

Concreting is usually not permitted at ambient (shade) air temperatures below 3°C. Hot weather concreting must also be avoided as the uncured concrete will dry out too quickly. Usually concreting is not permitted in ambient (shade) temperatures above 40°C. In ambient temperatures well below this figure structures and aggregates in direct sunlight can rise to unacceptable temperatures. Shading and timing of concreting during cooler hours can be important countermeasures.

## 9. CONSTRUCTION



Concrete strength and durability depends particularly on the correct mix proportions as specified elsewhere in this guideline. Batching boxes or weighing methods should be used to ensure correct quantities. Volume batching should be carried out using batching or gauge boxes of volume equivalent to one 50kg bag of cement. A box of internal dimensions 400 x 300 x 300mm will have the correct unit volume of 0.036m<sup>3</sup>.

Hand or machine mixing of concrete is acceptable. Either method must ensure complete mixing of the components. For Mechanical mixing the order of adding the materials to the

drum should be: coarse aggregate, cement, fine aggregate, water. Water should be added at the specified water:cement ratio. Less water will not allow the materials to be properly mixed and placed. Too much water will lead to segregation and a weak concrete. If the aggregates are already wet, then adjustment of the quantity of added water will be necessary. The slump test should be used (refer to chapter 7) to check the water:cement ratio and workability of the wet concrete.

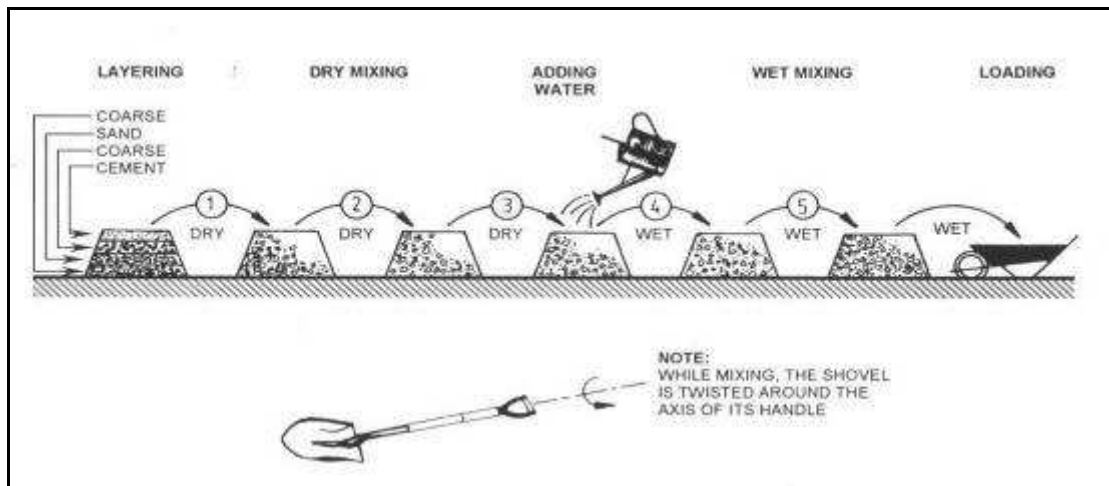


Figure 9.12 Concrete hand mixing

Wet concrete must not be transported long distances as segregation will occur. It must not be dropped more than 1.5 metres as this will also encourage segregation. Concrete should be vibrated with a mechanised immersion poker placed throughout the fresh wet concrete to agitate the particles into a compact matrix and expel the excess air. Over vibration must be avoided as this will result in segregation. The vibrator should be kept away from the formwork. For minor works and standard concrete grades it is acceptable to use lengths of reinforcing rods to agitate the concrete if a vibrating poker is not available. Good supervision is required to ensure a methodical process.

Finished concrete surfaces should be tamped and screeded with excess concrete removed and disposed of. Exposed surfaces should be finished smooth with a steel or

## 9. CONSTRUCTION

wooden trowel. The finished surface of the concrete must be protected from rain within the first two hours after placing. Curing with water should commence three hours after casting. Concrete must be adequately cured for quality and durability and adequate arrangements must be made for this for at least the first 7 days after casting. Sacking or sand or other suitable material should be used to cover the concrete and retain the curing moisture/water. The surface of the concrete should be kept damp with repeated wetting during the curing period.

Formwork must not be removed until the concrete is strong enough to support its loading. Removal must be carried out carefully as point loads can damage “green” concrete.

### Supervision check box - Concreting

- ◆ Permissible air temperatures for placing
- ◆ Clean water for concrete mix
- ◆ Correct mixing proportions (check especially that correct cement quantities used and that batches are weighed or gauge/batching boxes are used)
- ◆ Correct water:cement ratio (check workability with slump test)
- ◆ Concrete placed and compacted within 30 minutes of mixing
- ◆ Cure continuously (keep all surfaces damp) for at least 7 days

### Precast concrete

Where possible and where transport arrangements allow, precast units can be built at a central location (e.g. culvert pipes or reinforced concrete beams). This should allow the benefits of efficient production arrangements and greater quality control.

Precast culvert rings should be carefully lowered into position using ropes or straps to control the operation. Particular care must be taken to prepare the bed to ensure uniform support of the pipe. Final adjustment of position should be carried out with the aid of crowbars. Joints should be mortared and protected (for example with banana leaves) prior to backfilling. After backfilling the joints should be inspected internally and repaired if necessary. Precast box culvert deck slab units or even bridge deck beams may be cast on site and then placed in final position. Crane or heavy lifting and moving equipment will be required for precast deck beams.

### Timber Stave Culverts

These pre-treated timber culverts may be transported in component form to the site. The efficiency of the system means that a number of culverts can be transported in one truck load. The timber culvert is assembled with its binding hoops at ground level alongside the culvert site. It is then gently lowered into its permanent location. Particular care must be taken to ensure that the culvert does not move during backfilling and compaction.



Figure 9.13 Timber stave culvert

## 9. CONSTRUCTION

As with all precast unit systems, particular care is required to ensure a completely uniform bedding, surround and backfill operation to avoid later settlement or failure problems.

### Masonry Work

In masonry work, the corners and ends should be constructed first, with particular attention to verticality and alignment. String lines can then be stretched between the initial work to guide and ensure smooth faces and coursing of the subsequent work.

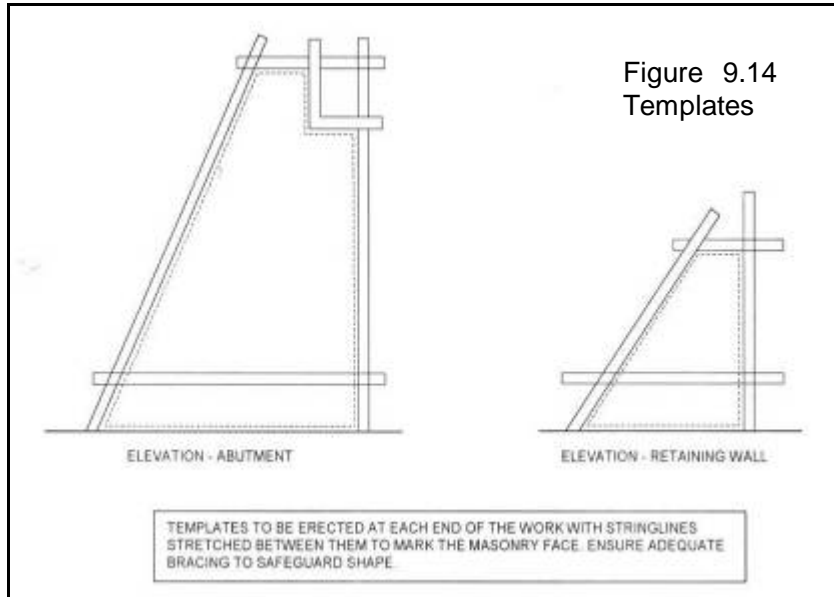


Figure 9.14  
Templates

Adequate bonding should be ensured with vertical joints staggered.

A timber template may be fabricated to assist with constructing irregular shapes.

Mortar must be used within 30 minutes of mixing. Masonry work should be cured as concrete.

### Supervision check box - Masonry

- ◆ Stone must be clean, sound and firm
- ◆ Vertical joints staggered
- ◆ Edges and corners true, and appropriate stones selected for these locations
- ◆ Faces true without irregularities, dishing or bulges
- ◆ All joints to be pointed to ensure effective load transfer and minimise water penetration

### Timber Superstructure

Although timber may be used for bridge abutments and piers, its eventual replacement can involve considerable work when resources may not be readily available. Timber beams, decks and running boards are comparatively low cost and easy to replace, and are discussed in the following text.

Sawn timber or logs can be used for bridge deck beams or bearers. Timber plank decking or running boards can be fixed to the timber

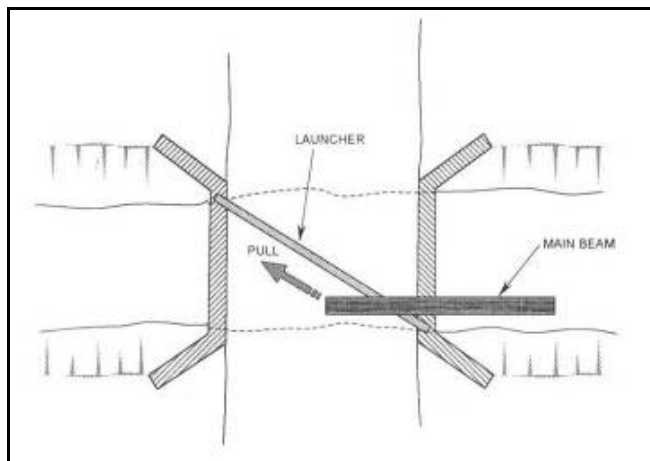


Figure 9.15 Timber beam launching

## 9. CONSTRUCTION

bearers or to steel beams. All timbers should be carefully treated prior to installation to achieve acceptable service life. A small diameter pole or timber can be used to launch the first main beams across the bridge span as shown in the diagram, using log rollers and ropes if necessary. Once two main beams are in place then these can be used as a platform to manhandle the remainder of the main beams into place.

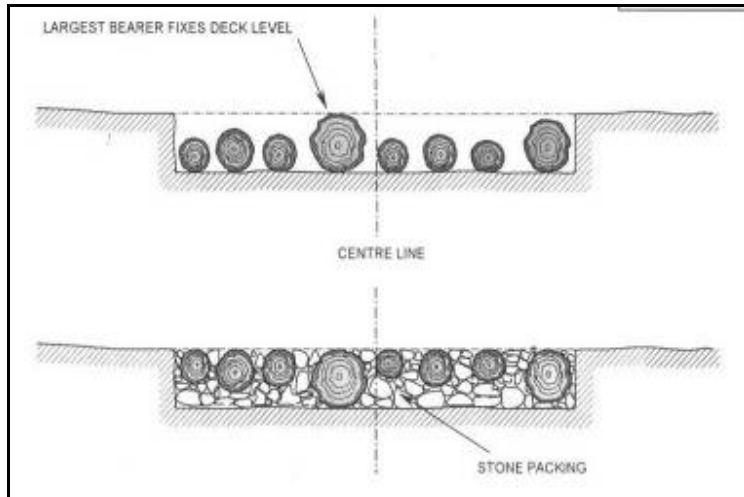


Figure 9.16 Log packing

Log bearers should be selected which are as straight as possible and do not taper substantially over their length. Log bearers will not all be of exactly equal diameter. After all bearers are in place they should be levelled with string lines and spirit level so that all top faces are reasonably level. They should then be packed with stones/bricks and mortared into position at the abutments and piers. The ends of the logs should be concreted

or mortared to discourage insect access. If logs vary in diameter along their length, then adjacent logs should be laid with their thick sections at opposite ends of the deck to provide uniform deck stiffness and strength.

There will usually be high and low points on the log beams. These are either trimmed off with an axe or built up with packing to achieve a level area to which the deck planking can be fixed. Packing timbers should be at least 300mm long, treated and securely nailed to the bearers before the deck planking is laid.

Decking timbers are fixed by nailing or bolting at right angles to the main beams (even on a skew bridge). These timbers will spread the vehicle loads to the main beams. Each deck timber should be fixed to every beam as close to its centre as possible.

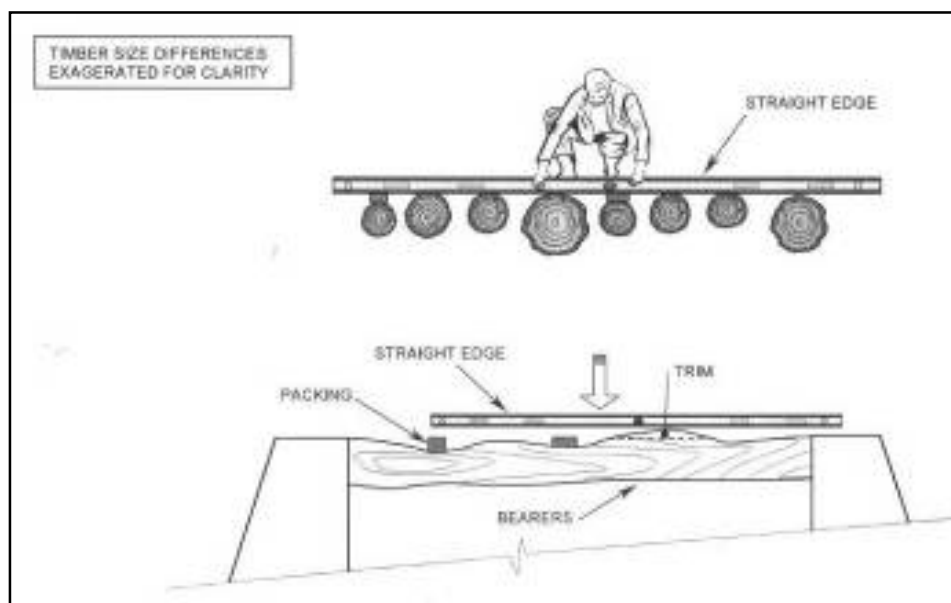


Figure 9.17 Fixing deck timbers

## 9. CONSTRUCTION

If the timber is particularly hard the nail holes may need to be pre-drilled to a diameter slightly smaller than the nails to avoid the timber splitting yet achieve a secure fixing.

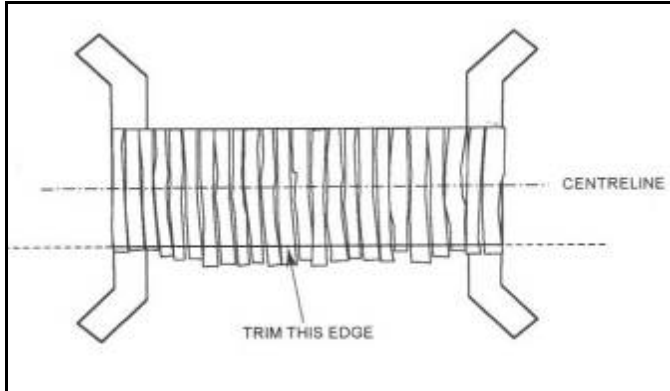


Figure 9.18 Trimming running boards

Excess timber should be trimmed from the ends of the deck planking.

Running boards are fixed to the decking by nailing or bolting. Heads should be recessed to avoid damage to vehicle tyres. Running boards should be laid to form a running surface for each wheel of at least 1.1m wide for safety. Joints in running boards should be staggered and cut square. All board ends

must bear on a decking timber and be securely fixed to it. A threshold board should be fixed across the end of the running boards at each end of the bridge. This will absorb the initial impact of a vehicle and protect the running boards.

Kerb timbers should be fixed to the edges of the deck and parapets provided for pedestrian safety.

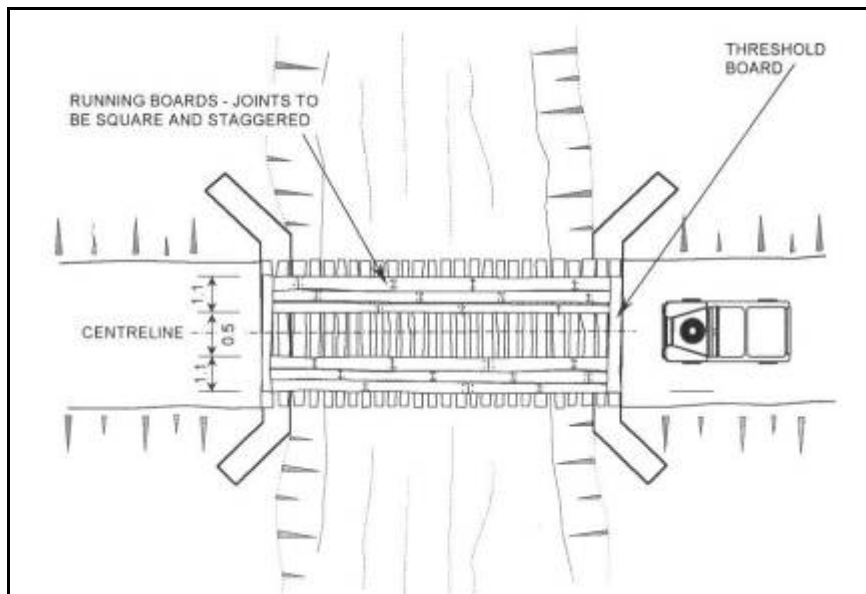


Figure 9.19 Kerb timber fixing

### Earthworks/Backfilling

Prior to backfilling, weep holes in masonry and concrete walls should be backed with a lean concrete plug. This will be porous to allow ground water drainage, but will prevent the backfill material from washing out.

Backfilling and compaction should be carefully and methodically carried out. Adjacent to structures it is usually not possible to use heavy compaction equipment; in confined spaces small plant or handtools must be used. The backfilled area adjacent to the structure is particularly susceptible to settlement in contrast to the relatively rigid structure. Good procedures and supervision are required to minimise the risk of later settlement so that particular care must be taken within 5 metres of the structure. The control of layer thicknesses is important.

## 9. CONSTRUCTION

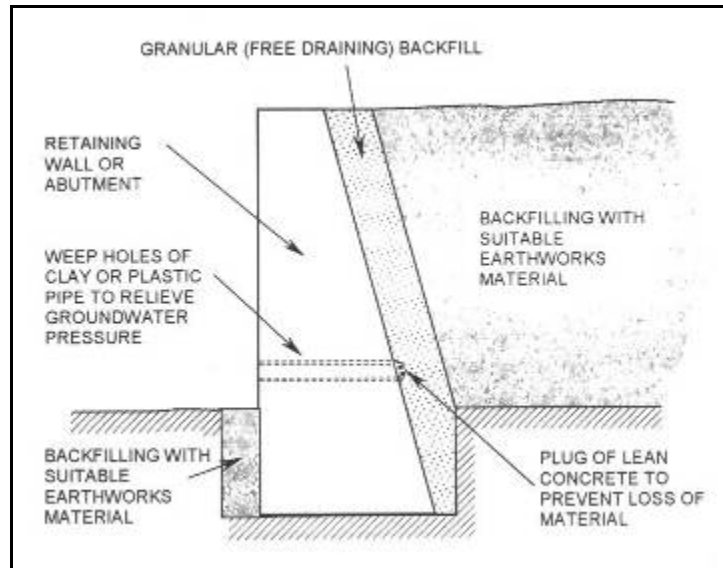


Figure 9.20 Backfilling

Control of compaction should either be by “end-product” specification, or “method” specification. Nuclear density testing is quick and convenient and avoids the need for laboratory testing and time delay using the sand replacement density method. Method specifications rely entirely on the presence and integrity of an inspector throughout the filling and compaction process.

### Supervision check box - Backfilling

- ◆ Backfill with selected suitable material in even layers of no more than 150mm thickness and thoroughly compacted. Material to be moistened if necessary to aid compaction.
- ◆ No large stones or rocks to be placed directly against structure.

### Safety Measures

Markers, chevrons and/or reflectors should be installed at the ends of the bridges to clearly show the extent of the structure and the vehicle path. Kerbs and ends of the structure should be painted white. Warning signs should be installed on the bridge approaches in accordance with the local traffic sign recommendations.

### Site Administration

The following activities will be required to be carried out in support of the site works. It is important to keep accurate records of the actual works carried out to compare to the planned progress, resource use and expenditure. This will help to ensure value for money. Any problems encountered should be recorded along with explanations of how they were overcome. This will assist in explaining any delays or cost over runs and help to improve future planning of structures.

## 9. CONSTRUCTION

### **Checklist of site administration tasks**

- ◆ Set and review individual/gang task rates
- ◆ Daily muster roll and work achievement record for site labour force
- ◆ Daily diary of works achieved; problems encountered and methods of solving them should be recorded
- ◆ Update work programme
- ◆ Daily checks on site stores, tools, materials, re-order as necessary
- ◆ Daily checks and service of site equipment
- ◆ Testing of materials, inspection and quality control
- ◆ Prepare payrolls
- ◆ Arrangements for payment of labour force
- ◆ Keep a careful record of all costs
- ◆ Reporting of progress to client/senior management
- ◆ Safety and first aid arrangements

Weekly and daily programmes should be prepared based on the Bills of Quantities, the overall works programme and expected local productivities. Adjustments will be required to be made continuously based on actual experience. Weekly reports should be prepared for management monitoring purposes. Key indicators should be used to monitor the progress of the work, such as cement or worker days used against the quantities planned.

For structures, 'as-built' drawings should be prepared; these should particularly record differences from the original design, and important details such as actual foundation levels and concrete strengths.

A cost analysis of the completed structure should be carried out to enable cost estimating of future structures to be more accurate.

A final inspection of the completed structure should be carried out prior to handing over to the authority that will be responsible for its maintenance. The following chapter discusses maintenance arrangements.

It is advisable for an independent performance audit to be carried out on a completed structure to review the works. This should verify the structure's 'fitness-for-purpose' and value for money.

## 10. Maintenance

Cross drainage structures usually account for a high proportion of the total cost of a road. They are the potential weak points in a road network due to the damaging effects of floods and high water flows being concentrated at the points where the water crosses the road. The failure of these structures results in high replacement costs and long delays due to the closure of the road. It is particularly important therefore, that sufficient attention is given to structures to ensure that they are maintained in good condition.

A culvert, bridge or other structure is an integral part of the road, and its condition will affect the level of service that the road provides. A structure should be designed so that no major repair works should be required during its 'design life' (e.g. replacement of abutments, piers or deck structural members). Eventually major works may be required such as a complete new timber bridge deck or safety barrier replacement. However, the structure should be designed to provide many years of service through its design life with only minor maintenance.

Importantly, if the maintenance is not carried out, there can be serious consequences for road users. It can result in increased safety hazards, reduced quality of service or even loss of the structure and severing of the transport link.

It is usually not possible with the resources available in developing countries to devise a 'maintenance-free structure' for a watercourse crossing. However, application of the design and construction guidelines contained in this document should reduce maintenance requirements to an acceptable and manageable level.

Conversely, poor design or construction will result in an abnormally high requirement for maintenance, or even eventual loss of the structure.

There are a number of aspects which should be appreciated in devising appropriate management and maintenance arrangements for structures. This applies to consideration of an individual structure, or a large number constructed at various locations on a road network.

- ◆ Structures will often need no maintenance for periods of many months or sometimes even years.
- ◆ Deterioration or damage to a structure can progress slowly (e.g. corrosion, attack by insects), or suddenly (e.g. in a flood or vehicle accident).
- ◆ The need for repairs may not be obvious to road users or through casual observation from the road. However, the deterioration can progress, if not checked, to result in the need for major works at great cost and requiring substantial unplanned resource mobilisation.
- ◆ The resources for maintenance and repair of a typical structure are required intermittently, not continuously.
- ◆ It is usually most efficient to provide maintenance resources only when the structure requires maintenance or repair works.

It is important to ensure the maintenance of a structure so that it remains in its intended condition, providing the service and benefits to road users and the community that it was designed for. It is an asset that needs to be managed.

### Managing the Structure

The maintenance works required to be carried out on a structure will range from basic seasonal clearing of silt and debris to ensure it continues to function properly, through to replacement of components of the structure when they are worn out or damaged. It can be expected that ALL structures will normally require at least some basic maintenance each year.

It is necessary to set up a management system to ensure that the structure stays in a condition that it is able to carry out its function in a safe manner. In essence this 'system' should identify when work needs to be carried out. From this assessment the maintenance funding and works can be arranged and supervised to ensure that the maintenance is completed satisfactorily.

A system of inspections is required to identify any damage or deterioration of the structure, or problems adjacent to the structure which may threaten its stability.

The key components of a structures management system are:

- ◆ An inventory of all structures (i.e. What is the asset? What are its key features? These are management records which generally do not change with time, except for new structures or after major structural changes to an existing one)
- ◆ An inspection system (to determine the condition and repair needs)
- ◆ Arrangements for specifying, arranging, supervising, recording/reporting and paying for the works. Arrangements should also be in place for checking the 'value for money' of maintenance operations and expenditures.

TRL Overseas Road Note 7 provides comprehensive guidelines on the inspection and documentation of inventory and condition information on structures. A paper based system is quite adequate. Computer systems can help if the number of structures being managed is substantial and the operating environment can support the maintenance of the computer system itself, including arrangements for the ongoing costs and skilled resources required. In a limited resource environment it can be difficult to justify and secure the recurring costs of administration, computer support personnel and inevitable software and hardware upgrades required for a computer system.

Certain maintenance activities such as de-silting and removal of debris should be carried out under a routine programme of works. For example, before the rainy season all silt should be removed from culverts, their inlets and outlet channels. After the rains, and particularly after individual floods, silt and debris should be cleared from structures to avoid later damage due to blockages or diversion/concentration of water.

These routine clearing operations are an ideal opportunity to carry out an inspection of a structure. With the scarcity and expense of engineering personnel, it is possible to train persons with limited education (e.g. the gang leader) to carry out inspections and to alert engineering staff to situations that require their action.

Inspections of ALL structures should be carried out after a flood situation as this is the most likely time for damage to have occurred. Particular attention should be paid to identifying any movement, especially at joints, cracking/spalling and assessing whether erosion has occurred around abutments and piers, or at the ends of aprons. Where water is permanently standing against the structure, probing with ranging rods, poles or plumb lines should be carried out to identify unseen scouring. A boat or raft may be required for this inspection.

All structures, from culverts to bridges, should receive a documented routine inspection at least once each year. As indicated above these can be carried out by relatively unskilled personnel if the appropriate training is provided. Inspection records should be carefully

## 10. MAINTENANCE

filed for future reference. Even a report of 'no defects' is important management information.

The management of a structure costs money and, even before a structure is built, the ongoing provision of the funds and resources for the management (including inspections) as well as the maintenance of the structure should be assured.

### Maintaining the Structure

Structure maintenance activities can be grouped into regular routine maintenance and periodic major operations.

#### Routine

1. Cleaning/clearing
  - a. sweeping
  - b. de-silting
  - c. unblocking
  - d. removal of vegetation and flood/wind borne debris).(This includes inlets and outlet channels as well as culvert openings themselves)
2. Repair of loose/missing connectors and fixings
3. Replacement of damaged/missing planks or kerbs
4. Painting
5. Wood preservation
6. Pointing/repair of masonry
7. Repair of parapets, marker posts, safety barriers and features/signs

#### Periodic

1. Random stone filling
2. Retaining wall repairs
3. Riverbed scour repairs
4. Gabion repairs
5. Structural repairs to the following defects:-
  - a. structural timber decay, splitting or insect attack
  - b. bulging masonry
  - c. cracked concrete or masonry
  - d. honeycombed concrete
  - e. spalling concrete
  - f. serious rust or chemical stains
  - g. exposed or corroding reinforcement or pre-stressing steel
  - h. damp patches on the concrete
  - i. seriously corroded structural steelwork
  - j. damaged/distorted structural steelwork
  - k. loose structural rivets, bolts or other fixings
  - l. cracks in structural steelwork
  - m. settlement of deck, piers, abutments or wingwalls
  - n. expansion joint or bearing defects
  - o. erosion requiring piling works

Major repairs will generally require technical expertise for the design and supervision of remedial work.

## 10. MAINTENANCE

Maintenance works should be planned, organised and supervised using the guidelines set out in the previous construction chapter. Maintenance records should be kept for each structure, which include:

- ◆ Estimates of work proposed
- ◆ Details of work carried out
- ◆ Date of completion of the repair
- ◆ Supervisor's quality control reports
- ◆ Actual costs of repair

Storage of information should be on a structure by structure basis so that the complete history can be easily viewed.

Further guidance on maintaining structures is provided in the PIARC International Road Maintenance Handbook, Volume 4. The handbook includes advice on the defects, resources and maintenance methods involved.

### Common maintenance requirements

Damage due to scour and erosion is the most likely cause of major or unrepairable damage to a structure. Once scour or erosion around a structure starts the damage can increase very rapidly. It is therefore essential that maintenance is carried out quickly to prevent further structural damage.

#### Drifts

The drift must maintain a firm roadway across the width of the river which is not covered by debris or eroded by the flood water. The face of the river embankments should also be protected against scour and erosion. It may be possible to encourage the growth of vegetation along the banks to improve the bank stability and prevent erosion. The common maintenance issues to address are:

- ◆ cracking of the slab
- ◆ undercutting on the downstream side
- ◆ erosion at ends of slab where it is not extended above high flood levels
- ◆ lack of downstream protection
- ◆ guidestones knocked off

#### Culverts

The most common maintenance problem associated with culverts is blockage due to silt and other debris. A blocked culvert can result in damage to the road in 3 ways:

1. Water can seep into the subgrade of the road and reduce its strength. The road will tend to subside and the road surface will break up.
2. The water can undermine the head and wingwall of the culvert causing it to collapse. The road embankment will then be unsupported and rapidly subside.
3. In an extreme case the water level may continue to increase until the water floods over the road. The road may then become impassable and major damage occur as the water erodes the road and culvert. Ultimately the road will be washed away and a large gully will be scoured across the road.

Water discharging from culverts with excessive velocity will erode the stream bed and possibly undermine the whole structure. It is therefore essential to provide some form of protection to the beds below the outlet of a culvert. The protection is usually in the form of a masonry apron. It may also be necessary to prevent erosion of the watercourse itself further downstream of the culvert. Bio-engineering planting may be an appropriate and low-cost solution.

## 10. MAINTENANCE



Figure 10.1 and 10.2 Culvert cleaning tool



Figure 10.3 Box culvert partially blocked by vegetation

The main cause of blockage of culverts is by water carried debris. Larger debris tends to collect at the entrance to the culvert causing blockage at the headwall, while silt is deposited in the culvert barrel. If unchecked this silt can build up until it fills the culvert barrel. Long grass at the outlet of a culvert can cause silting at the outlet and eventual blockage of the culvert. It is therefore necessary, particularly before the rainy season, to clean culvert barrels, inlets and outlets to allow water to flow freely through the culvert. Any material removed

from a culvert should be disposed of downstream of the culvert to prevent it washing back into the structure. Other common defects that require maintenance to be carried out on culverts include:

- ◆ downstream erosion
- ◆ headwall knocked down or damaged
- ◆ outfall channel eroded or silted
- ◆ undercutting of the culvert outfall apron
- ◆ ponding of water at the inlet and/or outlet causing subsidence of the road embankment

### **Vented drifts and large bore culverts**

The common maintenance requirements with vented fords and large bore culverts are similar to culverts and drifts. In addition to the issues discussed above the following defects may need to be corrected during maintenance:

- ◆ floating debris, such as tree branches, can block the culvert barrels
- ◆ cracking and breaking of roadway slab
- ◆ cracking and breaking of structure faces.

## References

The references below may be used to supplement the information contained in this guideline. In order to assist readers in the selection of relevant additional information the following information has been provided with each reference;

- ◆ list of the topics covered
- ◆ a brief review of the issues discussed in each reference
- ◆ contact details of selected publishers

Many of the documents and further information on specific topics may be accessed on the global Transport Knowledge Partnership website: [www.gtkp.com](http://www.gtkp.com)

Berger L, Greenstein J, Arrieta J, 1987, *Guidelines for the Design of Low Cost Water Crossings*, TRR 1106, Transportation Research Board, Washington  
(Finance, Bridges, Design, Materials) pp10

This paper reviews the different designs and materials used for the construction of bridges on low volume roads in Central America. The article indicates that the standards used on these roads need only be suitable for vehicles up to 10 tonnes, resulting in major cost savings when compared with full specifications. The use of gravelled fords, split deck concrete bridges and timber bridges are discussed. The paper outlines a design for timber bridge decks.

Brandon T, 1989, *River Engineering – Part 2, Structures and Coastal Defence Works*, Institute of Water and Environmental Management, London  
(Design, Hydraulics, Maintenance) pp332

This book is the second of two volumes and covers the design, construction and maintenance of water structures. It is primarily concerned with the design of river control structures such as locks, weirs and sluices, but also includes limited discussion on river protection, culverts and bridges. There are two useful chapters on maintenance issues and construction planning and management.

Clark J, Hellin J, 1996, *Bio-Engineering for Effective Road Maintenance in the Caribbean*, Natural Resources Institute, Chatham, UK  
(Environmental, Materials, Erosion Protection, Slope Stability) pp122

This book discusses the use of vegetation for the control of erosion and stabilising slopes, indicating the functions different types of vegetation can perform. Six simple techniques are described, along with the vegetation species that may be used, which are useful in the road sector for drainage control. The book also contains a large section which gives background details of eleven species which are suitable for bio-engineering. These species are normally found in the Caribbean, however the description of the species and specification of different planting material should allow practitioners in other areas to make use of the information.

Dzung Bach The, Petts Robert, 2009, *Report on Rice Husk Fired Clay Brick Road Paving, Vietnam*, global Transport Knowledge Partnership

This report documents the experiences in Vietnam of the established practice of burning high quality clay bricks for building and road works use. The flexibility of the process suggests that other agricultural wastes could be used to produce high quality clay bricks for structures and other road works uses.

Farraday R, Charlton F, 1983, *Hydraulic Factors in Bridge Design*, Hydraulics Research, Wallingford  
(Bridges, Design, Hydraulics, Erosion Protection) pp102

## REFERENCES

This book explains in fairly simple terms the different hydraulic issues which need to be addressed when designing bridges over rivers. It describes the data which needs to be collected and a step by step design process which must be undertaken to ensure that bridges will be able to withstand the loads exerted by the water and changing flow patterns due to scour of the river bed. Each chapter is extensively referenced.

Flavell D. (ed), 1994, *Waterway Design*, Austroads, Sydney  
(Bridges, Culverts, Design, Hydraulics) pp138

This book provides guidance on the selection of design floods required for the various aspects of the design of waterway structures and the hydraulic design of bridges, culverts and floodways. It also provides information for the design of works required to protect these structures from the effects of scour.

Gupta D P, 1997, *Manual on Route Location, Design, Construction and Maintenance of Rural Roads*, Special Publication 20, Indian Roads Congress, New Delhi  
(Design) pp108

This book primarily covers the design and construction of roads, however it has two chapters covering drainage and cross drainage structures. Other sections of the book highlight design issues which are affected by highway structures. This book would be a useful reference if structures were to be designed on a new road.

Heyman J, 1980, *The Estimation of the Strength of Masonry Arches*, Proc. Institution of Civil Engineers Part 2 Dec 1980  
(Design) pp921-937

This paper discusses the development of the simplified method for estimating the strength of masonry arches by the military load classification. It discusses the mathematical proof of the assumptions made and explains that the strength of an arch is closely related to its span and crown thickness. The paper suggests that nomographs could be used to predict strength with correction factors used to account for span/rise ratio, mortar condition and quality of material used.

Hindson J, 1983, *Earth Roads: Their Construction and Maintenance*, IT Publications, London  
(Culverts, Design, Drifts, Erosion Protection, Site Construction) pp124

This book covers the design and construction of earth roads for traffic up to about 50 vehicles per day. It concentrates on the control of water through drainage control measures. The first half of the book deals with the theory of road design which includes splashes, drifts and culverts. The second half of the book deals with the techniques of construction offering different solutions for different topological conditions. The second half of the book also includes a section on maintenance.

ILO, 1991, *Stone Masonry*, (Training Element and Technical Guide for SPWP Workers Booklet 2), UNDP/ILO, Geneva  
(Materials, Site Construction) pp84

This booklet covers the design, construction and maintenance of small masonry structures which include culverts and small headwalls. It may be used as a technical manual for site personnel or as the basis for a training course for site supervisors in the use of masonry for construction.

ILO, 1986, *Gabions*, (Training Element and Technical Guide for SPWP Workers Booklet 3), UNDP/ILO, Geneva  
(Materials, Site Construction) pp84

This booklet is similar to its predecessor covering stone masonry. It does not specifically deal with highway structures but highlights the uses of gabions and how they should be constructed.

Jayanetti, L. 1990, *Timber Pole Construction*, IT Publications, UK

## REFERENCES

(Materials) pp64

Although not focused on road structures this book provides information to designers of timber pole bridges.

Jones T, Parry J, 1993, *Design of Irish Bridges, Fords and Causeways in Developing Countries*, Highways and Transportation (Jan 1993), Institution of Highways and Transportation, London

(Drifts) pp28-33

This article explains the differences between the different types of low level water crossing. It discusses site selection and the materials which may be used for different crossings. The article also describes with a series of photographs and diagrams the key design points of the different structures.

Kadam S.P, 1993, *Vented Paved Dips for Rural Roads*, Indian Highways

(Design, Hydraulics, Drifts) pp14

This paper discusses the use of vented fords on rural roads to allow for monsoon rains. It concentrates on the issues of scour downstream of the structure but also discusses the hydraulics of a vented ford when it is being overtopped. The optimum dimensions for a structure are provided which include a standard construction drawing.

Khanna, P.N. , 1996, *Indian Civil Engineer's Practical Handbook*, 15th Edition, Engineer's Publications, New Delhi.

(Design, Site Construction)

This book provides a wide range of practical information for engineers involved in the design, planning and construction of civil engineering projects. The handbook contains a chapter specifically covering the engineering aspects of roads and road structures, in addition to chapters covering surveying, setting out, material properties and basic design principles.

Lal G, 1995, *Guidelines for the Design of Small Bridges and Culverts*, Special Publication 13, Indian Roads Congress, New Delhi

(Bridges, Culverts, Design, Hydraulics, Drifts, Erosion Protection) pp176

This book covers the complete design of small bridges and culverts from the collection of the initial design data to the preparation of construction drawings. It concentrates on the mathematics of the estimation of maximum water flows and scour around structural supports. However, other empirical results and solutions are also described throughout the book to simplify the design process where applicable.

Morris, J, 1995, *Earth Roads*, Avebury

(Bridges, Culverts, Drifts, Materials, Maintenance, Erosion Protection, Site Construction) pp304

This book is a practical guide for managers and engineers of agricultural estates to provide guidelines and advice on how roads can meet the needs of their commercial operation. It concentrates on earth and other unsealed roads in developing countries, but has extensive sections covering bridges and culverts. The majority of the solutions discussed make use of timber which is likely to be available as a by-product from the agricultural operations.

PIARC, 1994, *International Road Maintenance Handbook*, Transport Research Laboratory (for the World Road Association (PIARC)), UK

Vol. 1 Maintenance of Roadside Areas and Drainage,

Vol. 2 Maintenance of Unpaved Roads,

Vol. 3 Maintenance of Paved Roads,

Vol. 4 Maintenance of Structures and Traffic Control Devices (Maintenance)

These four handbooks are aimed at the supervisors of road maintenance contracts. They explain the causes and the measures required to prevent road deterioration. Each

## REFERENCES

maintenance task is addressed in turn with simple text and illustrations to show the labour and tools required to carry out the task.

Shadmon, A, 1989, *Stone; An Introduction*, IT Publications, London  
(Materials), pp184

This book provides a good introduction to the extraction and use of both field and cut stone. It describes the different types of stone and outlines tests that can be carried out to determine the tensile and compressive strength of stone samples.

Spence, R, and Cook D, 1983, *Building Materials in Developing Countries*, John Wiley and Sons.

(Materials) 356pp

This book provides practical information about various building materials commonly available in developing countries. The majority of the information is focused on housing construction. However, a significant proportion of the information available will be useful to designers of road structures.

Stern, P. et al, 1983, *Field Engineering*, IT Publications, London  
(Bridges, Culverts, Design, Maintenance, Site Construction) pp272

This book is aimed at individuals working on engineering projects in rural areas. It has a detailed section dealing with site survey and setting out techniques. In addition to sections on roads, simple river crossings and bridges, it also covers water supply, sanitation and small dams.

Stulz, R and Mukerji, K, 1993, *Appropriate Building Materials*, SKAT, St Gallen, Switzerland.

(Materials) 456pp

This book provides technical data and practical information about various building materials for low cost construction. The majority of the information is focused on non road structures. However, a significant proportion of the information available will be useful to designers of road structures.

Thagesen B (ed), 1996, *Highway and Traffic Engineering in Developing Countries*, E & FN Spon, London

(Culverts, Design, Maintenance, Site Construction) pp485

This textbook covers the planning, design, construction, maintenance and management of roads in tropical developing countries. It contains a section on drainage design which covers hydrology and hydraulic design and another section which discusses maintenance strategies and management.

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(Bridges, Culverts, Maintenance) pp40 & pp250

The object of these two volumes is to allow a district engineer to establish and operate an effective bridge and culvert record system. The guide explains the principles of record keeping and contains a series of proforma record sheets. The pocket size handbook (Vol. 2) deals with the actual inspection, highlighting, through the use of photographs and drawings, the items which should be checked and recorded.

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This manual prepared by TRL offers a comprehensive set of guidelines to highways engineers for the design of small bridges and culverts. It covers the whole process from the planning stage to the final preparation of detailed specifications and drawings. It is intended for practising engineers who may not be highway specialists. The designs which

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Hydraulics Research:

Hydraulics Research Station Ltd, Wallingford, Oxfordshire, UK, [www.hrwallingford.co.uk](http://www.hrwallingford.co.uk)

International Labour Organisation (ILO):

4 route des Morillons, Geneva, CH 1211, Switzerland, [www.ilo.org/public/english/](http://www.ilo.org/public/english/)

Indian Roads Congress (IRC):

Sector 6, (Near RBI Quarters), R K Puram, New Delhi- 110022, India, [www.irc.org.in](http://www.irc.org.in)

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The Bullock Building, University Way, Cranfield, Bedford, MK43 0GH, UK, [www.iagre.org](http://www.iagre.org)

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The National Academies, 500 Fifth Street, NW, Washington, DC 2000, USA, [www.trb.org](http://www.trb.org)

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