

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

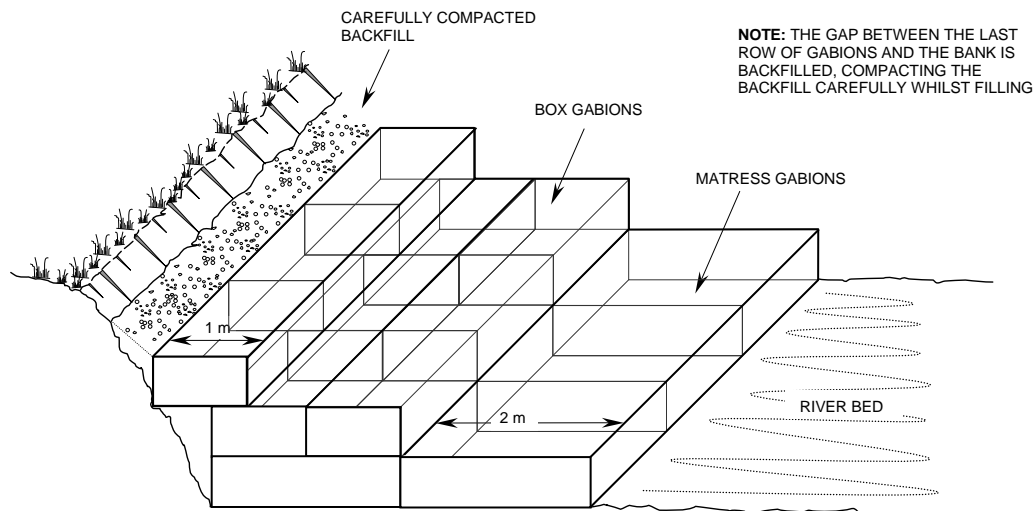


Figure 8.41 Gabion protection on steep banks

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 1m.

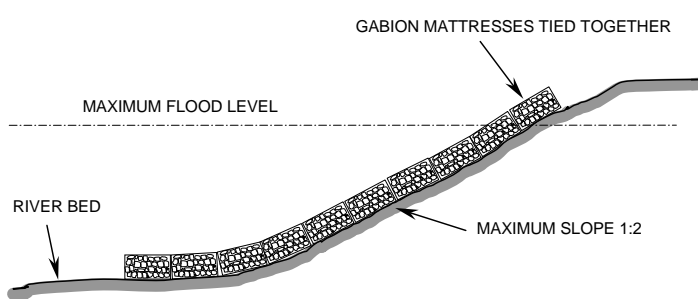


Figure 8.42 Gabion protection on shallow banks

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.

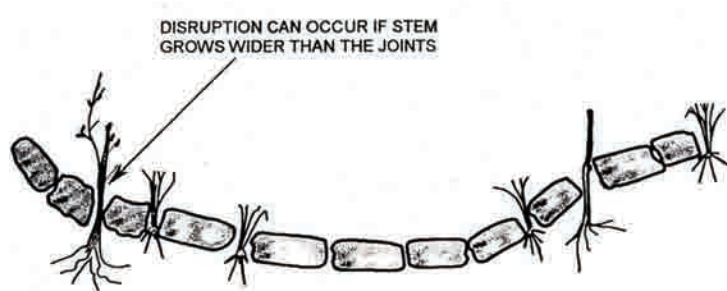


Figure 8.43 Care required with roots

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.

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.

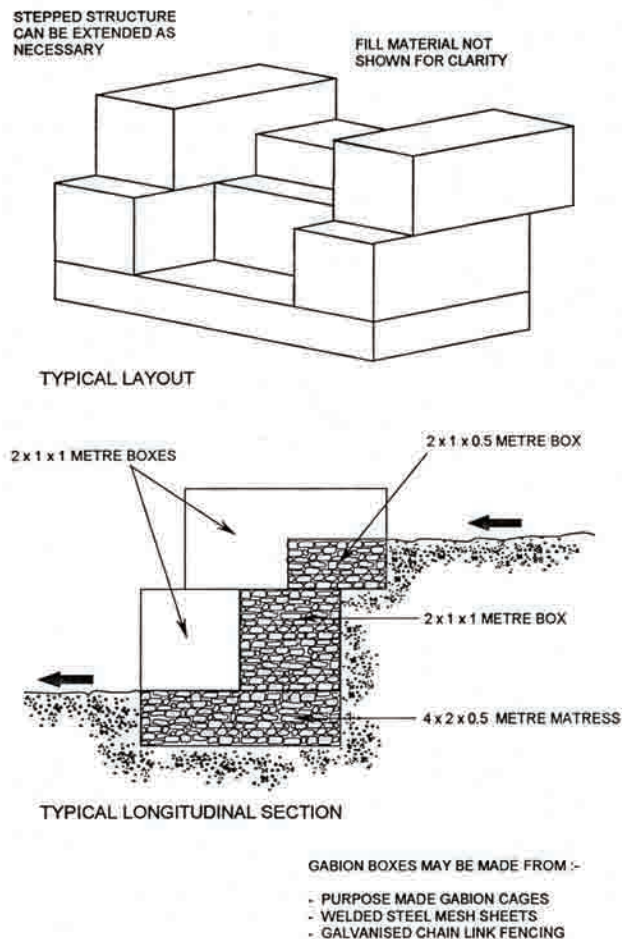


Figure 8.44 Gabion step-waterfall

Care must be taken to ensure that the sides of 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.

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.



Figure 8.45 Gabion basket step waterfall

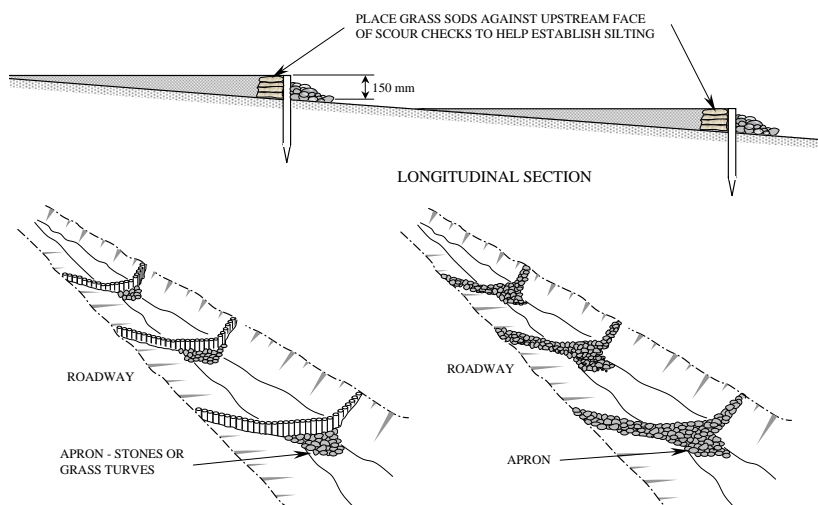


Figure 8.46 Scour checks

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

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.

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

Arches

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.



Figure 8.47 Masonry Arch

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.



Figure 8.48 Arch bridge

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. 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.

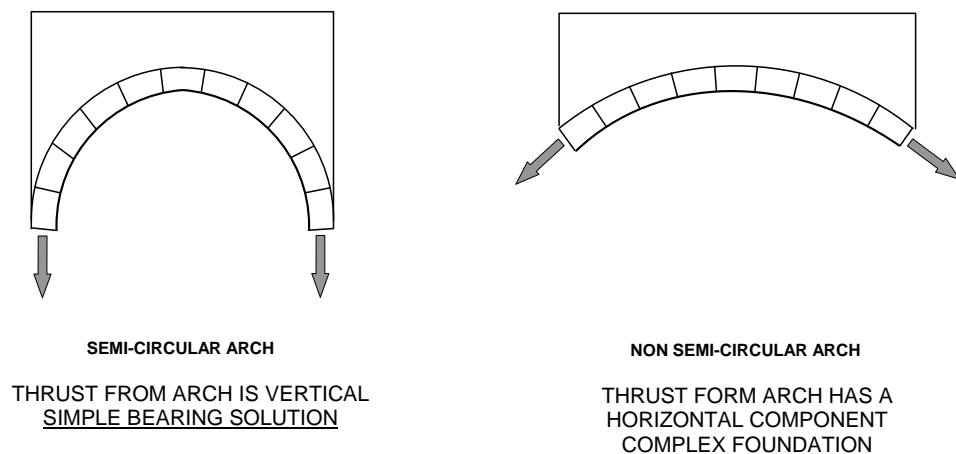


Figure 8.49 Arch forces

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.

Small Versus Large arches?

Small arches

- Easier to construct using labour based techniques
- Piers will be required to be constructed in the water course
- The bearing pressures exerted by the piers will be lower than for large arches

Large arches

- Formwork may require cranes to manoeuvre components into place
- 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 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 formwork is likely to cost as much as the

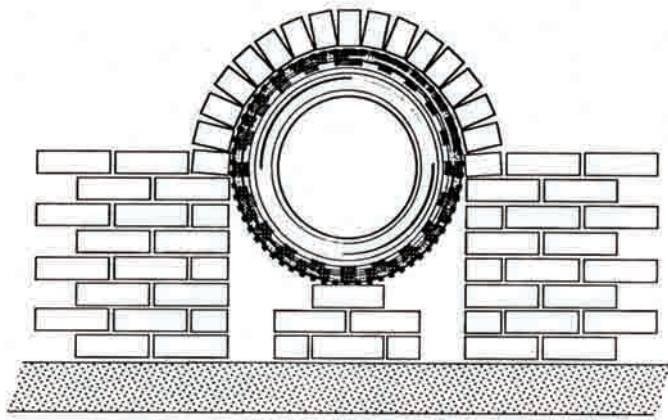


Figure 8.50 Use of tyre in formwork

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.

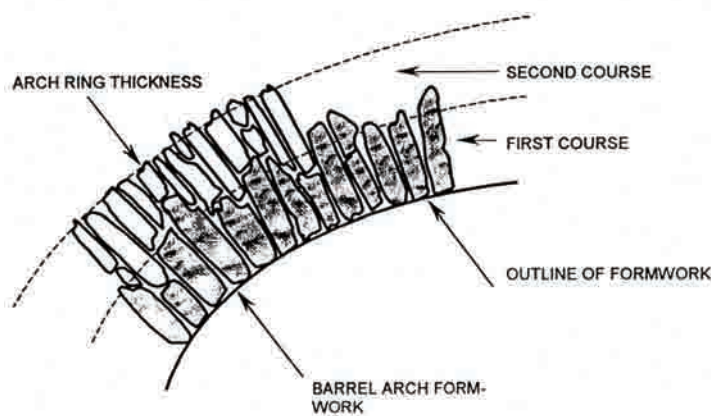


Figure 8.51 Two course arch

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. 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.

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.

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

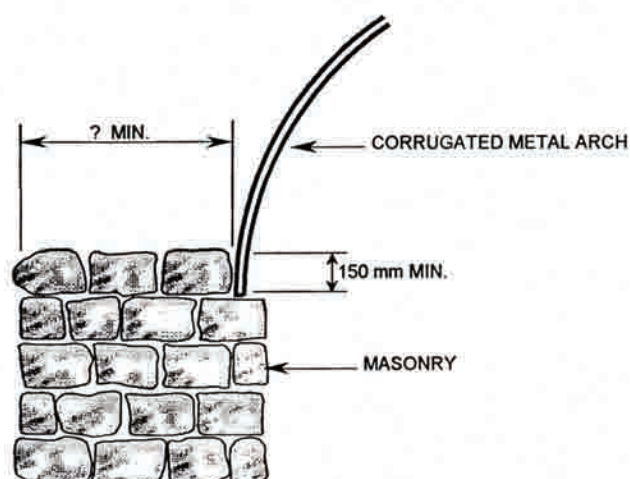


Figure 8.52 Corrugated metal sheet arch

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.

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.

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 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 64. 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 that in order to minimise the total cost of the structure, maximum use should be made of local materials and



Figure 8.53 Reinforced concrete deck on masonry abutments and pier

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 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

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 $300\text{kN}/\text{mm}^2$. 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.

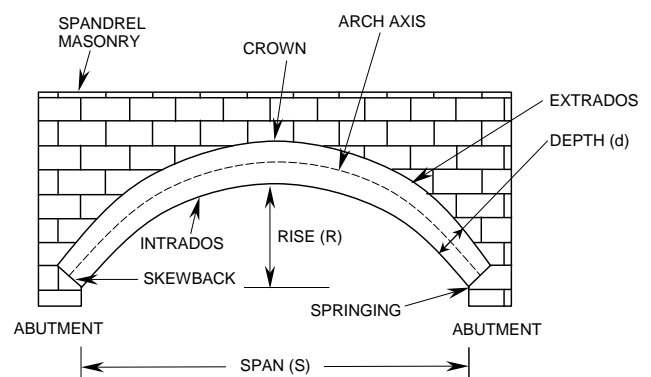


Figure 8.54 Arch bridge details

Arch bridges can be built in different forms and shapes. The key elements of an arch bridge are shown in Figure 8.54. 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.

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 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.

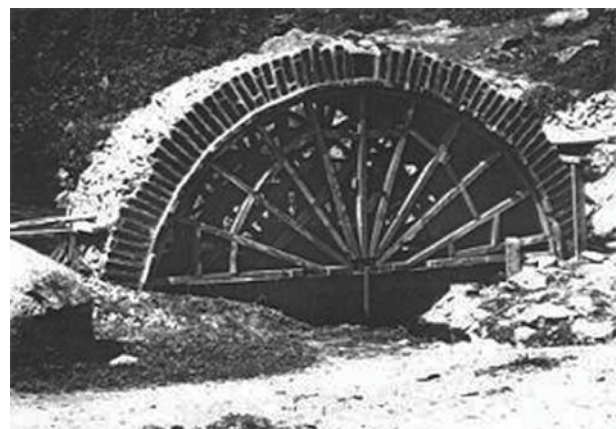


Figure 8.55 Masonry arch under construction with wooden formwork

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 49 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, i.e. a brick laid radially to provide a key between the rings. For larger spans, the number of rings can be increased towards the springings. It is recommended that skewed arches are avoided.



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

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.

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 5kN/m² 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 1/100th 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 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).



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

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 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.

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.

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.

Sawn timber girder bridge deck for 6 ton vehicles		
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/m³		

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



Figure 8.58 Log stringers from underside of bridge deck

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).

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.

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

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

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.

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

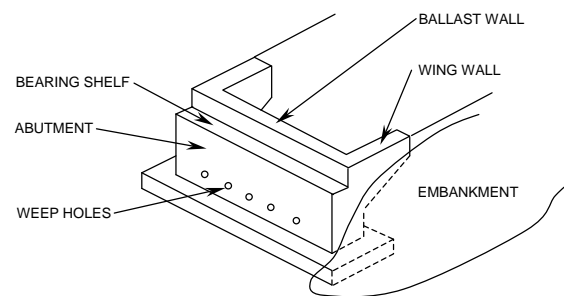
Abutments provide the support system for the deck and retain the soil under the approach road and can be built using various forms and materials. The main function is to transfer the loads from the deck to the supporting foundations. They are also located at the transition between the approach embankment 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.

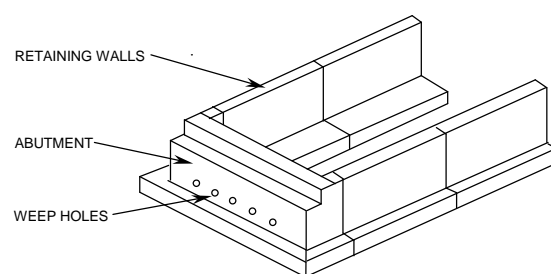
Timber abutments may be considered acceptable for low volume road structures but their vulnerability to deterioration and short service life should be recognised. Gabions can also be used providing fill material of suitable size and resistance to water damage is available. They have the advantage of 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 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.



ABUTMENT WITH WINGWALLS



ABUTMENT WITH SEPARATE RETAINING WALLS

Figure 8.59 Abutment details

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.

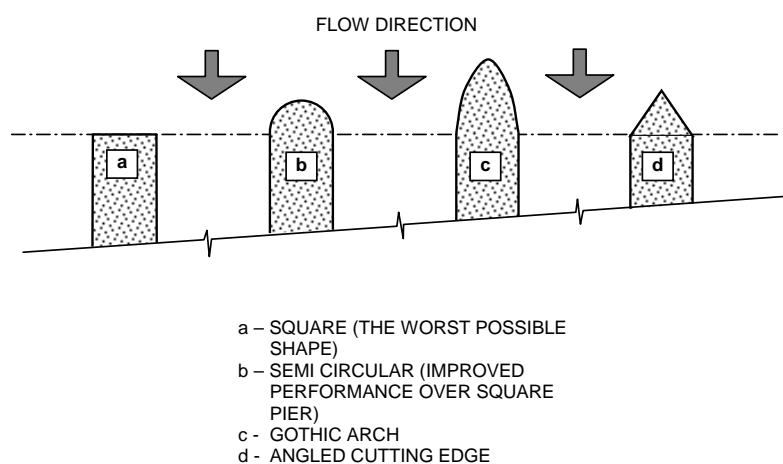


Figure 8.60 Pier shapes (Plan view)

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

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.



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.

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 8.63 Timber bridge with handrails

Discharge (m ³ /s)	Minimum clearance (mm)
< 0.3	150
0.3 - 3.0	450
3.0 - 30	600
> 30	1000



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 not designed to withstand the water flow. The adjacent table provides minimum clearances that should be provided between the maximum water level and the bottom of the bridge deck.

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.

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.

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

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.
11. Construct foundations.
12. Construct temporary works for superstructure.
13. Erect abutments, piers, deck, wingwalls.
14. Fix deck timbers and running boards where applicable.
15. Erect kerbs, parapets barriers and safety structures.
16. Install drainage layers and features against structure.
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.
18. Construct road pavement/surfacing and markings, road shoulders.
19. Construct road drainage features.
20. Construct gabions and erosion control measures.
21. Lay topsoil/turves and planting.
22. Install traffic warning signs if necessary.
23. Clear site, remove surplus materials and leave tidy.

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 douse 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.

Recommended productivity standards

Site clearance (bush clearing, tree felling, etc.)	100 – 350m ² / worker day
Removal of tree stumps	1 / worker day
Soil excavation (and stockpiling alongside)	2 - 5m ³ / worker day
Rock (fractured) excavation (solid rock will require drilling and blasting/splitting)	0.8m ³ / worker day
Loading	8.5m ³ / worker day
Haulage by wheelbarrow	
• 0 - 20m	8.5m ³ / worker day
• 20 - 40m	7.0m ³ / worker day
• 40 - 60m	6.5m ³ / worker day
• 60 - 80m	5.5m ³ / worker day
• 80 - 100m	5.0m ³ / worker day
• 100 - 150m	4.5m ³ / 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 ³ / worker day
Erect masonry work	1.0m ³ / 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. 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

Checklist of handtools and site equipment

Handtools

- Ranging rods
- Spirit level /Abney level / water tube level
- Stringlines, pegs
- Profile boards & travellers
- Plumb bob
- Tape measures

- Felling axes
- Tree felling saws
- Bush knives
- Brush hooks
- Ropes

- Pick axes
- Mattocks
- Hoes
- Crowbars
- Shovels
- Sledge hammers
- Wheelbarrows
- Head pans/baskets
- Earth 'stretchers'

- Carpenters tool kits

- Hand drills
- Plugs and feathers

- Masons trowels
- Masons hammers
- Spirit levels
- Straight edges
- Lifting tackle
- Buckets
- Mortar pans
- Mixing boards
- Water containers/drums
- Screeding boards
- Pointing tool

- Hand rammers
- Rakes/spreaders

- Slump test equipment
- Concrete cube moulds and curing tank
- Soil density testing equipment

- Sandbags for water control

Equipment

- Culvert moulds

- Plate compacter
- Pedestrian vibrating roller
- Water bowser
- Water pump
- Concrete mixer
- Batching boxes
- Vibrating poker
- Piling equipment
- Hydraulic excavator
- Compressor and air tools
- Craneage
- Aggregate crushing eqp.
- Aggregate screens
- Supply and site transport
- Formwork/moulds

- Traffic signs and barriers

- Safety helmets and equipment

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

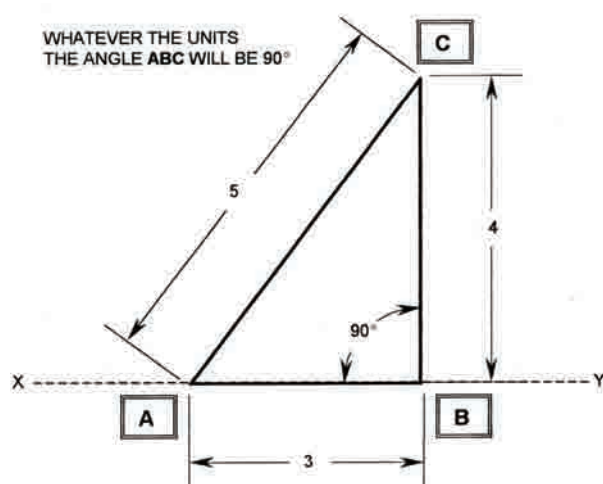


Figure 9.1 Setting out a right angle

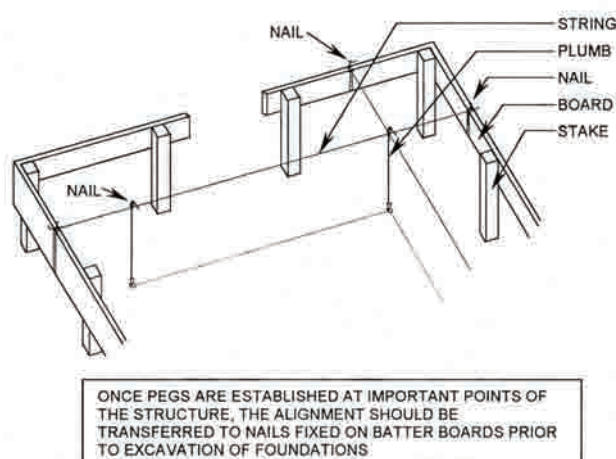


Figure 9.3 Use of batter boards

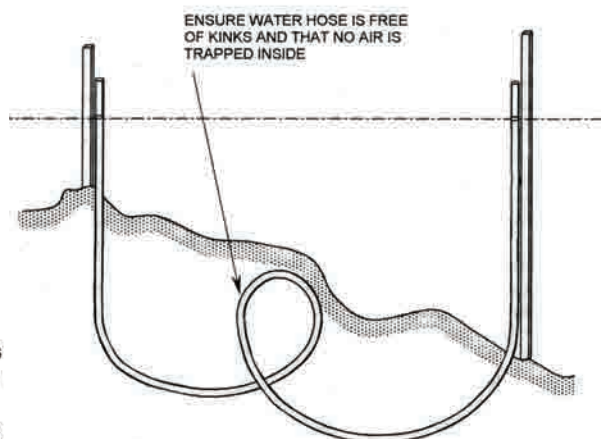


Figure 9.2 Levelling with a water hose

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.

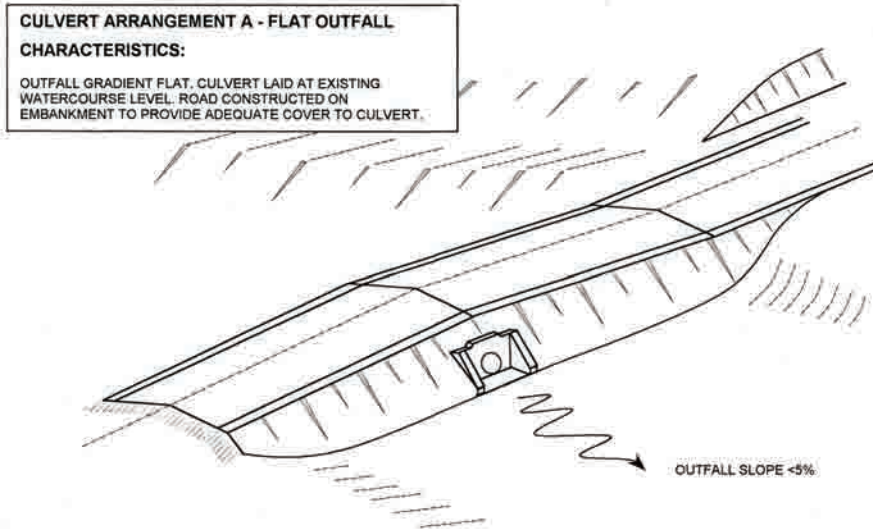


Figure 9.4

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 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.

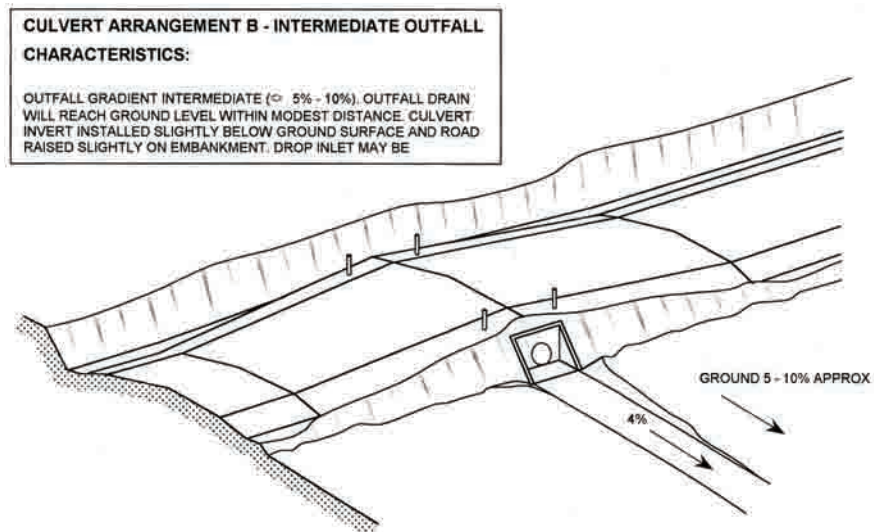


Figure 9.5

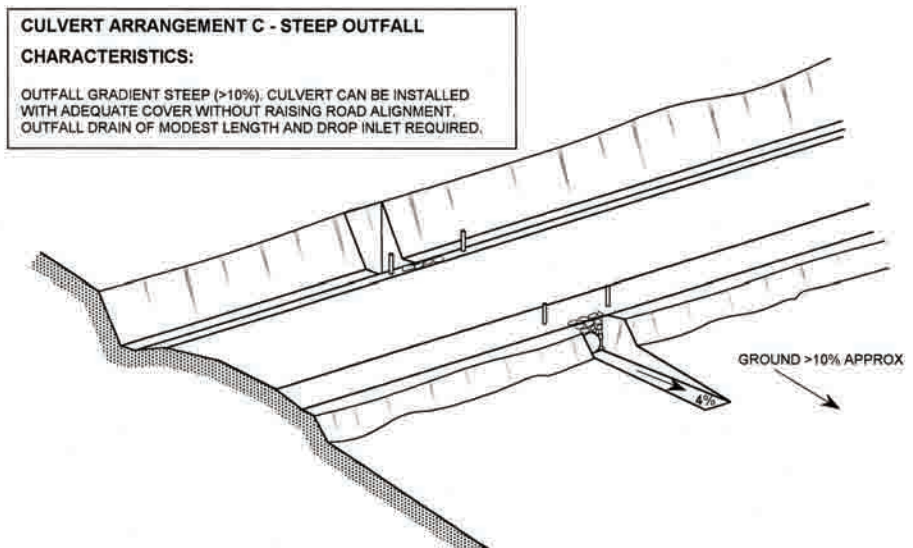


Figure 9.6

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 Ø 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>STEP 1</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>STEP 2</p> <p>Measure distance between peg A and B (5.50 m, or 'w' for other cross sections).</p>													
<p>STEP 3</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 border="0"> <tr> <td>OUTSIDE DIAMETER OF CULVERT ø 600 mm</td> <td>0.72 m</td> </tr> <tr> <td>OVERFILL (MINIMUM COVER)</td> <td>+ 0.45 m</td> </tr> <tr> <td>TOTAL DEPTH (d)</td> <td><u>1.17 m</u></td> </tr> </table>	OUTSIDE DIAMETER OF CULVERT ø 600 mm	0.72 m	OVERFILL (MINIMUM COVER)	+ 0.45 m	TOTAL DEPTH (d)	<u>1.17 m</u>						
OUTSIDE DIAMETER OF CULVERT ø 600 mm	0.72 m												
OVERFILL (MINIMUM COVER)	+ 0.45 m												
TOTAL DEPTH (d)	<u>1.17 m</u>												
<p>STEP 4</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 border="0"> <tr> <td>GRADIENT:</td> <td>4%</td> </tr> <tr> <td>DIFFERENCE IN LEVEL:</td> <td></td> </tr> <tr> <td>$\frac{4\% \times 5.50 \text{ m}}{100\%}$</td> <td>= 0.22 m</td> </tr> <tr> <td></td> <td>(FOR ROAD WIDTH w,</td> </tr> <tr> <td></td> <td>= 0.04 w)</td> </tr> </table>	GRADIENT:	4%	DIFFERENCE IN LEVEL:		$\frac{4\% \times 5.50 \text{ m}}{100\%}$	= 0.22 m		(FOR ROAD WIDTH w,		= 0.04 w)		
GRADIENT:	4%												
DIFFERENCE IN LEVEL:													
$\frac{4\% \times 5.50 \text{ m}}{100\%}$	= 0.22 m												
	(FOR ROAD WIDTH w,												
	= 0.04 w)												
<p>STEP 5</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 border="0"> <tr> <td>ROAD WIDTH (m)</td> <td>5.50</td> <td>(w)</td> </tr> <tr> <td>INLET DEPTH</td> <td>1.17 m</td> <td>1.17 m</td> </tr> <tr> <td>DIFFERENCE IN LEVEL +</td> <td>0.22 m</td> <td>0.04 w</td> </tr> <tr> <td>DEPTH AT OUTLET</td> <td><u>1.39 m</u></td> <td>y = (1.17 + 0.04 w)</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	DEPTH AT OUTLET	<u>1.39 m</u>	y = (1.17 + 0.04 w)
ROAD WIDTH (m)	5.50	(w)											
INLET DEPTH	1.17 m	1.17 m											
DIFFERENCE IN LEVEL +	0.22 m	0.04 w											
DEPTH AT OUTLET	<u>1.39 m</u>	y = (1.17 + 0.04 w)											

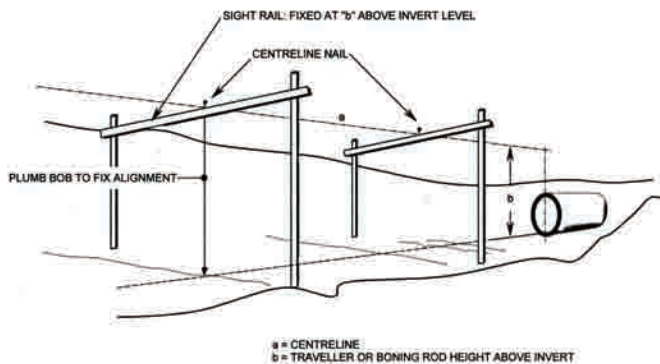
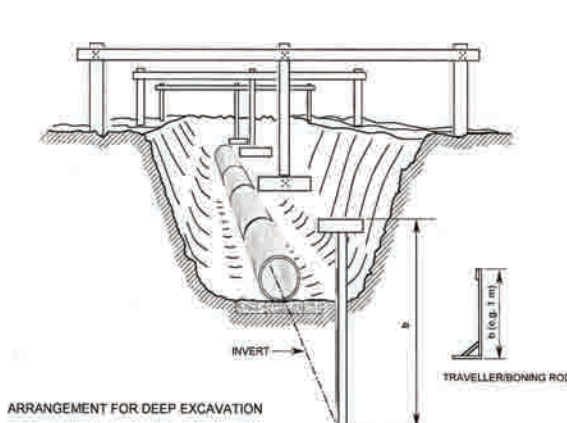
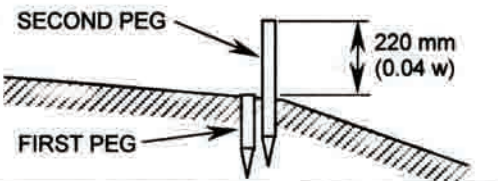
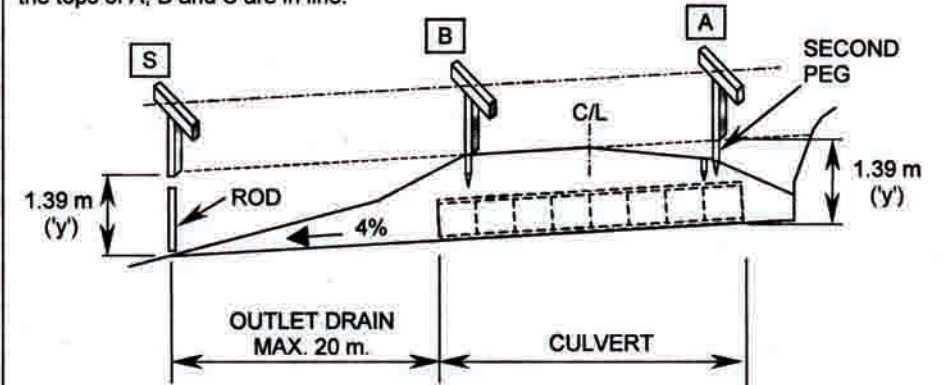


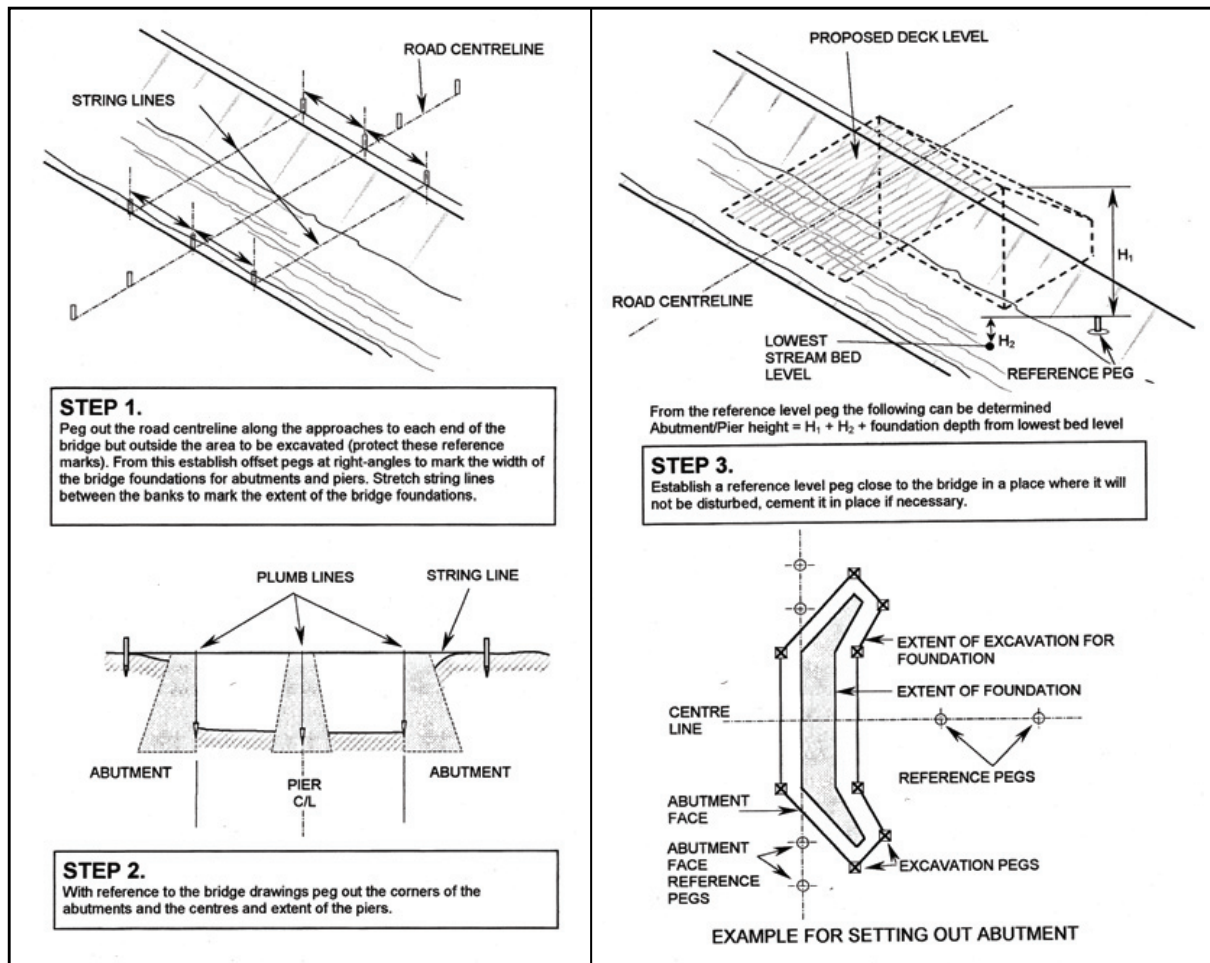
Figure 9.7 Setting out culvert profiles

PROCEDURE STEP BY STEP	EXAMPLE/EXPLANATION
<p>STEP 6</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>STEP 7</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 Arrangement C. (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>STEP 8</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 Arrangement 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>	

- NOTE:**
1. Where pipes will be bedded on imported material, excavation levels will have to be lowered by the thickness of bedding material.
 2. For 900 mm \varnothing culverts the dimension in step 3 is increased to $1.05 + 0.70 = 1.75$ m. In step 5 the depth at outlet will be 1.97 m ($1.75 + 0.04 w$).

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).



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.

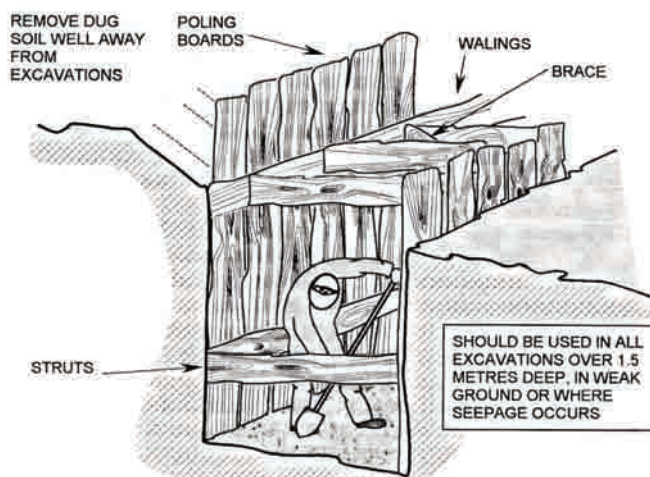


Figure 9.8 Safety issues

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).

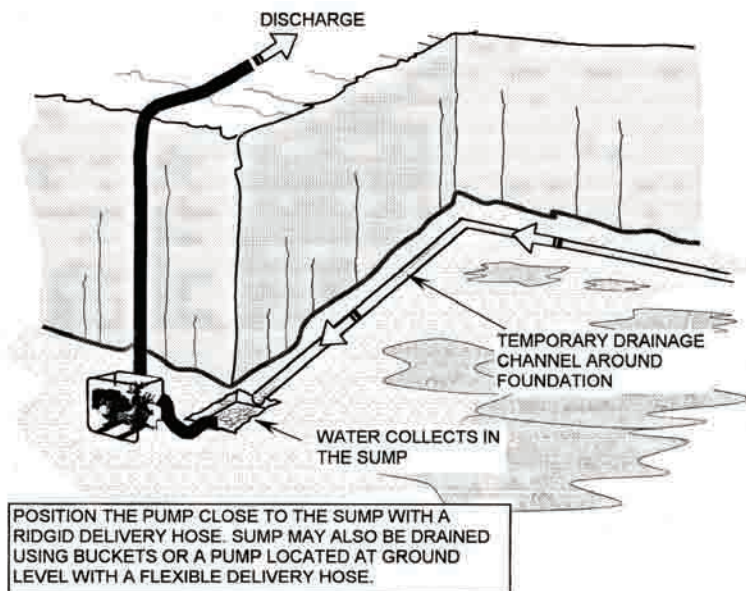


Figure 9.9 Pumping arrangements

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).

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.

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.

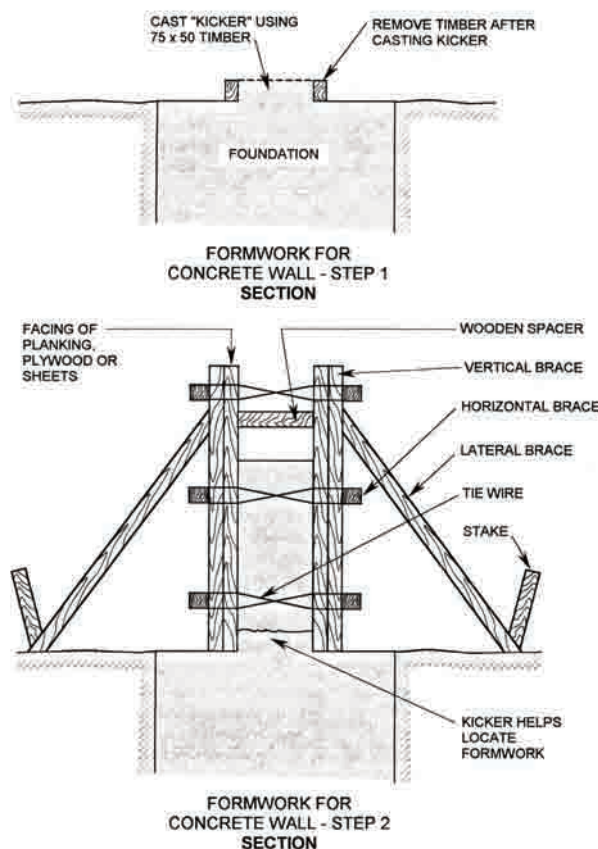
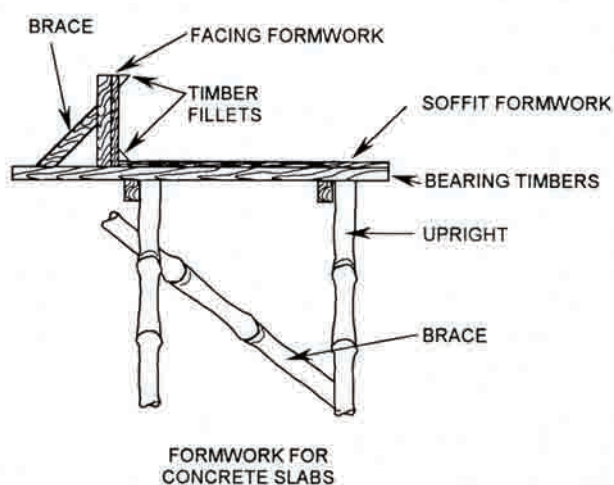


Figure 9.9 Formwork should be coated with mould oil to allow easy striking of formwork after the concrete has set. Linseed oil, old engine oil or other cheaply available oils may be suitable for this.

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

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.

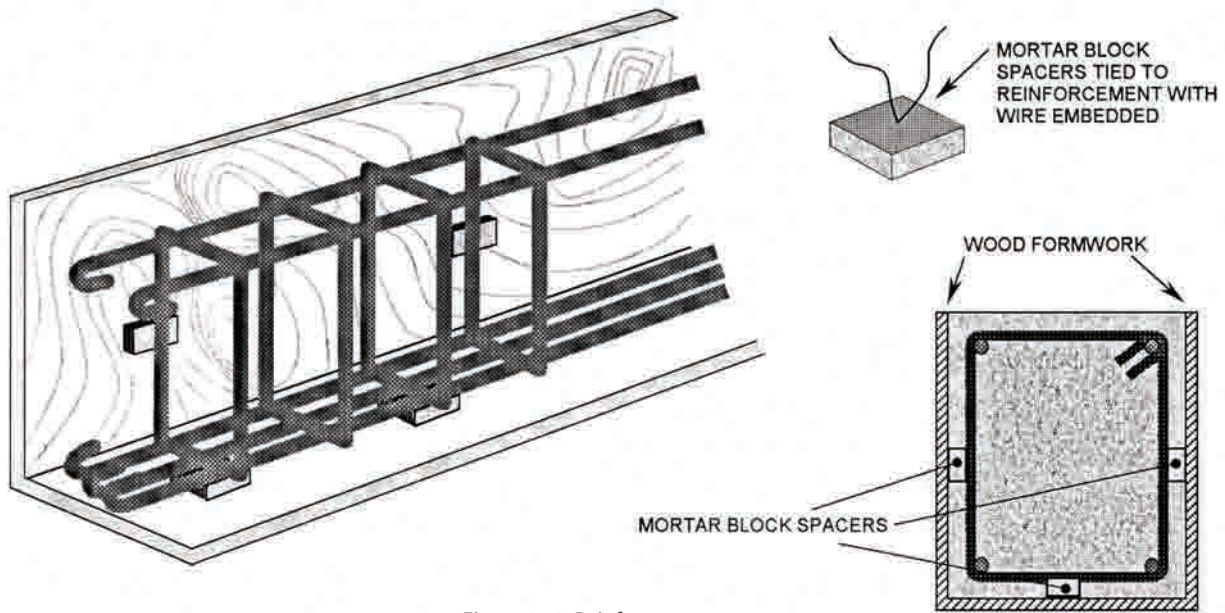


Figure 9.10 Reinforcement spacers

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.

CONCRETE CAN BE BATCHED BY VOLUME.
GAUGE BOXES MADE FROM STEEL, WOOD OR PLYWOOD ARE USED FOR THIS.

BOX DIMENSIONS - INSIDE MEASUREMENTS

LENGTH = 400 mm, WIDTH = 300 mm, HEIGHT = 300 mm

VOLUME

0.036 m³ OR 36 LITRES

36 LITRES ARE EQUAL TO 1 (50 kg) BAG OF CEMENT

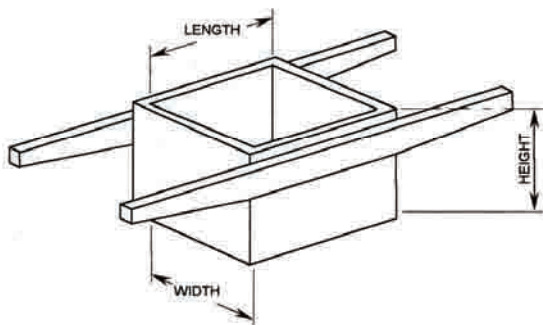


Figure 9.11 Batch box

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.

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 0.036m³.

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.

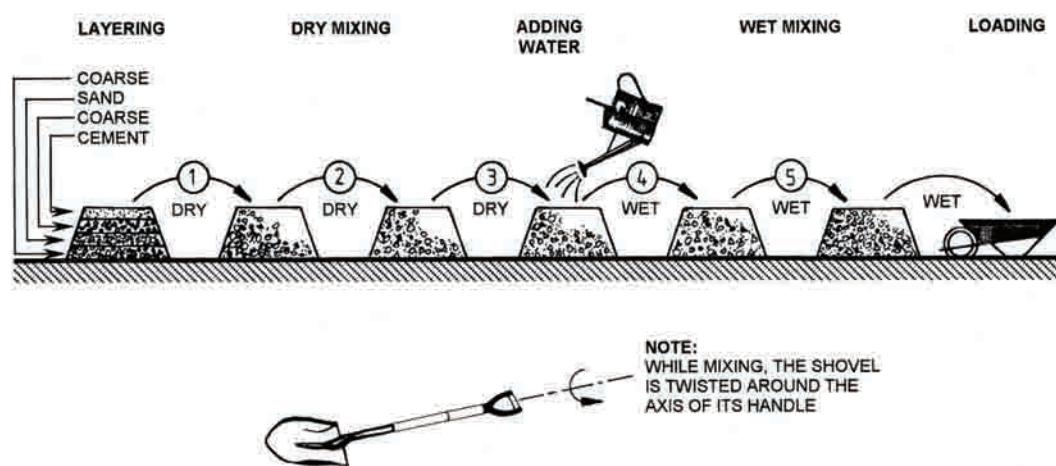


Figure 9.12 Concrete hand mixing

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 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.



Figure 9.13 Timber stave culvert

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.

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

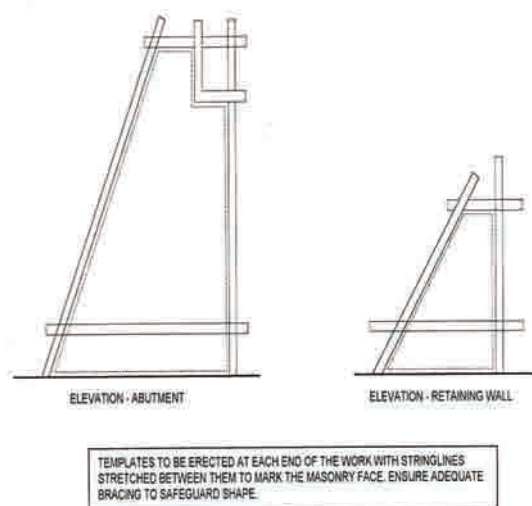


Figure 9.14 Templates

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

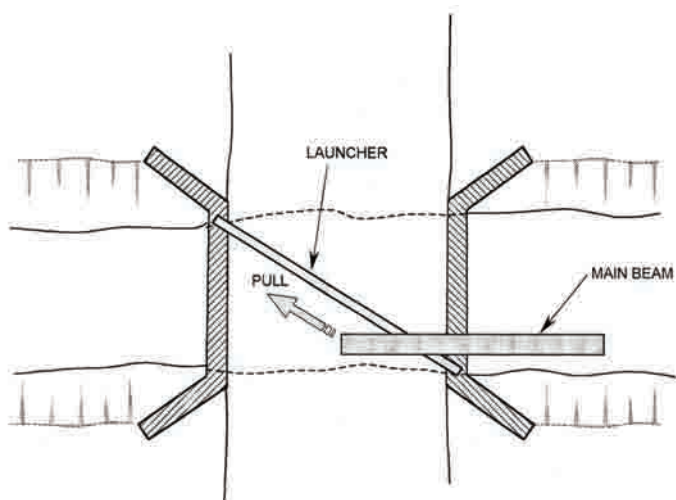


Figure 9.15 Timber beam launching

and alignment. String lines can then be stretched between the initial work to guide and ensure smooth faces and coursing of the subsequent work.

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.

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 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.

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

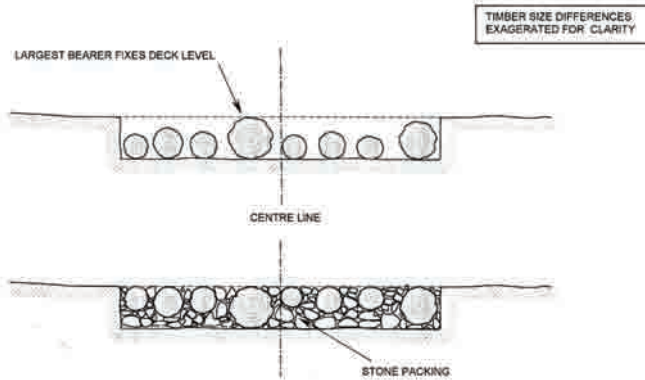


Figure 9.16 Log packing

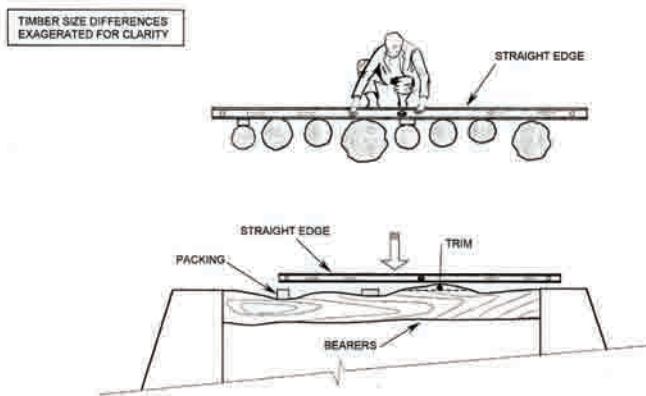


Figure 9.17 Fixing deck timbers

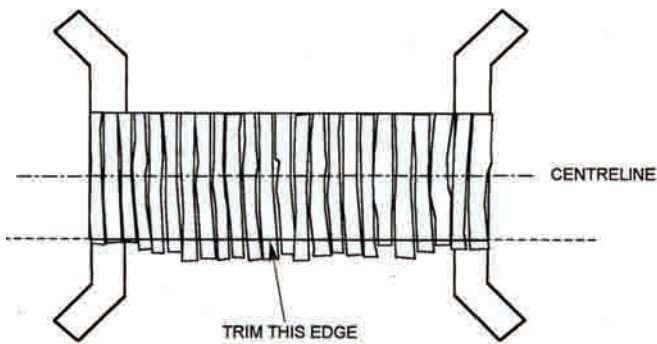


Figure 9.18 Trimming running boards

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.

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.

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.

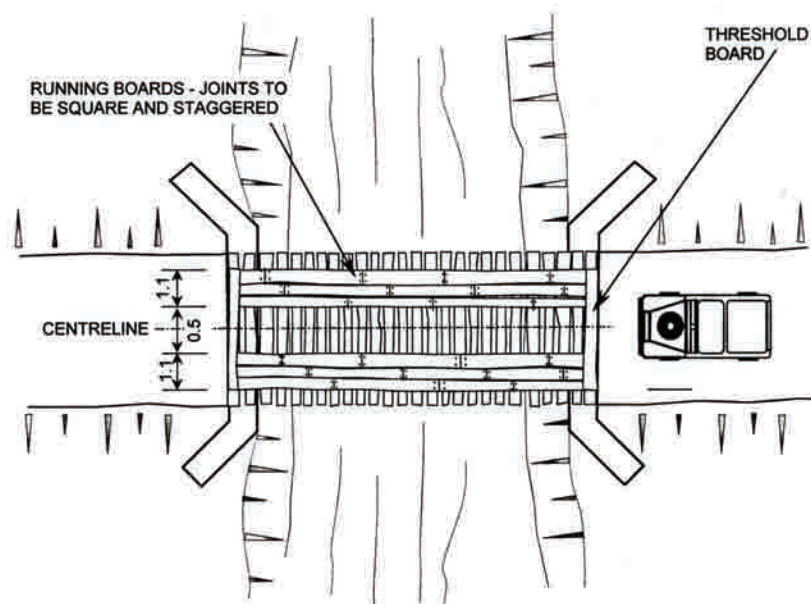


Figure 9.19 Kerb timber fixing

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.

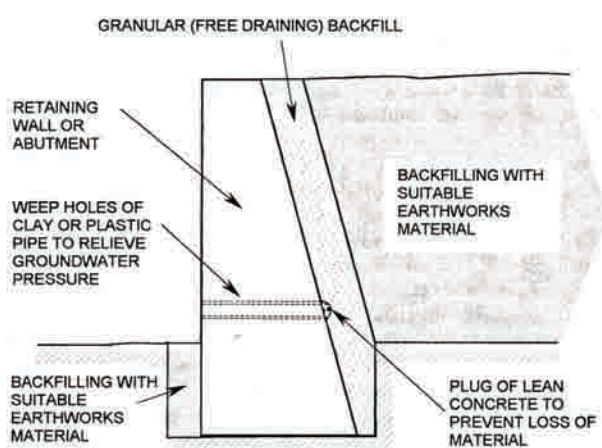


Figure 9.20 Backfilling

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.

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 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
 - sweeping.
 - de-silting.
 - unblocking
 - 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:
 - structural timber decay, splitting or insect attack
 - bulging masonry
 - cracked concrete or masonry
 - honeycombed concrete
 - spalling concrete
 - serious rust or chemical stains
 - exposed or corroding reinforcement or pre-stressing steel
 - damp patches on the concrete
 - seriously corroded structural steelwork
 - damaged/distorted structural steelwork
 - loose structural rivets, bolts or other fixings
 - cracks in structural steelwork
 - settlement of deck, piers, abutments or wingwalls
 - expansion joint or bearing defects
 - erosion requiring piling works

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

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.



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 manual. 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

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

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

(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 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.

TRL, 1988, Bridge Inspectors Handbook Vol. 1 & 2, (ORN7), Transport Research Laboratory, Crowthorne, UK

(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.

TRL, 1992, A Design Manual for Small Bridges, (ORN9), Transport Research Laboratory, Crowthorne, UK

(Bridges, Culverts, Design, Hydraulics, Drifts, Materials, Maintenance, Erosion Protection, Site Construction) pp223

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 are discussed in the manual are appropriate for relatively large roads or traffic flows and predominantly utilise reinforced concrete.

TRL, 1997, Principles of Low Cost Road Engineering in Mountainous Areas (ORN16), Transport Research Laboratory, Crowthorne, UK

(Culverts, Environmental, Erosion Protection, Slope Stability) pp150

This manual describes and explains techniques for designing, constructing and maintaining roads in mountainous areas. It contains sections on drainage and retaining walls as well as methods to control erosion and maintain slope stability.

Tufnell R, 1995, Dry Stone Causeways, Appropriate Technology Vol. 22 No. 1, IT Publications, London

(Drifts, Materials) pp3

This article explains in simple practical terms, with sketches, how to build a masonry causeway or vented ford.

Watkins L and Fiddes D, Highway and Urban Hydrology in the Tropics, Pentech Press, London

Selected publishers' addresses:**Austroads**

Suite 2, Level 9, 287 Elisabeth St, Sydney, NSW 2000, Australia
Fax: +02 264 1657, www.austroads.com.au/

Global Transport Knowledge Partnership (gTKP)

Chemin de Blandonnet 2, 1214 Vernier, Genève, Switzerland, www.gtkp.com

Hydraulics Research

Hydraulics Research Station Ltd, Wallingford, Oxfordshire, UK, www.hrwallingford.co.uk

International Labour Organisation (ILO)

4 route des Morillons, Geneva, CH 1211, Switzerland, 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

Institution of Agricultural Engineers:

The Bullock Building, University Way, Cranfield, Bedford, MK43 0GH, UK, www.iagre.org

Institution of Civil Engineers (ICE)

1 Great George St, Westminster, London, SW1A 3AA, UK, www.ice.org.uk

Intermediate Technology Publications / Practical Action Publishing

The Schumacher Centre for Technology & Development, Bourton on Dunsmore, Rugby, Warwickshire CV23 9QZ, United Kingdom, www.practicalactionpublishing.org/publishing

Natural Resources Institute (NRI)

University of Greenwich at Medway, Central Avenue, Chatham Maritime, Kent, ME4 4TB, United Kingdom, www.nri.org

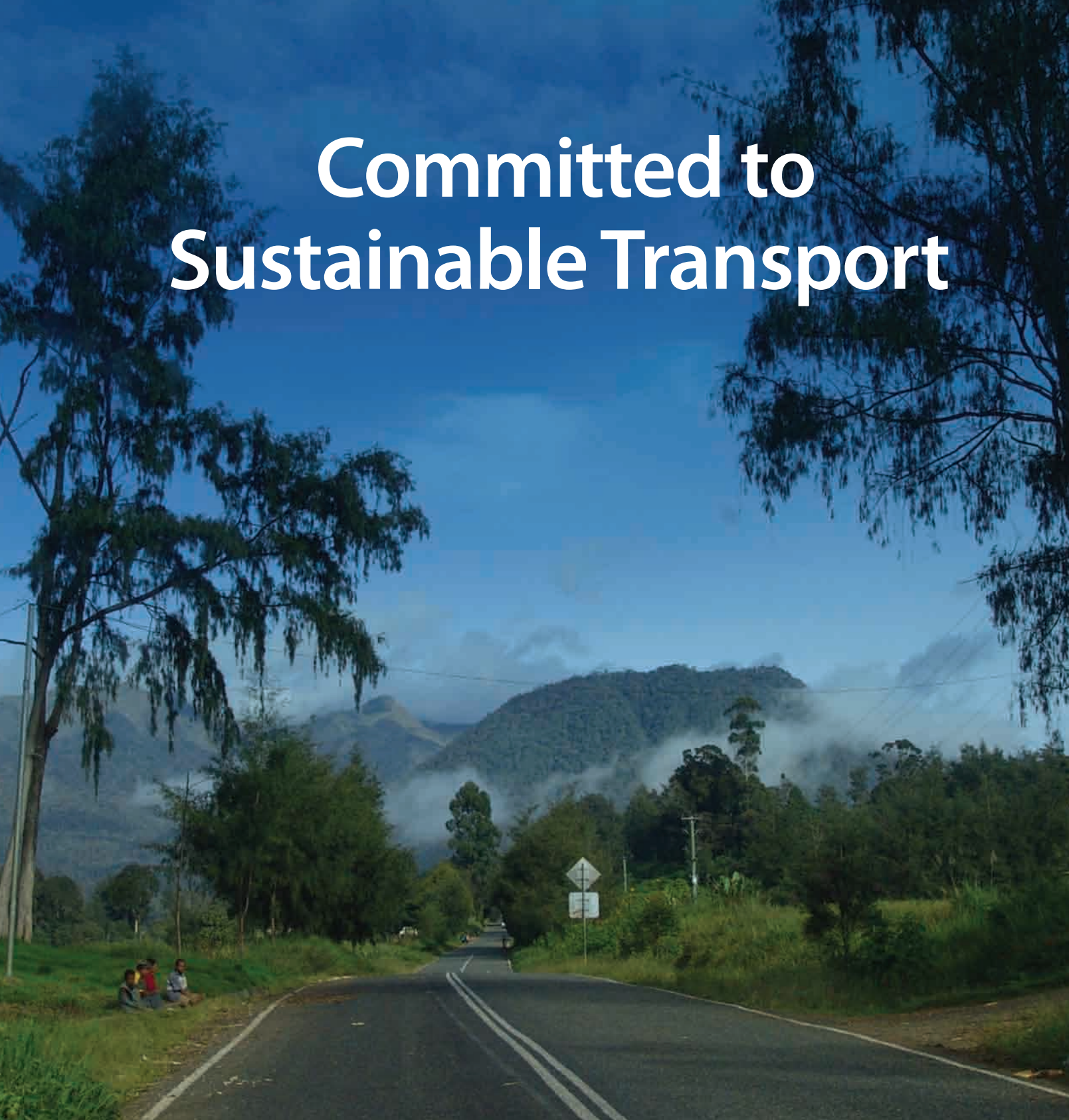
Transportation Research Board (TRB)

The National Academies, 500 Fifth Street, NW, Washington, DC 2000, USA, www.trb.org

Transport Research Laboratory (TRL)

Crowthorne House, Nine Mile Ride, Wokingham, Berkshire, RG40 3GA, United Kingdom, www.trl.co.uk

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