Volume-1
Planning & Initial Design

Small Structures for Rural Roads

A Practical Planning, Design, Construction & Maintenance Guide

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English Version, May 2010

gTKP
global Transport Knowledge Partnership
committed to sustainable transport

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

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Glossary

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

Abutment	The support for each end of a bridge deck that also retains the material forming the approach embankments.
Aggregate	Stone, sand, gravel or other inert material forming the major constituent of concrete. Fine aggregate is less than about 5mm in diameter, coarse aggregate is greater than about 5mm in diameter.
Approach Embankments	The earthworks that carry a road to a bridge, culvert or other structure
Apron	The flat area at the inlet and outlet of a culvert or the area of the watercourse bed which is protected downstream of a structure.
Arch bridge	A structure consisting of a curved beam spanning between the abutments, which may support a road over a watercourse, rail line or other road.
Barrel	1. The main part of an arch which supports fill material or masonry superstructure. 2. The pipe or box part of a culvert which carries the flow of water.
Bearing	A connection between a bridge deck and abutment or pier that allows differential movement between the deck and supports.
Bill of Quantities	A list of all construction activities (materials, labour, supervision, transport, etc.) and other measures and requirements necessary to build a structure, which enables a total cost of the structure to be calculated through the application of quantities and unit rates.
Bio-engineering	The use of vegetation in engineering design to protect natural terrain and man-made structures from the problems associated with soil erosion.
Block(s)	Blocks are uniformly sized masonry units, normally made from aggregates and cement and designed to satisfy standards requiring a minimum crushing strength.
BoQ	See Bill of Quantities.
Brick(s)	A rectangular masonry unit made of baked clay or sand/cement, for example with dimensions 225 x 112.5 x 75mm.
Bridge	A structure with a span of 3 metres or more which permits the crossing of a watercourse (or another road or railway etc.) consisting of abutments and a deck. Bridges may also have wingwalls, approach embankments and pier(s). [This guideline considers bridges with spans up to 10m].

Camber	A slope across the width of the road to ensure water drains off the carriageway.
Carriageway	The part of the road that is normally driven over by vehicles.
Catchment area	The area drained by a watercourse.
Causeway	Similar to a vented drift. Causeways tend to be longer than vented drifts and have a larger number of openings.
Cement	A grey powdered substance, usually derived from processed limestone, which when mixed with water sets and hardens to form the binder in concrete.
Cofferdam	A temporary dam to exclude water from a submerged area allowing construction or maintenance work to be carried out.
Concrete	A manmade material which has similar properties to stone and is made from cement, aggregates and water.
Contours	Lines on a map which join points of the same altitude.
Cover	1. The thickness of fill material between the top of a culvert pipe or arch and the road surface. 2. The thickness of concrete between its outside face and a reinforcement bar.
Culvert	A structure which allows water to flow under a road. Culverts are usually up to 1.2m in diameter and may be round, square or arched.
Dead load	The weight of a structure including any items fixed to it.
Debris rack / grill	An open structure built upstream of a culvert, drift or bridge to collect debris (e.g. driftwood) and thereby prevent clogging of the road structure.
Deck	A part of a bridge which spans between abutments or piers and is driven on by traffic.
Design flood	The discharge of water used to calculate the size of a bridge or culvert opening. The design flood is normally based on an estimated probability of occurrence at a certain return period.
Dia	Diameter
Discharge	The amount of water which flows past a point in a watercourse in a given time.
Downstream protection	Engineering work carried out in a watercourse to prevent scour or erosion.
Dressed (stone)	Stone that has been shaped into rectangular blocks.
Drift	A simple structure, constructed from local or imported materials, which provides vehicles with a firm surface to drive through a watercourse.

Embankment	Compacted earth which supports a road above the normal ground level.
Falsework	Temporary boards or sheets and other materials used to support the underside of a concrete structure during hardening e.g. on the deck of a bridge. See *Formwork*
Ford	See *Drift*
Formwork	1. Temporary boards or sheets and other materials used to contain concrete and produce its final shape during hardening. 2. Temporary boards or sheets used to provide support and give arches their shape during construction. See *Falsework*
Foundation	The lowest part of a structure on which the rest of the structure is supported. Foundations are usually under the ground.
Gabion	Stone filled steel wire or mesh cage. Gabions can be used for retaining walls, abutments, downstream protection and drifts.
Headwall	A wall at each end of a culvert pipe used to retain the road formation.
High flood	The highest flood level that is known to have occurred in a watercourse.
IMT	Intermediate Means of Transport (e.g. bicycles, motorcycles, carts)
Invert	The floor of a culvert or channel.
Invert slab	See *drift*.
Irish bridge	See *drift*.
Kerb	A hard edge to a road that stands up above the level of the carriageway.
Large bore culvert	A culvert with a diameter of greater than 1metre.
Live load	A temporary load on a structure e.g. pedestrian or vehicle.
Low level water crossing	*Drift, splash, causeway, Irish bridge* or *(vented) ford.*
m	metre
mm	millimetre
m^3/s	cubic metres per second
Masonry	A generic term used to describe the following materials; *bricks, blocks, dressed stone, random stone, rubble.*

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

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

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

1. Introduction

Why is this Guideline needed ?

Access is a universal need, and transport facilities of various kinds are essential to the achievement of both economic development and social welfare. Although roads are only part of the solution to the transport problem in developing countries, at least a basic road network is vital to:

- enable goods and services to be delivered efficiently to their users
- enable buses, taxis, private cars, motorcycles, bicycles and other vehicles to move people from their homes to places of work, public facilities and market places
- allow national social services to be delivered throughout the country
- allow social interaction in and between communities
- promote agriculture, industry and trade, leading to economic growth

Many rural roads are normally passable for maybe 95% of their length but may then turn into an impassable quagmire for the remaining 5% where they are crossed by watercourses or at low points in the alignment. Drainage and water crossing structures form a major part of the construction cost of a road which, depending on the topography, may account for up to 40% of the total cost. Once a road has been constructed the passability and maintenance cost are closely linked to the quality of the cross drainage provision for the road.

It is clear that road structures are an important aspect of road design and construction. Unfortunately it is an aspect that is often given little or insufficient attention which is shown by the fact that when roads become impassable it is usually where they cross a watercourse. Although the length of road structures forms only a very small fraction of the total road length the time spent on their design must be a much greater portion of the total planning process.

There are many guidelines and codes for the design and construction of large structures using concrete and steel, these include the widely recognized medium bridge design guidance included in TRL Overseas Road Note 9. However, little guidance is available concerning small structures, particularly with respect to the optimum use of resources such as labour, local skills (which may include masonry and carpentry) and local materials and small enterprises, yet still achieving durable and adequate structures. Intelligent use of these resources will often produce the lowest cost structures. It is certainly inadvisable to blindly apply standards, practices and 'rules of thumb' derived from rich economies for use in developing countries where the balance of influential factors such as labour wage rates, availability and cost of standard materials and equipment, skills, access to finance and the support environment can be very different.

Similarly there are many guidelines which deal with design, construction and maintenance of low cost roads, but each one has only a short section on structures. This guideline aims particularly to satisfy this need to assist engineers and technicians in the planning and provision of road structures by:

- providing concise and complete information in one document
- explaining the steps required in the design process
- providing different levels of information depending on the structure's complexity
- providing guidance on costing, construction and maintenance of structures
- assisting in the approval and adoption of low cost structural designs

The lack of access for designers and planners to design information and other resources requires this guideline to provide all the basic information needed in the design of low cost structures. References are provided at the end of Volume 1 and 2 for more complex structures or problems, where these issues were considered outside of the scope and objectives of the guideline.

The guideline has been written as a design guide, to complement existing national design codes and standards from the relevant Ministry or Roads Department. However, experience has shown that in many areas national design standards are not applicable to or are not yet developed for the small structures covered by this guideline. It is therefore envisaged that this document will be recognised by road authorities as a useful tool and that, by following the advice and information contained in the guide, engineers and technicians will be able to design, construct and maintain affordable and acceptable structures. It is also intended that the guideline will assist in the process of establishing more comprehensive and appropriate planning, design, construction and maintenance procedures and practices.

Investigations and fieldwork have shown that steps in the design process are often missed or neglected. The guideline therefore explains the steps that should be carried out and the reasons for undertaking them. It also explains the type and detail of data that are required and how they should be used in order to undertake a design.

The gTKP Small Structures for Rural Roads Guideline (SSRRG) is also intended to complement the gTKP Low Cost Road Surfacing Guideline (LCRSG) to provide the practical tools for planning, designing, constructing and maintaining affordable Basic Access to the more than 1 billion people currently estimated globally by the World Bank to lack the essential transport services and infrastructure to actively take part in social and economic development.

What is a small road structure?

For the context of this guideline a road structure is a construction which provides support and/or drainage to the road carriageway or associated road works. Roads form a barrier to the natural drainage of surface water from the surrounding land into streams, lakes and rivers. In the absence of any control arrangements the water would find its own way across the road, resulting in gullies and washouts along the road. An effective drainage system is therefore the most important part of a low cost road and should protect the road from damage due to water. The most basic drainage provision is the camber of the road carriageway which directs water off the road to each side. Water is then removed from the road by the side and mitre (turn-out) drains. In some cases it may be necessary for water to be moved across the road, at a low point in the alignment or at a stream, for example. As quantities of runoff water build up in the side drains, at low points in the alignment or at watercourses, it will be necessary to allow water to cross from the high side of the road to the lower. This guideline deals with the road structures required to manage the drainage of water across a road.

Scope of the Guideline

The scope of the guideline includes:

Rural / Urban Roads

Although the guideline primarily discusses issues associated with the design and construction of structures on rural roads, many of the ideas and design factors discussed are applicable to urban and peri-urban roads. In these cases it will be necessary to consider pedestrian issues in more detail. Existing built infrastructure and planned development can also influence options with regard to the siting, type, size and ancillary works associated with structures design.

Paved / Unpaved Roads

The majority of low volume roads will be unpaved. However, many of the structures discussed in this guideline will also be suitable for low volume paved roads. Roads may initially be built to earth or gravel surface standard and then upgraded by spot improvements or comprehensive paving to partial or fully sealed roads at a later date. Road structures designed and constructed with reference to this guideline will be suitable for paved roads provided that possible increased loadings and higher design standards such as roadway widths are satisfied.

Structural Assessment

Although this document is primarily a design guide, principally dealing with the design and construction of road structures, it may also serve as a useful reference for the assessment and maintenance of existing structures. As assessment is a check of an existing design, the guideline is able to highlight structural aspects which should be checked during an inspection and assessment under an appropriate asset management and maintenance regime.

Reconstruction / Construction / Maintenance

The guideline primarily deals with new structures; however, the design principles are the same for reconstruction, rehabilitation, extension and upgrading of existing structures. In these cases it may be possible to make use of elements of existing structures, for example, using an old drift slab as downstream protection for a new piped drift built adjacent to the existing structure. The guideline deals with the construction aspects of structures which are of interest to supervisors and engineers. The construction chapter in Volume 2 concentrates on the management and supervision of the construction that must be undertaken by the field officer/engineer overseeing the project.

Better Use of Local Resources

Adoption of the recommendations in this guideline will increase the use of local material and labour resources. This will help to relieve the constraints that road authorities face due to a shortage of funding and may allow a foreign exchange saving as fewer materials may have to be imported. The increased use of local labour will assist in stimulating the local economy and greatly reduce the mobilisation costs of road construction. The maintainability of structures will also be improved as the skills required will be established during the construction phase within the local community.

Unskilled and semi-skilled labour could be utilised for a range of tasks in the construction of road structures, such as timber growing preparation and formwork, quarrying dressing and crushing stone, fired clay brick production, local transport, masonry and brickwork in structures, retaining walls, ditch linings and culverts, collection and preparation of river gravel for structural fill, and construction of components such as gabion baskets. The creation of jobs in the area will not only provide financial uplift but will also allow the development of skills. This skills transfer will have three benefits. Firstly, there will be the capacity in the local community to undertake maintenance on the structures. Secondly, there will be an increase in employment opportunities in other construction sectors for the labourers employed on the road works. Thirdly, studies have also shown the employment generation multiplier effect of jobs created on rural infrastructure works.

Structure Types

The guideline covers a wide range of drainage structures from drifts to small bridges (chapter 4 describes the characteristics of these structures.). These structures vary in complexity and are ranked in order of increasing complexity as follows:

1. Drifts
2. Simple culverts
3. Vented fords
4. Large bore culverts
5. Small bridges

It is difficult to define the boundaries between the categories above: for example, when does a large bore culvert become an arched bridge? The background information, site data and technical knowledge and support required to undertake the design also vary significantly. The guideline therefore addresses the information required for more complex structures but also indicates the reduced level of survey and technical knowledge required to design more simple structures. There are other road structures which are not covered in this guideline, such as large bridges and viaducts. Similarly street furniture, which may include street lights, signs and safety barriers, is adequately covered by other documents, and therefore not mentioned further here.

The guideline does not cover steel girder or lattice frame structures. These structures require specialist design and erection expertise. Neither does the guideline cover steel Bailey bridges etc. Bailey bridges are a temporary steel structure that can be erected at short notice from panels that would normally be held in a store.

Figure 1.1 Steel lattice bridge for motorcycle traffic

Figure 1.2 Bailey Bridge

Such structures are suitable for short term measures where an unforeseen flood disrupts access at a critical location. The Bailey bridge can also be readily dismantled and the units returned to store once a permanent solution has been constructed on the access alignment.

The first volume of the guideline covers planning and initial design assessment of structures. The second volume focuses on detailed design, construction and maintenance. The third volume of the guideline contains some standard designs of low cost structures. The fourth volume contains the designs in A3 format. It is hoped that standardising these designs which have been independently checked technically, will result in:

- reduced design costs and economies of scale, leading to an improvement in cost and quality;
- increased speed of construction, as labourers, supervisors and engineers will become more familiar with the standardised design;
- simplified approval procedures.

Target Audience

The guideline is aimed principally at private contractors and consultants, local government highway/ road departments and other organisations involved in infrastructure provision. It will also be of interest to policy and decision makers, infrastructure managers and financiers in the private sector, government, non-government organisations and development agencies working in developing countries and economies in transition. Its layout is geared towards educated readers but does not assume any formal engineering training. The guideline aims to offer all the engineering background which will be required to make the necessary decisions from planning and assessment, the choice of appropriate structural design and construction method through to maintenance of the structure.

Role of Guideline for:

Designers/Field Engineers/Technicians - The guideline is primarily aimed at field engineers and technicians who are directly involved in the selection, design and construction of road structures. The guideline should assist them to select and design the most appropriate structure, and highlight important aspects of construction and maintenance supervision. The guideline should assist those responsible for setting standards, specifications and procedures to introduce more appropriate and lower cost solutions under demanding and challenging operational environments.

Senior Engineers - The guideline should act as a useful reference guide highlighting alternative design solutions and standards which may be implemented on low volume roads to reduce the cost of road construction and maintenance.

Programme and Project Planners/Policy Makers - The guideline highlights low cost options which may not already have been considered for the rural road network. Many of the solutions can utilise local resource based techniques which may reduce the overall cost of road construction and sustainable rural access.

How to Use this Guideline

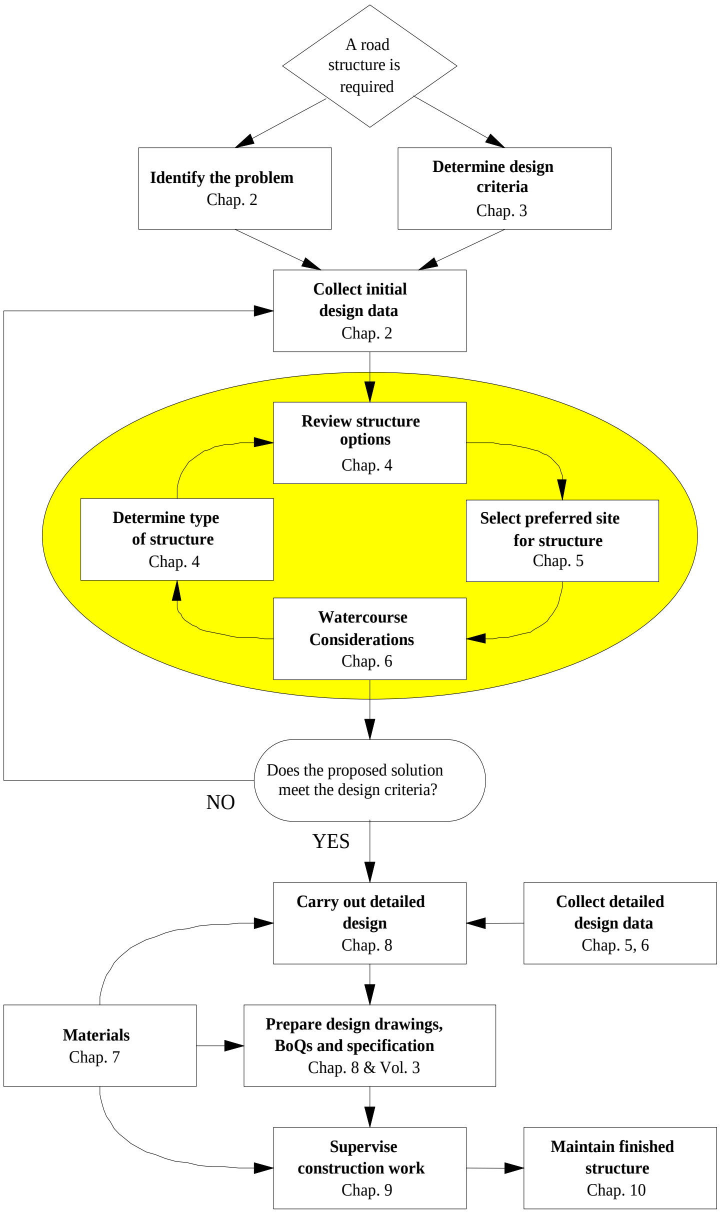


Figure 1.3 Flow diagram of the planning, design and construction process

There is a logical sequence of work that must be undertaken in the selection and design of any road structure. This guideline is laid out in sequence with each chapter covering one aspect of the process shown in the diagram Figure 1.3. The two initial tasks which should be carried out are to identify the problem (chapter 2) and determine the design criteria (chapter 3) for the structure. The initial design data may then be collected (chapter 2) to enable the preliminary design to be carried out. Preliminary design, shaded yellow in the flow diagram, involves four different stages which may be performed a number of times before a design solution is proposed. It is suggested that a review of structural options (chapter 4) is initially undertaken followed by an appraisal of a potential construction site (chapter 5). The water flow characteristics of the watercourse (chapter 6) should then be considered before a selection of the most appropriate structure is made (chapter 4). It is likely that the preliminary design loop will need to be followed a number of times to review different potential structures and construction sites.

Following completion of the preliminary design the proposed design solution should be checked to ensure that it complies with the design criteria. Detailed design of the structure can then be undertaken (chapter 8) which will require further reference to be made to chapters covering site selection and appraisal (chapter 5) and watercourse characteristics (chapter 6). It will also be necessary to review the options for construction materials (chapter 7) that may be available.

Volume 3 of this guideline contains standard design drawings and Bills of Quantities that may be useful and contribute to the preparation of design drawings. Where national specifications do not exist, material specifications may be prepared from information contained in chapter 7. During supervision of the construction work (chapter 9) it will be necessary to ensure materials used in the structure meet and are used according to the specifications. This may require additional reference to the materials chapter. Chapter 10 covers the maintenance requirements of structures after they have been built and highlights the problems that may be encountered if maintenance is not carried out. Depending on the complexity of the structure, the level of work and detail required at each stage will vary. Although each stage of the design process shown in the diagram Figure 1.3 must be covered, it may be possible to skip more detailed issues in each chapter for simple structures such as drifts or culverts. Throughout the subsequent chapters of the guideline there is guidance to indicate which sections may be ignored depending on the type of structure to be built.

Units

There is a wide range of units, metric and imperial, that are associated with structural design. The box below provides some conversion factors:

Area

1 hectare = 10 000 m^2 = 2.47 acres

100 hectares = 1 km^2

1 sq. mile = 2.59 km^2

Pressure or Stress

1 kPa = 1 kN/ m^2

1 N/mm^2 = 1 MN/ m^2

1 ton/in^2 = 15.44 N/ mm^2

1 ton/ft^2 = 107.3 kN/m^2

Velocity

1 m/s = 3.6 km/h

1 m/s = 3.26 ft/s

Length

1 mile = 1.61 km

1 yard = 0.914 m

1 foot = 0.305 m

1 inch = 25.4 mm

Volume

1 m^3 = 35.3 cubic ft

1 m^3/s = 1000 litres/s

k - kilo = x 1000

M - Mega = x 1 000 000

2. Project Planning

Setting Priorities

The approach adopted by this guideline assumes that a road network and the associated structures are the responsibility of an authority. From time to time there will be a requirement for new, rehabilitated or upgraded structures. The approach is also applicable for a 'one-off' initiative to provide, replace or rehabilitate a structure by an authority or community group. It may take many years to construct all the roads and associated structures to all-weather standard required by a community due to the limited financial resources and the capacity of the available equipment and labour. Priorities must therefore be set on the order that work should be undertaken. It may be possible to build a high priority road in the short term, but construct some of the structures at a later date. However, these roads may be seasonally impassable until the structures have been completed. A more pragmatic strategy with limited resources may be to initially provide all of the structures and durable surfacing on problem sections of the route (Basic Access strategy), and provide an engineered earth surface to the remainder of the route until additional resources are available to attain a more durable road surface throughout. This can be termed a stage construction, spot improvement or differential upgrading strategy. In setting priorities the following factors should be taken into account.

General

- Standard - will a low cost drift suffice until resources for a more expensive structure can be mobilised ?
- Reconstruction of a damaged structure may have a higher priority over provision of a new structure in a different location.

District Road Network / Location

- The level of priority given to the road/structure within the road inventory
- The location of the road in relation to other structures/roads. For example, is there an alternative route with an acceptable detour ?
- The requirements of access for construction. Is it necessary to construct a new road or upgrade an existing alignment before work can commence on the structure ?
- Proximity to other work in order to prevent avoidable transportation of equipment etc. over long distances.

For example, if there are 3 potential structures that are required and two are close together while the other is a long distance away. It will be more efficient to construct the two structures that are close together at the same time as labour and equipment can easily be transferred between the two sites. If the programme requires the construction of two structures that are a long distance apart it would be less efficient to move labour and equipment between the two sites as the construction demand varied.

Road Category

- The class of road and hence its strategic importance within the road network.
- The design level of structure required on the road network which will determine the resources and time required for construction.

Work Status

Any work that has already commenced should be given the highest priority for funding in order to be completed so that the benefits of the investment already made will be realised.

Justification

A simple cost benefit analysis and assessment of social benefits can be useful, both to raise the finances and compare the various options to utilise the available resources.

- Need - An assessment of the number of people who will benefit from the construction of the road or structure coupled with the availability of other access in their area. Improved access to important services such as health centres should also be considered.
- Costs - The cost of providing one road or structure should be compared against providing another. For example, if a budget of $15 000 is available would the best option be to construct one structure which costs $15 000 or provide 5 smaller structures around the road network, which only cost $3000 each?

Resource Availability

It will be necessary to make an assessment of the resources (equipment, labour, artisans, supervisors, materials, enterprises) which may be available in the locality. Assessments must also be made for the timeframe required to obtain equipment and materials from other areas. Labour may not be so freely available in agricultural areas at certain times of the year. Specific skills may need to be trained or imported into the locality. It would also be easier to manage if the labour resource requirements were steady rather than increasing and decreasing throughout the year. For many authorities the expected timing of funding availability from internal/external sources (and possible conditionality) is an important consideration.

Climatic factors

In regions which have a pronounced wet and dry season, or occasional flooding, it may only be possible (or much more straightforward) to undertake construction in the dry season. Drifts constructed in seasonal streams would not require the additional cost and time for diverting the water or providing cofferdams if they were built during the dry season.

Assessment of the Problem or Need

In order to set priorities it will be necessary to assess the general condition of the road network, highlighting which roads require improvement and where new or improved structures are required. This assessment should allow the responsible engineers to:

- prioritise construction of structures

- calculate the structures programme budget requirements
- develop work programmes and construction timeframe
- identify resource requirements.

This information can then be collated for senior planning engineers to co-ordinate the overall budget and resource requirements for the whole road network. The basis of this work should be an inventory of all structures (or required structures) on the road network. TRL Overseas Road Note 7 provides guidance on the preparation of these inventories.

It is essential that detailed assessments are undertaken at each structure site as structures form a large percentage of the overall cost of the road infrastructure. Assessments undertaken at sites of proposed structure locations should be sufficiently detailed to ensure:

- Enough time is spent identifying the best location for the structure. (If the road is already built and the structure is being upgraded it may not be possible to identify new crossing sites)
- The appropriate type of structure is chosen
- The structure is adequate for the purpose (traffic type and numbers, water flows and size etc.)
- The design should not need to be significantly changed during construction, as this would result in an increase in the cost of the structure.

Assessment of the Potential Structures

The main issues to be decided during the assessment of new structures are:

- Type of structure - Chapter 4
- Location of the structure - Chapter 5
- Size of structure - Chapter 6

Each of these topics is covered in detail in the chapters shown above.

The assessment may be undertaken for either a new structure or the upgrading of an existing structure. In either case the design work will be similar. There are two main stages to be undertaken in the planning and assessment of potential structures.

Desk Study

- Obtain a map of the area. Ensure that it shows the important features (roads, villages, watercourses and contours)
- Mark the catchment areas on the map and calculate the catchment size for each structure location
- Review the topography of the area.

The desk study should allow the designer to develop an initial idea of the size and possibly type of structure required.

Field Study

- Prepare a sketch map of potential site(s) - plan and x-section
- Field investigations of the soil conditions and strengths (chapter 5)
- Surface exploration - identify soil types in the water course for potential erosion
- Sub surface exploration - trial pits
- Record results in tables or on maps
- Site survey, including water measurements (chapter 6)
- Determine section and gradient near potential sites by surveying the watercourse
- Determine area of the waterway for normal and flood flows
- Check local resource availability
- Cross check information with local community members regarding flood levels, frequency and duration.

The value of consulting with the local community should not be underestimated, particularly with regard to levels and frequency of flooding, and waterborne debris etc. Also in generally flat terrain their knowledge of the extent and direction of flood flows is valuable. They should be able to inform regarding local materials and labour/skills resources and any seasonal accessibility problems. The consultation opportunity should also be used to listen to any concerns and allay fears regarding the potential effects or impact of any new or rehabilitated structure.

Synthesis of data

By consulting chapters in this guideline and referring to collected data an appropriate design can be proposed for the structure.

Collection of Initial Design Data

The collection of the initial design data will affect the primary choice of structure. This design data should be gathered during the desk and field studies. The tables below show the range of data that can be collected in the assessment of the potential structure, which is discussed in more detail in the following chapters. It will not be necessary to collect all the data for the more simple structures. Some of the data may also be collected on a further visit during more detailed survey of the selected structure site.

Local Resources

1. Labour
    - Is there an availability of trade skills in locality e.g. carpentry, stone masons?
    - What is the standard of workmanship available?
    - Options of:
        - Specialist skills vs. training local labour
        - Time/cost vs. skills transfer and ongoing maintenance potential
        - Labour wage rates

2. Materials (chapter 7)
    - What is the availability of local materials e.g. masonry stone (rough/dressed), timber, locally manufactured brick and blockwork ?
    - What is the strength, quality, durability and quantity of local materials?
    - Steel: what are the imported and delivery costs to site, delays, welding, bending and fixing skills available ?
    - Cement: what are the strengths achievable, delivery/ import delays, types of concrete and experience, quality control and possible testing arrangements?
    - What are the unit costs of materials?

3 Equipment
    - What basic specialist equipment is available / would be required for construction AND maintenance (transport, production, loading unloading, mixing, placing, craneage etc.?)
    - What are the costs of equipment (including transport and servicing costs) ?

Design Criteria (chapter 3)

1. General
    - What is the reliability of collected data ?
    - Is a separate structure needed to allow work to commence further along the road ?
    - What will be the cost for construction AND maintenance ?
    - Do pedestrians, animals or IMTs frequently travel along the road ?

2. Vehicle Traffic
    - What is the class of road ?
    - Are local standards established for structures on this category of road?
    - What is the largest type of vehicle that uses the road ?
    - Does vehicle and axle load data exist ?
    - If funds are severely constrained, is a one lane, alternate traffic flow option feasible?
    - What is the traffic density, does it vary e.g. seasonally or on market days in the local town or village ? Review standards used elsewhere & recommend appropriate ones.
    - Will vehicle size or loading increase if the road or structure is improved (new or re-routed traffic) ?
    - Are any exceptional loads transported? - check for logging, quarries or other industries in the area.
    - What are the possible traffic, economic and safety implications ?

Type of Structure (chapter 4)

1. General
    - Which types of structure would be acceptable ?

2. Existing Structure
    - What is the general condition of the structure ?

- What was the original design life ?
- Do as-built records exist ?
- Are there indications of maximum flood levels on structure ?
- Are there any signs of post construction settlement ?
- What are the main problems with the existing structure ?
- Are there failures in any of the structural elements ?
- What is the current level of scour around structure ?
- Indications of excessive loading or abuse ?
- Dimensions and any possibility of refurbishment or adaptation ?

Site Selection (chapter 5)

1. General
    - Is the depth to firm strata or rock known ?
    - What type of material is available to build on for foundations ?
    - What is the level of the water table ?
    - What is the compressibility or strength of subsoil ?
    - What is the best location of trial pits - to provide the most valuable information ?
    - Is the water/soil chemistry aggressive to building materials ? (specialist advice may be required)

Water Parameters (chapter 6)

1. Watercourse Details
    - Is the stream perennial or seasonal ?
    - What is the type of watercourse ? (meandering, straight, bends, presence of weeds)
    - Is the watercourse and bed stable, e.g. in rock?
    - What is the low water level ?
    - What are the minimum or normal flow levels ?
    - What are the maximum flood levels (MFL) ? (frequency of occurrence and duration)
    - What are the watercourse cross sections at potential site ?
    - What is the gradient of watercourse upstream and downstream of the crossing point ?
    - Is there evidence of course/bank or level changes, erosion/deposition at the site, upstream or downstream? Consult with old maps and the community
    - Is there sometimes floating debris in the water?
    - What is the water velocity during floods?
    - What is the longitudinal section or profile along the watercourse ? Is the watercourse used for private or commercial traffic with headroom requirements ?

2. Catchment Details
    - Area of catchment ?
    - Are sudden floods encountered ?
    - Shape of catchment ?

- Gradient of terrain ?
- Permeability of soil ?
- Vegetation coverage and type ?
- Rainfall intensity ?
- Is the vegetation coverage changing rapidly e.g. Deforestation ?

The amount of information required will depend on the complexity and type of structure chosen. The following chapters of the guideline highlight the level of information required and assist in selecting the most appropriate design for the structure.

- Type - covered in chapter 4
- Location - covered in chapter 5
- Size - covered in chapter 6

The importance of collecting accurate information cannot be over emphasised. Although it may prove difficult to collect the required data it is not good practice to make superficial or un-supported assumptions as this will almost invariably result in higher costs due either to additional resources being required to amend the design during construction or the structure being unfit for its purpose.

Field Assessment Practicalities

To undertake a survey of a new road or site for a structure it is usually necessary to have the following equipment:

- vehicle - with an odometer
- map of the road network
- note book
- tape measure
- ranging rods
- graduated line and weight for measuring water depths
- hammer, nails, wooden stakes and paint for site survey marks
- Abney level (or simple survey level) and survey staff (only required for bridges)
- camera (optional - may be useful for recording potential sites for reference in design office)
- shovel and pickaxe/mattock for trial holes
- materials sample bags
- container for water samples
- Dynamic Cone Penetrometer (DCP) for soil strength assessment (desirable)
- water craft for deep water site

It is likely that more complex structures will require a second or even third site visit in order to collect the necessary detailed information required. These visits will probably require additional survey equipment to determine more accurate levels. Information about land use will also need to be collected from the whole catchment area upstream of the potential construction site.

Always ask the question: What is the contribution of the information to the design process ?

Following initial field investigations along a potential route or rehabilitation/ improvement of an existing route, the field engineer should compile a table of the structural works which may be required. This table can be used to assess the physical resources and financial costs required to provide the structures. It can also be utilised in assessing priorities and determining work plans for construction units.

The actual costs of structures will vary according to local resource costs and factors. The benefits of keeping a database of actual and estimated construction costs cannot be overemphasised. Because of the many factors that influence local costs and construction practices it is highly risky to transfer unit cost knowledge from one location to another, and most certainly between regions and countries. There is no substitute for careful consideration of all local cost components and variables.

Example Structures Survey Format

Date:	Road From -To:									Surveyed by:				
		Existing Structures & Reference Points								Preliminary Survey Recommendations				
N°	Chainage	Type	Principal Material	Culvert Length* or bridge width* (m)	Culvert/ Bridge span (m)	Diameter/Height: Pipe Diam. (mm)	Diameter/Height: Height (m)	Structural Condition	Remarks	Culvert Length* or bridge width* (m)	Culvert/ Bridge span (m)	Diameter/ Height: Pipe Diam. (mm)	Diameter/ Height: Height (m)	Proposed solutions
1	0+260	PC	RC	6.00	0.60	1Ø600	0.60	Good	Silted					Remove soil and debris. Check + survey outlet conditions
2	0+477	PC	RC	6.50	1.00	2Ø1000	1.00	Fair	Erosion base slab at RHS					Repair Base Slab
3	1+111	Bridge	RC	5.50	4.60	-	2.30	Good						No work required
4	1+864	Drift	Masonry	5.50	12.50	-	-	Fair	Erosion on LHS					Provide gabion protection
5	2+106	AC	Brick	5.50	1.20	-	0.80	Good	Headwall demolished by vehicle LHS					Rebuild brick headwall
6	2+750	Vented Drift	Masonry/ Concrete	6.00	8.50	1 Ø 600	0.60	Good	Channel erosion RHS downstream. Substantial erosion around structure			2Ø1000?		Prelim assessment indicates enlargement needed
7	3+113	BC	RC	6.50	1.20	-	0.60	Good	The Culvert is 2/3 filled by soil and debris				1.2	Culvert installed too low. Remove top slab and increase opening to 1.2m.
8	3+367	PC	RC	6.00	0.60	1 Ø 600	0.60	Fair	Severe erosion at outlet RHS					0.6 metre step at outlet. Requires new catchpit structure and repairs downstream
9	3+960								Water crossing road but no structure exists			1Ø600?		Provide new 1Ø600 culvert
10	4+335	Drift	Masonry	5.50	6.40			Poor	In centre of village with steep eroded approaches	6.5m	≈ 6m			New bridge
11	4+900								Erosion on cutting face RHS				4.5	Cascade and catchpit required, reline cut-off ditch
12	5+215	Bridge	RC	6.50	5.50	-	4.00	Good	LHS Parapet rail damaged					Replace one section of parapet rail.

Key
* Clear width across carriageway between headwalls or kerbs
PC = Pipe Culvert
BC = Box Culvert
AC = Arch Culvert
RC = Reinforced Concrete
RHS = Right hand side in direction of increasing chainage
LHS = Left hand side in direction of increasing chainage

3. Design Criteria

Selecting Design Parameters

Many countries have national standards established for the design of their road structures on the primary road network. However, these standards may be inappropriate for the size and level of traffic on low volume roads. For example, vehicle loading will probably be based on the largest long distance haulage trucks which rarely use minor roads in their fully loaded condition. Furthermore, some standards have been adopted which are based on the policies, priorities or economics of developed economies and these are inappropriate for some developing country situations. Designs based on these standards would usually incur excessive construction costs. Unfortunately, heavy and over loading of trucks is commonplace on some routes in developing countries due to factors of driver/operator discipline, economic pressures, lax controls or other local factors. This can lead to vehicle and axle loading being experienced well in excess of those typical in developed counties. Such occurrences are usually related to haulage of particular products such as bulk fuel, minerals, construction materials and timber. Therefore when designers are selecting design parameters for a particular structure they must ensure that they are appropriate for the conditions that will be experienced on that particular road. Examples of the factors which designers should consider are:

1. What is the nature and loading of traffic currently using the route? (Carry out loading surveys if necessary). Are conditions likely to change substantially in the foreseeable future? (e.g. could new quarrying operations start up?)
2. Are local design standards established for the relevant road category? Are these appropriate or achievable?
3. If overloading is prevalent, are their realistic possibilities to physically restrict access?
4. What are the cost implications relating to the loading criteria or restrictions?

It is impossible to state definitive design criteria in this guideline as overall site conditions will vary between locations and districts. The information given below should be considered as a guide to designers, and adapted according to specific conditions in their areas.

Design Life

The design life of a structure is the length of time that the structure can be expected to carry traffic without reconstruction or replacement of structural elements. It assumes that throughout the life of the structure regular standard maintenance is carried out.

When determining the structure's design life the factors which must be taken into account are:
- expected life spans for different structure types and materials
- expected initial and recurrent costs for the design life options

- finance currently available and future maintenance / rehabilitation finance probability
- future changes in the use of the road (e.g. increased traffic volumes or loadings)
- flood return periods (see below)
- consequences of structural failure
- Likely influence of climate change on future life of the structure, risk and consequences of failure

The design life of the road itself (i.e. the length of time before the road will become obsolete or require substantial improvement) should also be taken into account. After consideration of all of the relevant local factors, it is probable that a design life of between 10 and 40+ years will be appropriate for an individual structure.

Design Flood

One of the major design factors in the selection and size of road structures is the amount of storm water that will flow past the structure. Each year there will usually be a few heavy storms which will result in peaks in the water flow over or through the structure, but the largest of these peaks will vary in size each year. If the flows are recorded over a number of years, a longer period of recording will result in a larger maximum peak flow. The highest known flood that has ever occurred may be referred to as the high flood. For minor structures on low volume roads the designer cannot be expected to propose a design that is so large or wide that it could cope with a storm water flow of the high flood. Structures should therefore be designed to have the capacity to cope with a smaller flood, for example, the largest flood that occurs every 10 years. This flood is called the design flood and the time period between successive design floods is called the return period. The design flood is the largest flood that is practical and/or economic for design. Structures should withstand the design flood without any significant damage to the structure or adjacent road and/or embankments. Structures will have a design life greater than the return period between design floods. The designer should therefore consider the effects on a structure of a flood that is larger than the design flood, to ensure that significant or unacceptable damage will not occur. Further information about return periods is given in chapter 6.

In addition to the practical and economic considerations, the choice of return period for a design should be based on the risk of failure of the structure if a larger flow is encountered. It can be very difficult for the designer to undertake this risk analysis with the limited data that may be available. The table below therefore shows suggested return periods for design flood flows for different types of structures.

Recommended storm return periods in years

Road Types	Drifts & Ditches	Culverts and Vented Fords	Bridges
Very low volume roads to individual villages	1	5	N/A
Low volume rural roads	2	10	15
Important secondary rural roads	2	10	25

Clearly drifts and vented drifts may be overtopped during or after any storm. In these cases the design period would indicate a peak flow where it would be impossible for a vehicle to cross the structure safely for an extended period. This period would be determined according to the road's importance in the network. The strategic importance of a structure should also be considered. For example, would it be possible to use an alternative route if the structure is temporarily unusable or damaged ?

Traffic Categories and Widths

Careful consideration must be given to the types of vehicles which may use the road, both at the present time and in the future after road improvements have been made. For example, if the road is close to quarries or a logging area, extremely heavy vehicles may travel down the road. While it may be possible to establish a weight restriction on vehicles using the road due to the loads that particular structures can carry, they are often ignored by drivers and operators. It may only take one overweight vehicle to destroy a structure and make the road impassable. Engineers should therefore design structures to withstand the load of any vehicle that could travel down the road.

Typical loaded weights and dimensions of vehicles that may use low volume roads

Vehicle	Typical max. weight (kg)	Length (m)	Width (m)
Bicycles	250	-	-
Motorcycles	400	2	1
Carts	1500	-	-
Car / pick up	2500	5	1.75
4WD pick up	3000	5	1.75
Minibuses	5000	7	2
Tractor & trailers	12 000	10	2
Small trucks	17 000	8	2.5
Large buses	25 000	15	2.5
2/3 axle trucks	30 000	10	2.5
5/6 axle truck & trailer combinations*	60 000	18	2.5

*usually used for paved main road and urban routes only

Experience has shown that some countries are particularly prone to grossly overweight vehicles. If vehicle overloading is common practice the suggested vehicle weights may be up to twice the values shown in the table above.

If a type of vehicle can physically travel down a road then one of these vehicles will almost certainly pass down that road at some time in the life of the structure – therefore design structures to withstand the weight of the heaviest vehicle which can pass down the road.

With the resources available if it is not possible to construct a crossing which will withstand the largest vehicle that could travel down the road shown in the table above, it will be necessary to install a robust non-removable barrier each side of the structure to prevent overweight vehicles crossing.

Figure 3.1 Overloading and risk of related structures failure are important considerations for some routes

When the structure is designed, the size of vehicle should also be taken into consideration to ensure that it can safely cross the structure without damage to the vehicle or structure.

Figure 3.2 Robust width restrictions can be used in some instances to restrict heavy vehicles

The scope of this guideline covers low volume roads generally carrying up to 200 motor vehicles per day. However it is recognized that with double digit annual percentage increases in traffic typical of some developing country rural routes, the current flow volumes could at least triple even in a 10 year design period. The width of a structure will substantially influence the initial construction cost, for bridges the cost is roughly proportional to deck area and for culverts, roughly proportional to barrel length. In a severely constrained resource environment a vital decision is therefore with respect to whether one or two way traffic flow will be accommodated over the structure. The secondary decision is with respect to the safe width for the predominant traffic type and driver behaviour. These decisions become more important with the increasing size of proposed structure.

For culverts, a typical provision rate for rolling terrain would be about two or three per km. In severe terrain or in flat, floodable areas the frequency would be expected to be higher. However it should be noted that a culvert or other structure is required in all low points in a road. The cost of their provision is therefore usually not significant in the overall cost of the road provision. The frequent occurrence of culvert headwalls and width narrowings, and the difficulty for drivers to see them in advance particularly for travel at night without public lighting and hazard signing, raises important safety issues. The provision of minimum two-lane width culverts can therefore often be justified in all except the most constrained finance resource situations. Furthermore, culvert headwalls should not restrict the general roadway width. They should be set back behind the carriagewayand shoulder, and clearly marked or have guide stones at each end of the culvert to prevent vehicles driving into the inlets, outfalls or ditches when passing on-coming traffic. These requirements may be relaxed to provide only clear carriageway width in slow speed mountainous alignments.

Figure 3.3 Basic access structure for motorcycle traffic

The argument for restricting larger structures to one lane is more easily supported. At the very basic level, bridges for loaded motorcycle and bicycle traffic on village access roads can be provided with a carriageway width from about 1.5 metres.

For single lane motor vehicle traffic the clear carriageway width (between kerbs or guide stones) is recommended to be a minimum of 3.65 metres.

Figure 3.4 Guide stones narrowing road width

If the traffic is mostly light in nature (motorcycles, cars, carts or light goods vehicles) then a 4.6 metres 'one and a half' lane option may be appropriate to allow for the occasional safe passage of a heavy goods vehicle.

Where justifiable, full two lane motor traffic provision should allow a minimum of 6.5 metres between kerbs provided that vehicles are restricted to slow speed passage.

Where physical restrictions are necessary to prevent passage of heavy good vehicles these will need to limit free passage to about 2.3 metres.

It is recommended that the carriageway width (between kerbs or guide stones) should be between 3.75 and 4.5 metres for larger structures such as drifts, vented drifts and bridges. This width should allow easy single way traffic but not two vehicles to pass on the structure.

It is likely that these width restrictions will result in a reduction in the general road width which will require a clear indication that the roadway narrows (advance warning signs) as recommended by the national standards for the category of road.

Figure 3.5 Culvert head stone outside main running lanes

Although the widths given above should generally be followed, cross drainage structures are difficult to widen at a later stage. Consideration must therefore be given at the planning stage regarding the future use of the road and whether the traffic volumes are expected to increase significantly. It may prove more cost effective to construct a structure wider than current requirements in order to avoid reconstruction at a later date.

Serviceability

Vehicle Impact: One of the most common causes of damage to structures is vehicle impact. It is therefore important that reinforcement be placed in culvert headwalls and guide stones to prevent them being demolished by traffic. Safety barriers should be installed in the situations of particular hazards, according to the national standards for the category of road.

Fatigue Deflections: The majority of codes in use limit deflections to prevent fatigue damage to structural members by specifying permissible deflections as a function of length. Typically the permissible deflection is 1/800 of the span length. It would be suitable to relax this requirement to a deflection of 1/100 of the span (i.e. a 6mm deflection on a 6m span bridge) if only one vehicle would be on the bridge at one time and this level of deflection would not be noticed when compared to the ride from the approach roads.

Drainage of the Structure

There should be a camber or cross fall on any highway structure to ensure that water does not collect and lay on the structure, increasing the rate of deterioration or acting as a safety hazard. A minimum camber of 2.5% would normally be acceptable. Bridges should be constructed with adequate drainage arrangements, such as pipes, which drain water off or through the deck away from abutments or piers. Careful consideration should be given to water flow in the side drains along the road adjacent to the structure to ensure that it does not erode a deep channel along the side of the structure.

Maintenance Capability

When materials are chosen, consideration should be given to the predicted life of the material in relation to the design life of the whole structure. The resources required and frequency of maintenance should also be carefully reviewed.

Safety

Where there are a large number of pedestrians using the road, provision should be made for a 1.5m wide segregated footway across or on the side of the structure. If the structure is over 20m long but the number of pedestrians cannot economically justify a pedestrian footway it may be advisable to construct a wider section in the middle of the structure, or regular refuges, where pedestrians can wait while vehicles pass. In some cases it may be justifiable to construct a separate low cost, lightweight structure for pedestrian passage.

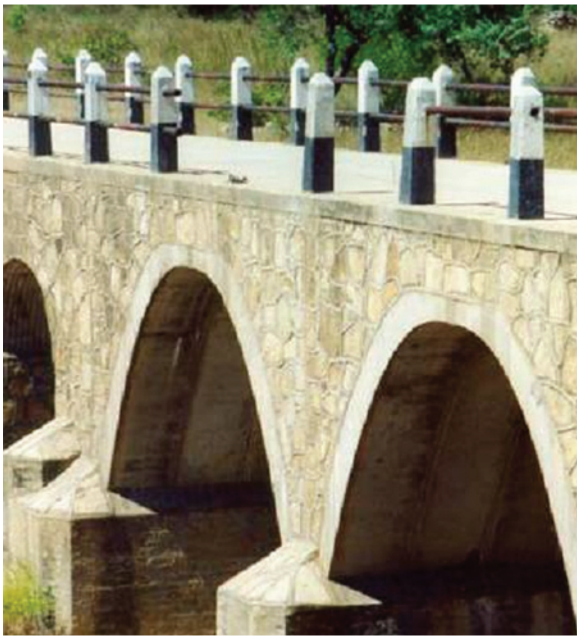


Figure 3.6 Pedestrian guard rails (in need of repair)

Guard rails and kerbs can be provided to prevent vehicles or pedestrians from falling off the structures. For structures which have pedestrians regularly crossing it is highly advisable to construct some form of guard rail to prevent pedestrian and child accidents. This guard rail would not normally be required to restrain vehicles from falling off the structure. The provision of guard rails or kerbs to prevent vehicle accidents would depend on the level of vehicle traffic. It is unlikely that vehicle guard rails can be economically justified where the vehicle flows are less than 50 vpd. If vehicle guard rails are not provided it is imperative that clearly marked kerbs or kerb stones are provided to indicate the extent of the roadway lanes. Where the structure is designed to be overtopped it is necessary to indicate the depth of water over the roadway and whether it is safe to cross. As it would normally be safe to cross fast flowing water up to a depth of 200mm, guide stones on overtopped structures should be made at least 200mm high. The stones will then remain visible and mark the edge of the roadway when the structure is safe to cross and be submerged under the water when it is unsafe to cross the structure. Guard rails should not be used on structures that are designed to be overtopped as they will trap debris.

Sight distances: Drivers should always be able to see the road far enough ahead to be able to stop safely if required e.g. when there is an obstruction on the road. It may not be possible to maintain a full sight distance over a cross drainage structure. However, the distances in the table below provide a guide to the desirable minimum distance that should be provided.

Safe Sight Stopping Distance (single lane)

Speed km/h	30	40	50	60
Distance m	50	70	100	130

(TRL, 1984 Towards Safer Roads in Developing Countries - A Guide for Planners and Engineers)

Future Changes in Road Use

During the initial design of the structure, careful consideration must be given to future changes in road use. For example, the type of traffic and number of vehicles of each type, which may affect the requirements of the structure, must be taken into account. The future changes should be reviewed for the predicted life of the structure but consideration should be given to the financial costs of building a larger structure if a smaller, simpler, structure would be acceptable for the majority of the design life.

Funding

In selecting design parameters and ultimately the choice of structure, the economic benefits of different types of structures should be taken into account. These economic considerations do not only include the physical costs of the structure and measurable benefits of increased access, lower transport costs, time savings and increased economic activity but also social benefits of increased access. For example, it may be considered beneficial to provide a small bridge across a river which will provide constant access to a health centre for a village on the opposite bank. A vented ford may be more suitable for the level of traffic using the road, but high flood flows may prevent a patient receiving treatment in an emergency.

In many cases, engineers will not have all the financial resources that they need to satisfy all the structures needs. If a structure is to be provided which does not fully meet the design requirements, the design should enable the structure to be upgraded at a later date with minimal reconstruction if further resources become available.

4. Structural Options

The greatest potential cost savings for water crossing options is in the choice of structure type. This chapter considers different water crossing options, explaining the characteristics of each and highlighting the conditions suitable for their use. The advantages and disadvantages associated with each structure are also discussed.

At the most basic level, a ford can be created in a stable sandy bed of an occasional watercourse by burying stones of 15 - 30 cm size just below the surface and re-covering them with sand. This substantially improves bearing capacity for vehicles. This guideline deals with improved crossing structures from drifts up to small bridges.

Drifts

Drifts are the most basic structure and can be the lowest cost form of watercourse crossing construction. There are two types of drift:

1. Relief drifts: relieve side drains of water where the road is on sloping ground and water cannot be removed from the uphill side drain by mitre drains, or as an alternative to a relief culvert (Figure 4.4).
2. Small watercourse (or stream) drifts: where stream flows are very small or perennial, drifts may be used to allow the stream to cross the road.

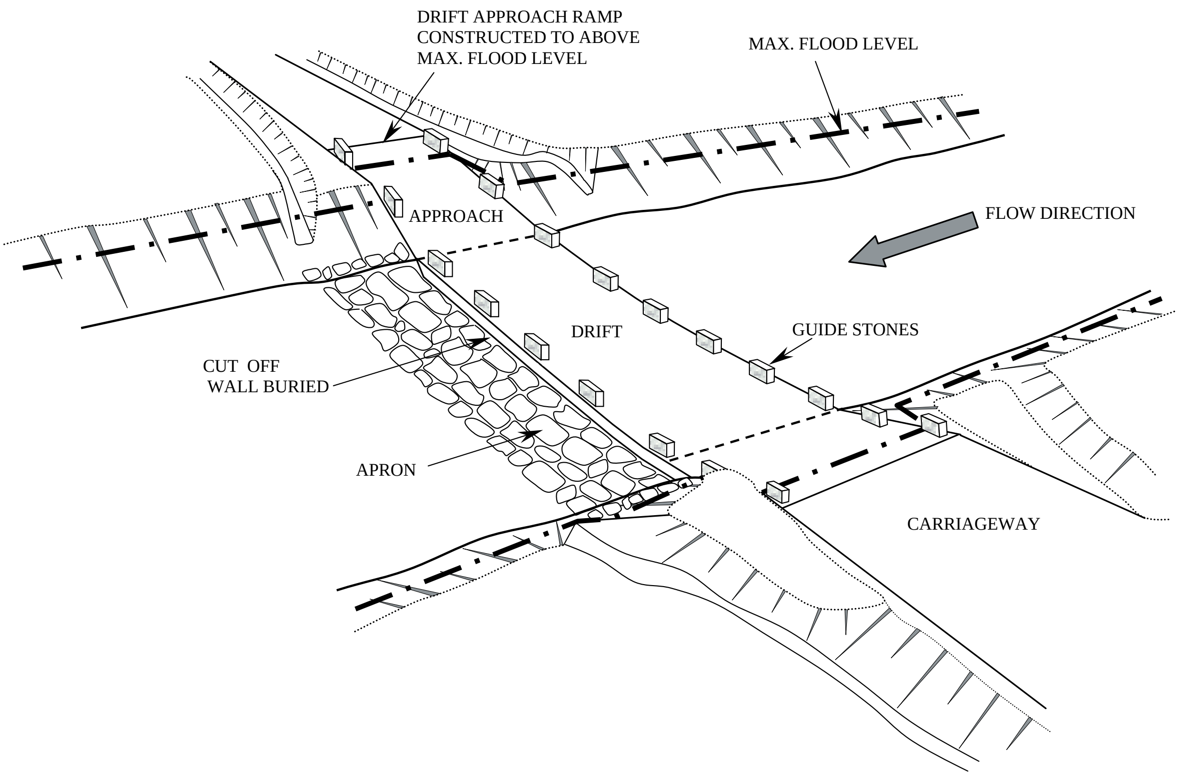


Figure 4.1 Key Features of a stream drift

Figure 4.2 A stream drift

Drifts can also be referred to as Irish bridges, fords or splashes. The terms describe essentially the same structure, however, it is generally accepted that a ford or splash is constructed from the existing riverbed e.g. a sandy river bed or level rock. A drift is a ford or splash with an improved running surface constructed from imported (or gathered) materials. A low water crossing is the collective term used to describe all drifts, fords, splashes and vented fords.

Key features:

- Stream drifts are structures which provide a firm place to cross a river or stream. Relief drifts transfer water across a road without erosion of the road surface. Water flows permanently or intermittently over a drift, therefore vehicles are required to drive through the water in times of flow.
- Drifts are particularly useful in areas that are normally dry with occasional heavy rain causing short periods of flood water flow.
- Drifts provide a cost effective method for crossing wide rivers which are dry for the majority of the year or have very slow or low permanent flows.
- Alternative solutions may be preferable for small permanent watercourses to prevent vehicles having to drive through the water.
- Drifts are particularly suited to areas where material is difficult to excavate, thus making culverts difficult to construct.
- Drifts are also particularly suited in flat areas where culverts cannot be buried because of lack of gradient.
- The drift approaches must extend above the maximum design flood level flow to prevent erosion of the road material.
- If necessary guide stones should be provided on the downstream side of the drift and be visible above the water when it is safe for vehicles to cross the drift.
- Buried cut off walls are required upstream and downstream of the drift to prevent under cutting by water flow or seepage.
- The approach road level will normally mean that approach ramps are required. Approach ramps should be provided to the drift in the bottom of the watercourse with a maximum gradient of 10% (7% for roads with large numbers of heavy trucks).
- Drifts should not be located near or at a bend in the river.
- Some form of protection is usually required downstream of a drift to prevent erosion.

Figure 4.3 A basic hand packed stone drift

Advantages	Disadvantages
• Low cost: at the most basic level, can be constructed and maintained entirely with local labour and materials • Ease of maintenance and repair • Volume of excavated material in most cases is minimal • Do not block with silt or other debris carried by flood water. • Can accommodate much larger flows than culverts • Easier to repair than culverts • Water flows over a wide area, resulting in less water concentration and erosion downstream than piped culverts	• Drifts require vehicles to slow down when crossing • The crossing can be impassable to traffic during flood periods • Foot passage can be inconvenient or hazardous when water is flowing

Culverts

Culverts are the next step upwards from drifts in terms of cost and complexity of structure. There are 2 types of culvert:

1. Relief culverts at low points in the road alignment or where there is no definable stream, but the topography of the ground requires a significant amount of cross drainage, which cannot be accommodated by side drains
2. Stream culverts which allow a watercourse to pass under the roadway

Key features:

- Culverts are the most commonly used structures on low volume roads. They can vary in number from about one each km in dry and gently rolling terrain up to six or more for severe terrain with high rainfall. With high rainfall, flat areas frequency may also increase due to the need to regularly allow water to cross the road alignment in manageable quantities.

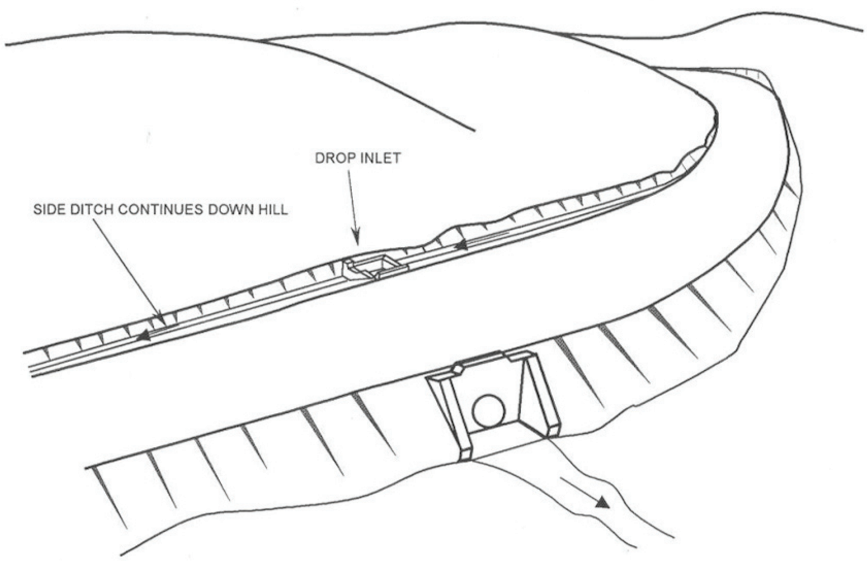


Figure 4.4 Key features of a relief culvert

Figure 4.5 A three barrel corrugated steel culvert with stepped outfall apron

- Culverts channel water under the road, avoiding the need for vehicles to drive through the watercourse.
- In addition to well defined water crossing points, culverts should normally be located at every low point or dip in the road alignment.
- Relief culverts may be required at intermediate points, where a side drain carries water for more than about 200 metres without a mitre drain or other outlet.
- Culverts can be pipe, box, slab or arch type.
- Headwalls are required at the inlet and outlet to direct the water in and out of the culvert and prevent the road embankment sliding into the watercourse. Wingwalls at the ends of the headwall may also be used to direct the water flow and retain material.
- Aprons with buried cut off walls are also required at the inlet and outlet to prevent water seepage, scouring and undercutting.
- Culvert alignment should follow the watercourse both horizontally and vertically where possible.
- Gradient of the culvert invert should be between 2 and 5%. Shallower results in silting; steeper results in scour.
- Culvert invert levels should be approximately in line with the water flow in the stream bed, otherwise drop inlet and/or long outfall excavations may be required.
- Typical culvert diameters are 600mm and 900mm.
- Cross culverts smaller than 600mm in diameter should not be installed as they are very difficult to clean.
- Where foundation material is poor, culverts should be placed on a good foundation material to prevent settlement and damage. On very soft ground, it may be necessary to consider concrete, steel or timber piles to provide adequate foundations. This would require specialist design expertise not covered by this guideline.
- It is necessary to protect the watercourse from erosion downstream from the structure.
- Culverts can exist in pairs or in groups to enable larger stream flows to be accommodated using standard unit designs.

Advantages	Disadvantages
• Culverts provide a relatively cheap and efficient way of transferring water across a road • Can be constructed and maintained primarily with local labour and local materials • Culverts allow vehicle and foot passage at all times. • Culverts do not require traffic to slow down when they are crossed • Culverts allow water to cross the road at various angles to the road direction for a relatively small increase in cost	• Regular maintenance is often required to prevent the culvert silting up, or to remove debris blockage. • Culverts act as a channel, forcing water flow to be concentrated, so there is a greater potential for downstream erosion compared with drifts. • Culverts are not suited to occasional high volume flows

Vented Fords and Causeways

These generally have higher capacity and construction costs than drifts or culverts.

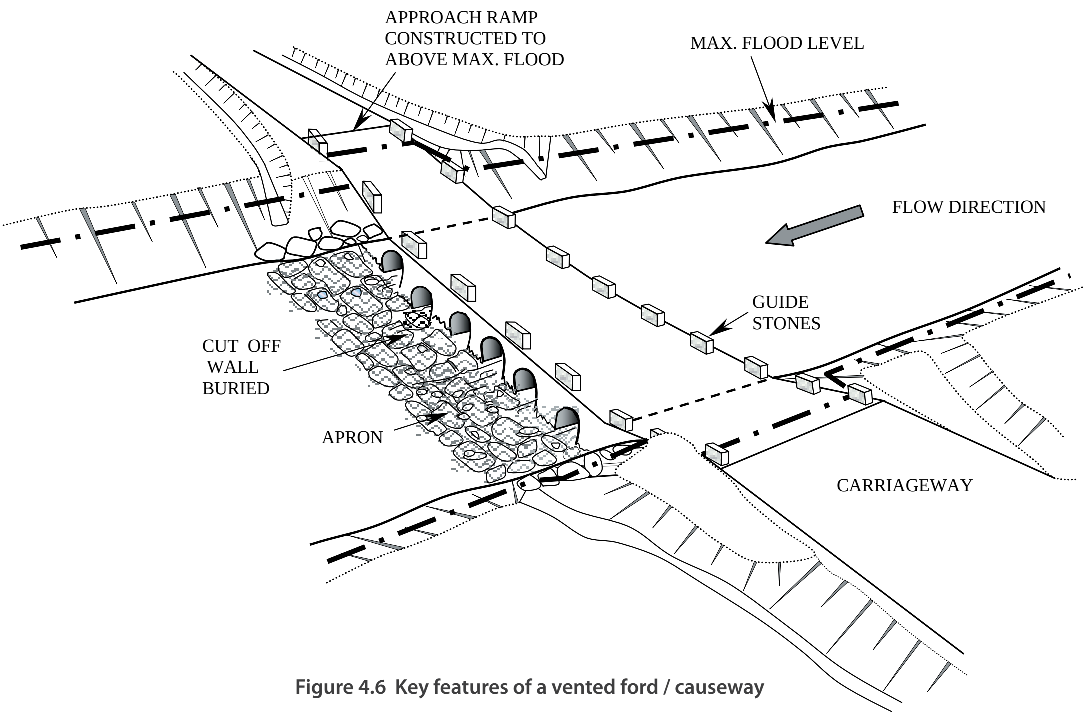


Figure 4.6 Key features of a vented ford / causeway

Key features:

- These structures are designed to pass the normal dry weather flow of the river through pipes below the road. Occasional larger floods pass through the pipes and over the road, which may make the road impassable for short periods of time.

Figure 4.7 A vented ford

- Vented causeways are the same concept as vented drifts but are longer with more pipes, to cross wider watercourse beds.
- The level of the road on the vented drift should be high enough to prevent overtopping except at times of peak flows.
- There should be sufficient pipes to accommodate standard flows. The location of pipes in the drift will depend on the flow characteristics of the river.
- Vented fords should be built across the whole width of the water- course.
- A vented ford requires approach ramps, which must be surfaced with a non erodible material and extend above the maximum flood level.
- Watercourse bank protection will be required to prevent erosion and eventually damaging the entire structure
- The approach ramps should not have a steeper grade

Figure 4.8 Downstream protection to a vented ford

Figure 4.9 Concrete vented causeway

than 10% (7% where there is significant heavy vehicle traffic).

- The upstream and downstream faces of a vented drift require buried cut off walls (preferably down to rock) to prevent water undercutting or seeping under the structure.
- An apron downstream of the pipes and area of overtopping is required to prevent scour by the water flowing out of the culvert pipes or over the structure.
- There is also a requirement to protect the watercourse from erosion downstream from the structure. There will be considerable turbulence immediately downstream of the structure in flood conditions.
- The road surface longitudinal alignment of the vented ford should be a slight sag curve to ensure that, at the start and end of overtopping, water flows across the centre of the vented drift and not along it.
- There should be guide stones on each side of the structure to mark the edge of the carriageway and indicate when the water is too deep for vehicles to cross safely.
- Vented fords can also be known as piped drifts

Advantages	Disadvantages
• Vented fords can allow a large amount of water to pass without overtopping • They are cheaper to construct and maintain than bridges • Construction of vented fords is fairly straightforward compared with bridges • Vented fords are well suited to cope with short high volume flows • Can be constructed and maintained primarily with local labour and local materials	• Vented fords can be closed for short periods during periods of flooding and high flow • Floating debris can lodge against the upstream side of the structure and block pipes • Foot passage can be inconvenient or hazardous when water is flowing over the structure

Large Bore Arch Culverts

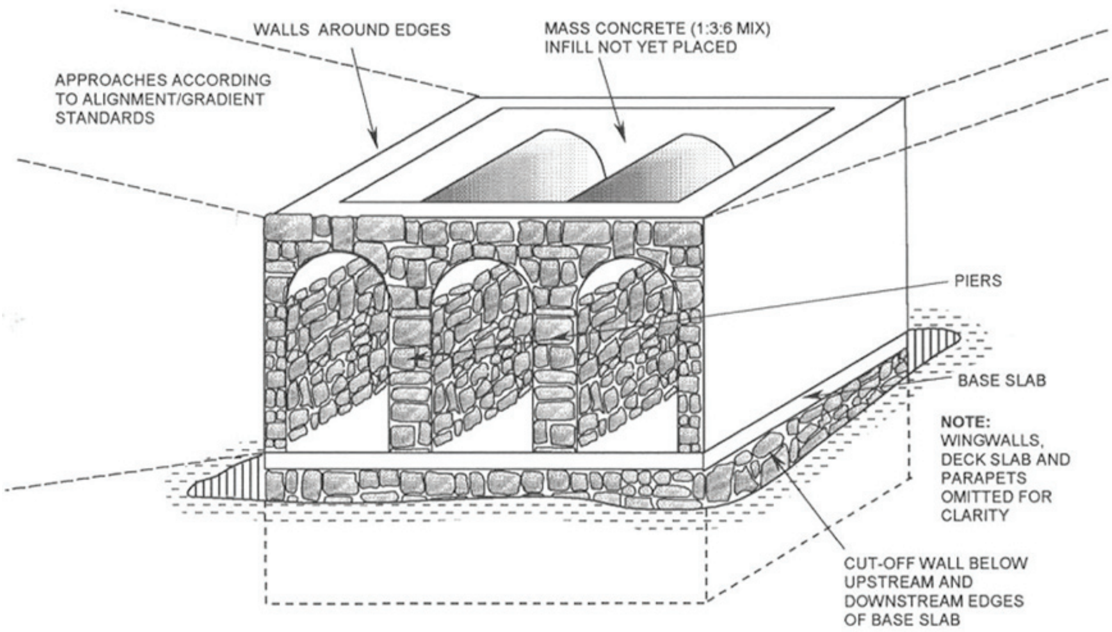


Figure 4.10 Key features of large bore culvert

Figure 4.11 Large bore arch culverts

Figure 4.12 Guide stones on large bore culvert structure

Key features:

- Large diameter culverts typically have openings greater than 1 metre and are capable of passing high flows, either through one large opening or a number of medium sized openings.
- Very large bore arch culverts may also be called arch bridges.
- Formwork is required to construct the openings. This formwork can be made from wood, stones or metal sheeting and either incorporated into the structure or removed once construction is complete.
- Although these structures are not in general designed to be overtopped, they can be designed and constructed to cope with an occasional overtopping flood flow.
- The road alignment needs to be a minimum of 2 metres above the bottom of the watercourse.
- Approach embankments are required at each end of the structure.

- Large bore culverts require solid foundations with a buried cut off wall on both upstream and downstream sides to prevent water seepage erosion and scouring.
- These structures require large amounts of fill material during construction.
- Guide stones or kerbs should be placed at the edge of the carriageway to increase vehicle safety.
- If the crossing is to be used by pedestrians consideration should be given to installing guard rails and central refuges for long crossings where pedestrians can move off the roadway to allow traffic to pass.
- Water from the road side drains should be carefully channelled into the watercourse away from the structure to prevent erosion of the bank or scour of the culvert structure.

Advantages	Disadvantages
• Large bore culverts are usually easier and cheaper to construct than bridges • They can accommodate flows significantly higher than smaller culverts and vented fords • Can be constructed and maintained primarily with local labour and materials, without the need for craneage • They may easily be designed and constructed for occasional overtopping • Central 'piers' are not so susceptible to damage by scour and erosion when compared with bridge piers • They generally require less maintenance than conventional bridges	• The water opening in large bore culverts is smaller than for a bridge of the same size, which reduces the potential flow rate past the structure at peak flows • Large bore culverts can require a significant amount of fill material

An alternative to a large or multi-bore culvert is a reinforced concrete box culvert. That type of structure is not covered by the scope of this guideline. For guidance on such structures refer to publications such as TRL Overseas Road Note 9.

Bridges (arch or simply supported deck)

These are generally the highest cost structures to construct. This guideline does not cover multiple span bridges, which may be simply supported or continuous over piers.

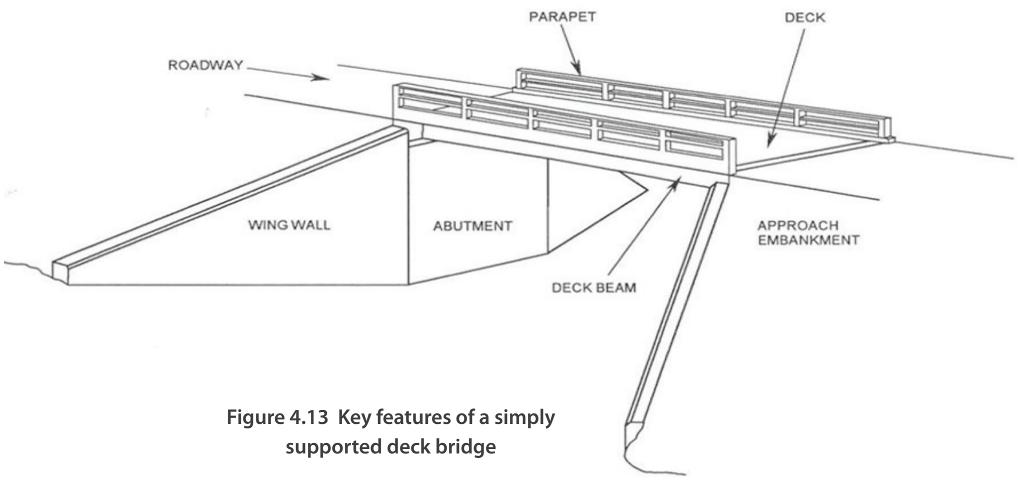


Figure 4.13 Key features of a simply supported deck bridge

Key features:

- The arch is the simplest form of bridge.
- There are a number of different elements to a simply supported deck bridge, which will comprise of a superstructure (deck, parapets, guide stones and other road furniture) and substructure (abutments, wingwalls, foundations, piers and cut off walls).
- Bridges are generally the most expensive type of road structure, requiring specialist engineering advice and technically approved designs.
- Bridges can be single span or multi span, with a number of openings for water flow and intermediate piers to support the superstructure.
- The main structure is always above flood level, so the road will always be passable.
- Abutments support the superstructure and retain the soil of the approach embankments.
- Wingwalls are needed to provide support and protect the road embankment from erosion.
- Embankments must be carefully compacted behind the abutment to prevent soil settlement, which would result in a step on the road surface at the end of the bridge.
- Weep holes are needed in the abutment to allow water to drain out from the embankment, and avoid a build up of ground water pressure behind the abutment.
- Bridges should not significantly affect the flow of water i.e. the openings must be large enough to prevent water backing up and flooding or over topping the bridge.
- The shape of the abutments and piers will affect the volume of flow through the structure and also the amount of scouring.
- Bridges require carefully designed foundations to ensure that the supports do not settle or become eroded by the water flow. On softer ground this may require piled foundations which are not covered in this guideline.
- Water from the road side drains should be channelled into the watercourse to prevent erosion of the bank or scour of the abutment structure.
- Guide stones or kerbs should be placed at the edge of the carriageway to increase vehicle safety.
- If the crossing will be used by pedestrians, consideration should be given to installing guard rails and a central refuge for long crossings where pedestrians can move off the roadway for passing traffic.

Advantages	Disadvantages
• The road is always passable as the structure should not be overtopped • Simple arch bridges can be constructed primarily with local skills and local materials, without the need for craneage (however simply supported spans are more complex)	• Bridges are normally significantly more expensive than other road structures • They are more complex than other structures and will require specialist engineering support for design and construction • Bridges may require heavy duty lifting cranes for the deck components • Although all structures should be inspected for defects, bridges require regular detailed checks • Bridges are likely to fail if flood flow predictions are incorrect and they are over topped • A small amount of scour and erosion can often result in major damage to the structure

Structure Selection

The objective in selecting a structure for a water crossing is to choose the most appropriate design for each location. This selection should be based on a number of factors:

- Costs
  Assessments will have to be made of the initial cost of construction which should include materials, transportation, equipment, labour, and supervision as well as overheads (and for a contractor, the profit margin). An assessment will also have to be made of the on-going maintenance costs that will be required for each structure.

  The example below compares the costs of a timber bridge with a masonry vented ford. Initially it may appear that the timber bridge is the cheaper option but even without inflation over the first 15 years, the masonry culvert can be shown to be the cheaper when whole life costs are considered. Furthermore, there may be risks that funding will not be available for maintenance, or that defects will not be identified and repaired in a timely manner on a high maintenance structure.

Example comparison of timber and masonry bridge costs

Year	Timber Bridge		Masonry Vented Ford	
	Work Undertaken	Cost	Work Undertaken	Cost
1	Construction	10,000	Construction	15,000
4	Inspection and replacement of running boards	1000	Repair of downstream protection	300
8	Inspection, replacement of running boards and 2 deck members	2000	Replacement of downstream protection	700
12	Inspection and replacement of decayed structural members	4000	Repair of downstream protection	300
15	Inspection replacement of running boards	1000	Replacement of downstream protection	700
	Total Cost	**18,000**	**Total Cost**	**17,000**

- Amount of traffic per day / acceptable duration of traffic interruptions
  The amount and type of traffic using the road each day will help determine carriageway width and the length of time that the road could be closed due to overtopping during periods of peak flood. The seasonality of traffic flows and relationships to likely flood periods should also be considered. For example; is there a risk to local perishable goods such as milk or green tea.

- Frequency of flooding
  The frequency and size of peak flows will determine the level of the structure roadway to ensure that the road remains open for all but the largest peak flows.

- Emergency / principal route
  Principal routes such as access roads to local markets or emergency routes to a nearby hospital will require higher levels of access and shorter periods of closure due to high water levels.

- Availability of alternative route
  The proximity and distance of an alternative route will also affect the choice of structure, as an alternative secure route with a short acceptable detour will allow the road to be closed for longer periods.

- Damage to land or property
  Whenever watercourses are channelled through pipes, such as in culverts and vented fords or through narrow openings in bridges, severe erosion can be caused to land and property downstream of the structure. If agricultural land or buildings are close to the proposed structure careful consideration must be given to erosion protection. Undersized structures can also cause water to back up causing flooding upstream and possible property damage.

- Uncertainties in flood prediction
  The choice and design of the structure will depend on the maximum water flow during flood conditions. If the maximum water flow is not known sufficiently accurately it may be necessary to provide a structure that can be over-topped during periods of unpredicted water flow.

- Bank elevation and bed material of the watercourse
  The resistance of the watercourse banks and bed to erosion will dictate the type of foundation bank protection and hence structure that can be built. For material which is easily erodible it will be necessary to have deep foundations and possibly extensive bed and bank protection, or structures which are not susceptible to damage. The steepness of the banks and difficulty in excavating soil material will also determine the most convenient approach roads.

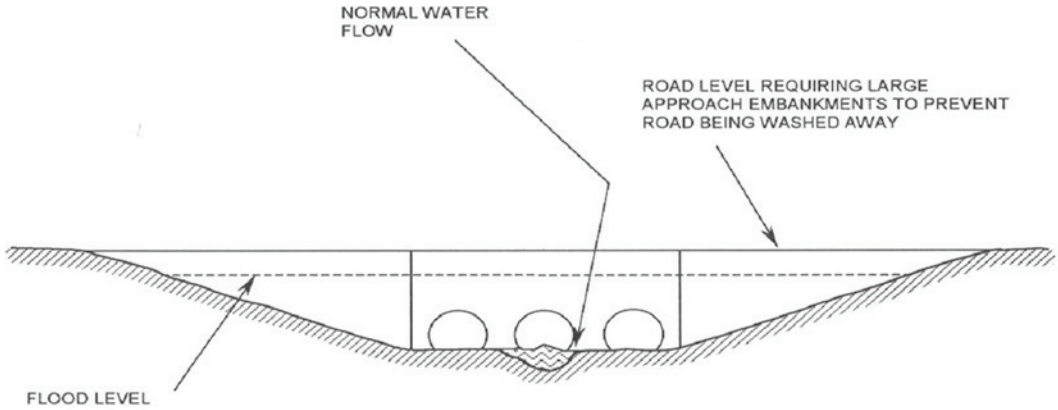
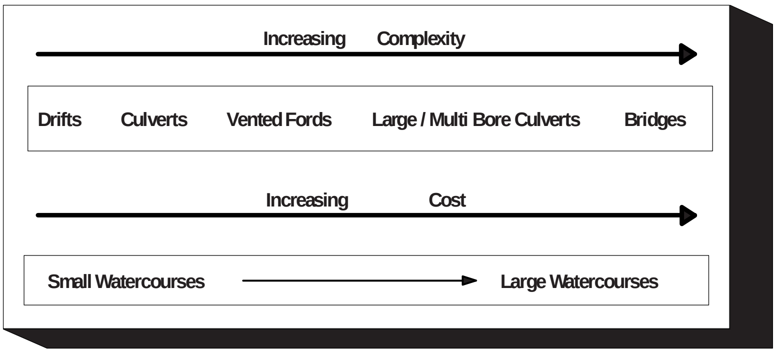


Figure 4.14 Large embankments required to prevent road flooding

A major factor affecting the cost of building a structure is the amount of material which needs to be imported to, or exported from, the site. Where the road alignment is at a similar level to the river bed it may be difficult to construct a structure that will not be overtopped without large approach ramps.

There is a general progression in complexity, and hence cost, of structures with the cheapest structure being a drift and the most expensive a bridge.



It may also be difficult to define the boundaries of different structures. For example, when does a vented ford become a multi bore culvert? In reality there are overlaps of suitability of each structure type so that in a particular situation more than one structure type may be suitable.

For small watercourses and relief structures the choice of structure will, in general, be between a culvert and drift, and for large watercourses between a vented ford and a large bore culvert, or possibly a bridge. The choice of structure will be determined by all the factors discussed above, but particularly by the predicted maximum water flow, its seasonal variations and the length of road closures that can be tolerated.

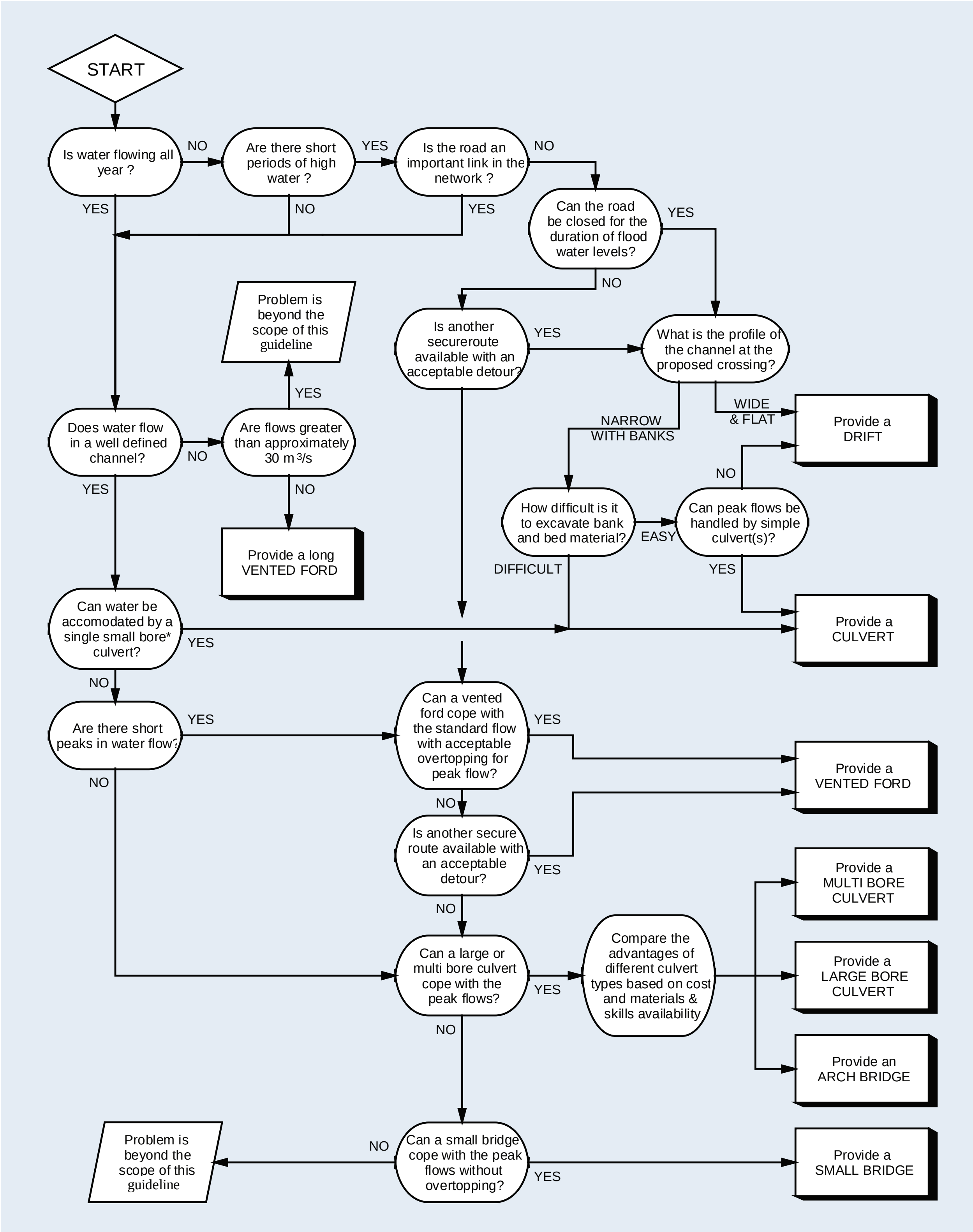
Figure 4.15 Is this a vented ford or a multi-bore culvert?

The flow diagram on the next page shows in more detail the questions and decisions that should be made when choosing a structure. Factors affecting the choice of structure are different for each location; therefore a number of questions need to be addressed. As the following flow diagram only highlights the key issues, it should only be used as a guide when determining the most appropriate structure.

The flow diagram also asks questions regarding the permissible closure time for a road during floods. Each individual case will have to be assessed separately depending on its particularly circumstances. In the absence of any local guidelines the table below, used by the Minor Roads Programme in Kenya, gives suggested upper and lower bounds for closure times etc.

Criteria	Drift most favourable	Drift least favourable
Average daily traffic (ADT)	Less than 5 vehicle per day	More than 200 vehicles per day
Average annual flooding	Less than twice per year	More than 10 times per year
Average duration of traffic interruption per occurrence	Less than 24 hours	More than 3 days
Extra travel time for detour	Less than 1 hour	More than 2 hours

Figure 4.16 'Route map' for the selection of a suitable structure



**Small bore – diameters less than 900mm*

When the problem is 'beyond the scope of this guideline' then specialist bridge engineering skills should be mobilised.

5. Site Selection and Appraisal

General

For minor structures such as drifts or culverts on existing routes there may be little choice available in site selection. Changing the existing road alignment could incur substantial additional road works costs.

For relief drifts or culverts, necessary to allow the build up of water in side drains to cross the road alignment, there is usually some flexibility in location. Normally side drains will require to be relieved by a turn out or cross structure after a maximum length of about 200 metres to avoid exceeding capacity or causing erosion. Ideal outfall sites are at field boundaries or where there is vegetation or stable ground to minimize the risk of damage or erosion downstream.

For larger structures and watercourses the selection of site location requires more attention. Adjustment of the road alignment is often justifiable to minimize the cost of structures and risk of damage or erosion.

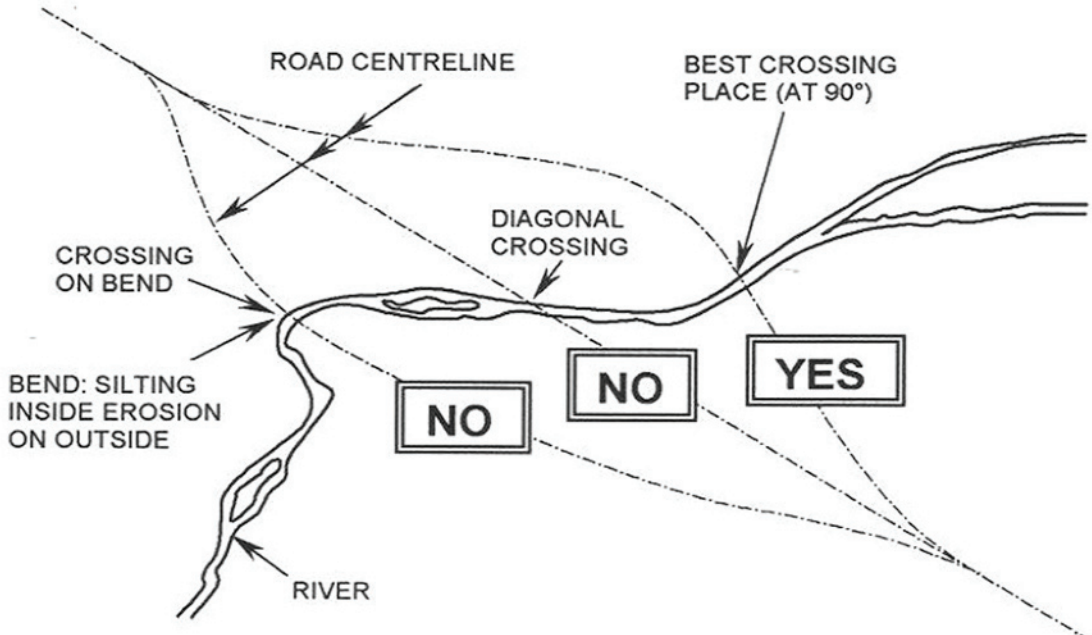


Figure 5.1 Suitable crossing points for larger structures

Careful site selection is essential to ensure ease of construction and to minimise the whole life cost of the structure. Poor site selection can result in a longer, wider or higher structure than is actually necessary. Poor siting can also lead to excessively high maintenance costs, and in extreme cases a high risk of destruction of the structure. Regardless of the type of structure to be constructed the following criteria should ideally be met when determining a site for a water crossing (other than at side drain relief, drift and culvert crossings):

1. The crossing should be located away from horizontal curves in the watercourse, as these areas are unstable, with the line of the watercourse tending to move towards the outside of the bend with time.

2. The crossing should be at an area of uniform watercourse gradient. If the gradient is steepening there is a greater possibility of scour and erosion, and if the gradient is reducing there is the potential for silt and other debris to be deposited near or inside the structure.
3. The crossing should ideally be at an area of the channel with a non-erodible bed. These areas have a reduced scour potential, reducing the amount of watercourse protection required.
4. The road should cross the watercourse at a point with well defined banks, where the stream will generally be narrower.
5. The watercourse should not be prone to flooding at the crossing point.

Road Alignment

In addition to the watercourse requirements noted above, the road should:

- Cross the watercourse at 90 degrees as this minimises the span length of the bridge or pipe. Compare length of culvert L1 with culvert on a skew crossing L2 in the diagram below.

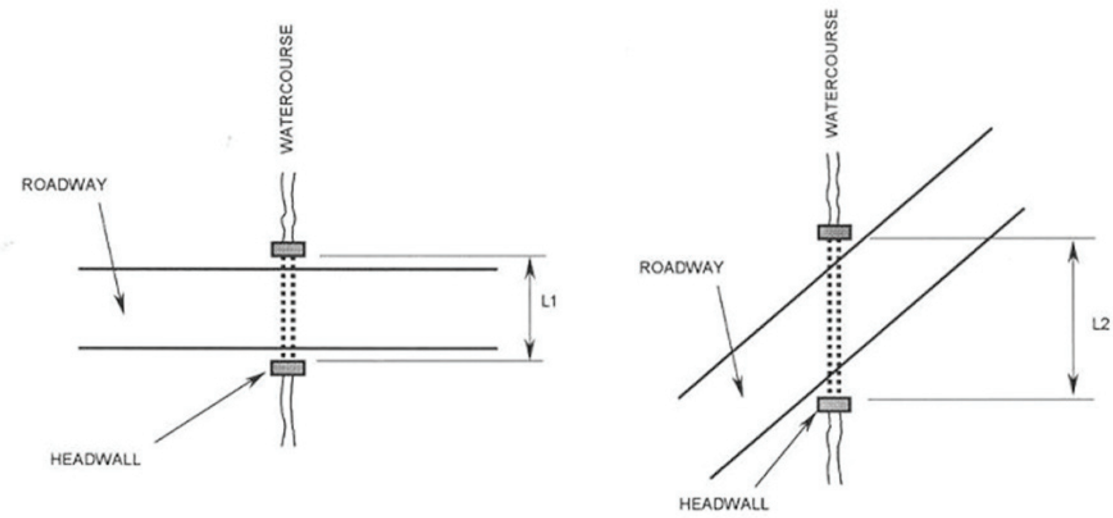


Figure 5.2 Right angle crossings reduce the length and cost of structure required.

- Cross on a straight length of road, rather than a curve, to reduce the width of a bridge or length of a culvert.
- Be fixed vertically at the minimum elevation necessary to pass above the design flood flow (this is obviously not required for drifts and vented fords). If the road alignment is fixed too high unnecessary costs will be incurred in abutment/wingwall/ headwall construction and approach embankments.
- Be centred above the centre line of the substructure.

Location

- A site with a natural narrow channel width rather than a wide one should be used.

- The crossing should be constructed at a straight stretch of river or watercourse, rather than a curved one where the stream is likely to cause erosion of the bank on the outside of the curve.
- Alignment should be at right angles to the water flow to avoid additional scouring. A skew crossing may channel the water towards one of the river banks. This channelling may erode the approach way and/or the bank eventually resulting in the river flowing around the bridge rather than under it.
- The approach roads should preferably be straight on each side to ensure sufficient sight distances and prevent traffic hazards.

It is very rare that all the criteria above can be satisfied for each crossing, therefore a balanced consideration of the various factors is required. It is necessary to establish the most cost effective solution for each structure depending on individual circumstances.

Existing Structure Assessment

Where existing roads are being improved, existing drainage sites should already have been provided with an appropriate structure. However, it is possible that an inadequate structure has been provided or the need for a structure had been overlooked. A common fault is that culverts have been installed at the wrong level; too high often results in erosion downstream and too low leads to repeated silting and a maintenance problem. When the road is inspected the following conditions indicate that further drainage work needs to be undertaken:

- Small gullies exist on the road due to water flowing across the running surface
- Existing culverts are damaged due to:
  - standing water softening the soil around the culvert
  - insufficient capacity
- Sand and silt has been deposited on the road in patches due to standing water
- Culverts, inlets or outlets are silted due to incorrect design or installation
- Evidence of erosion around the structure or culvert
- Debris trapped at inlet due to incorrect type, sizing or lack of protection.

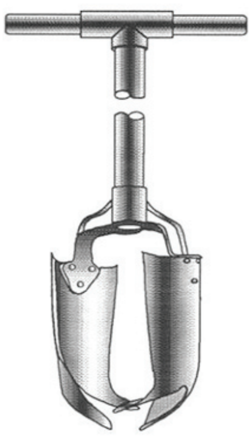


Figure 5.3 A hand auger

Site investigation

The objective of site investigation is to provide a, clear picture of the ground conditions, to enable a suitable design to be carried out. The level of site investigation clearly depends on the type and complexity of the proposed structure. A site investigation will involve taking samples of the ground material to determine its bearing capacity. These samples can either be obtained through digging trial pits or by using a hand auger.

Bearing capacity

The ground underneath a proposed structure should have an adequate bearing capacity to support the load of the structure itself and the vehicles which pass over it. If the soil has insufficient strength it will compress and the structure will subside, possibly causing failure.

The bearing capacity will depend on a range of different factors; including the proportions of sand clay, organic and other material in the soil, the mineralogy of the clay materials and the level of the water table. As the type of soil may change with depth it is necessary to dig small pits, called trial pits, at the proposed site to determine the bearing capacity at the proposed foundation level. By identifying the material excavated from different depths of the trial pits the bearing capacity of the soil can be determined. Bearing capacities are particularly important in the design of structures where large localised loads are expected, e.g. bridge abutments and piers, as the soil must have a high bearing capacity to support these loads.

Figure 5.4 Collapse due to settlement

The number of trial pits that should be dug will depend on the complexity of the structure and the uniformity of the soil. The table below gives a guide to the number and depth of trial pits that should be dug for different structures. If the ground conditions are known to vary over the proposed site, or two trial pits show markedly different results, then further trial pits should be dug as appropriate. The trial pit depth is only given as a guideline figure. If the soil conditions are very poor it may be necessary to increase the depth. Where bedrock exists close to the ground surface this offers the best foundation.

Trial Pits: Requirements and Locations

Structure	Number	Location	Depth
Drift	Not required	-	-
Culvert	1	At outlet	1.5 metres
Vented ford	2 (only 1 required if ford is shorter than 15 metres)	At each end of the vented section, preferably one on the upstream and one on the downstream side	1.5 metres
Large bore culvert	2 (additional pits at each pier location if required)	At each abutment and each pier	2.5 metres(deeper in poor ground conditions)
Bridge	2 (additional pits at each pier location if required)	At each abutment and each pier	To firm strata (minimum of 3m)

The only accurate method for determining the bearing capacity of any soil is through detailed field and laboratory investigations. If soils testing facilities are not available the tables/charts below may be used for determining an approximate bearing capacity of the soil. A Dynamic Cone Penetrometer (DCP) is a low cost, portable device that can also provide an approximation for in situ soil strength for some materials. However, care must be taken in interpreting results, particularly with regard to possible variations of in-service moisture conditions. The engineer should take samples of the soil from the trial pits and compare its properties with the descriptions in the table. As different materials have different strength criteria, the following three tables are applicable to rocks, clays and silts, and sands and gravels. The soils used for bearing capacity estimation should be in the same condition and state as they would be found at the proposed site. As a general guideline, the more complex and expensive the structure, the more extensive the soil and foundation investigation should be to minimise initial and whole life costs and the risk of later damage or failure of the structure.

Rock bearing capacity

Soil description	Rock strength	Allowable bearing capacity(kN/m²)	Uniaxial compressive strength (MN/m²)
A hammer blow required to break specimen, can be scratched with firm pressure from knife	Strong	10 000	50 - 100+
Easily broken with hammer, can be easily scratched with knife and pick end indents approx. 5mm	Moderately strong	2000	12.5 - 50
Broken in hand by hitting with hammer, can be grooved 2mm deep with a knife	Moderately weak	1000	5.0 - 12.5
Broken by leaning on sample with a hammer, can be grooved or gouged easily with a knife	Weak	750	1.25 - 5.0
Can be broken by hand and knife will penetrate approx. 5mm	Very weak	250	0.6 - 1.25

Note: The uniaxial compressive strength would normally be determined from laboratory tests. It has been included in this table for comparison against laboratory soil data where available.

Clays and silts bearing capacity

Soil description	Strength	Allowable bearing capacity(kN/m²)	Uniaxial compressive strength (MN/m²)
A thumb nail will not indent the soil	Hard	600	300+
Indented by a thumb nail, penetrated about 15mm with a knife	Very stiff	300	150 - 300
Indented by a thumb with effort, cannot be moulded by fingers	Stiff	150	75 - 150
Penetrated by thumb with pressure, moulded with strong finger pressure	Firm	75	40 - 75
Easily penetrated by thumb, moulded by light finger pressure	Soft	25 (should not be used as a foundation soil)	20 - 40
Extrudes between fingers when squeezed in hand	Very soft	0	< 20

Note: The undrained shear strength would normally be determined from laboratory tests. It has been included in this table for comparison against laboratory soil data where available. It is important to appreciate that clay soils in particular vary enormously in strength with moisture content. Dry weather visual assessment is certainly no indication of likely wet season performance.

Figure 5.5 Timber piles being driven into very soft ground for a culvert foundation (requires specialist expertise not covered by this guideline)

Soft or very soft clay/silt soils at the level of proposed foundations will indicate the likely requirement for special arrangements such as piling. This would require specialist expertise and designs for such conditions are beyond the scope of this guideline.

Sands and gravels bearing capacity

Soil description	Strength	Allowable bearing capacity(kN/m^2)	Standard penetration test N-value
High resistance to repeated blows with a pick	Very dense	500	>50
Requires pick for excavation, a 50mm diameter peg is hard to drive in	Dense	300	30 - 50
Considerable resistance to penetration by sharp end of pick	Medium dense	100	10 - 30
Can be excavated by spade, a 50mm peg is easily driven, can be crushed between fingers	Loose	50	5 - 10
Crumbles very easily when scraped with a pick	Very loose	Negligible	<5

Note: The standard penetration test N-value would normally be determined from in situ tests. It has been included in this table for comparison against laboratory soil data where available.

In addition to the general site selection criteria given above, the following factors should be taken into account for the different types of structures.

Drifts

- Avoid areas with steep banks (greater than 1.5metres) as these require a large amount of excavation to achieve acceptable approach gradients.
- The level of the drift should be as close as possible to the existing river bed level. This is most important as it will affect the amount of water turbulence and erosion that may occur around the drift.
- The normal depth of water should be a maximum of 150mm on the drift to allow traffic to pass.

Figure 5.6 Flat arid area location of the low point

- The watercourse should be clearly defined and stable at the crossing point to ensure that the water will not alter its flow away from the drift slab.
- In flat arid areas the exact location of the low point in the alignment or occasional watercourse may not be possible to determine without a detailed level survey.

Culverts

Figure 5.7 Ponding at culvert outlet

Culverts (or drifts) are usually required at every low point in the road alignment in addition to actual water crossing points. Exceptions to this are for an alignment along a hill or mountain ridge and where drifts or other structures are more suitable for a particular location. The culverts also allow water from the side drains to cross the road. In areas of sloping ground with little vegetation water will tend to run down the surface of a hill side and collect in the side drains. In these areas further culverts may be required to transfer this water across the road. On long continuous gradients it may also be necessary to provide additional intermediate culverts to transfer water across the road, to avoid large quantities of water building up and causing erosion to the drain, road or land downhill of the road. In such circumstances, these 'relief' culverts will be expected to be required at intervals of no more than about 200 metres.

Appropriate horizontal and vertical road alignments

The location of a culvert will be determined from the foregoing considerations. The next concern will be the level at which the culvert should be installed. On rural roads there is often insufficient attention paid to the alignment and forces related to the water flow, even when this is infrequent. This often causes problems for the performance and maintenance of the culvert.

The general guidance should be that where possible the natural water flow in terms of vertical alignment should normally be given preference over the vertical alignment of the road. If this is not done the flow of water will always be acting with any suspended material to erode the course to its natural gradient, and expensive measures may have to be taken to counter or react to this.

Some examples will illustrate this problem:

1. In flat ground, the invert of the culvert outfall should be determined by the level of the surrounding ground. Box culverts and arch culverts are preferable in these circumstances as the flat invert slabs cause less disturbance to the flow of water. Barrel culvert inverts should be similarly determined, however an outfall apron should be provided to ensure that the flow is stabilised and distributed horizontally before it reaches the natural ground downstream. If the invert is placed too low then the culvert outfall and opening will silt up. If the invert is fixed too high there will be ponding or silting upstream of the

Figure 5.8 Long culvert outfall

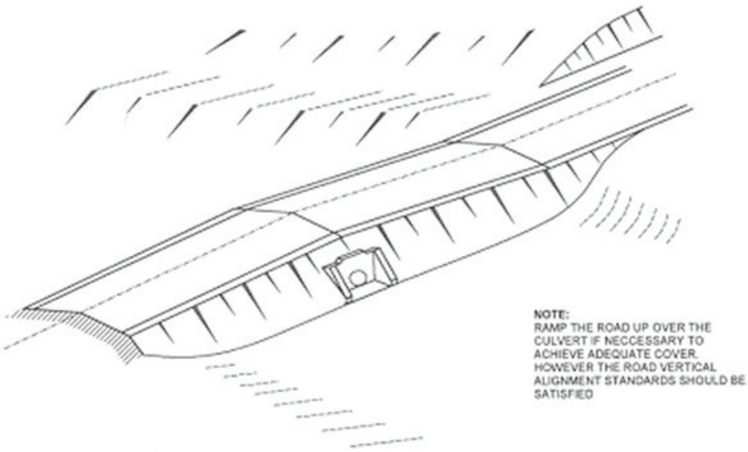


Figure 5.9 Road alignment raised over culvert

structure and the risk of erosion as the water drops to its natural vertical alignment downstream of the structure. It follows that the alignment of the road should be raised if necessary to provide the correct invert, adequate height for the structure and any necessary protective cover.

2. Where the road is on ground sloping across the alignment, a frequently observed mistake is to leave the road vertical alignment unchanged and 'bury' the culvert so that the outlet discharges in a long trench with a flat grade. Not only does this ditch often encroach substantially on the surrounding land, but it is also prone to silting and consequently to causing blockage of the culvert. Furthermore, vegetation growth and bank erosion are common related problems. In essence a maintenance problem is created. Localised raising of the road alignment can alleviate this potential problem (Figure 5.9). Long culvert outfall ditches should be avoided and their grade should not be less than 2%.

3. On steep sidelong ground a key consideration is to minimise the erosion risk. In these circumstances there is usually more opportunity to 'bury' the culvert under the road and provide a short outlet ditch. A 'drop inlet" or 'catchpit' arrangement is normally required at the inlet to provide a controlled drop in the water flow. Particular attention may still need to be paid to downstream erosion protection. Special arrangements such as energy dissipating cascades or gabions may be required in extreme cases. The drop inlet arrangements also need consideration to be made regarding risk of blockage and maintenance arrangements.

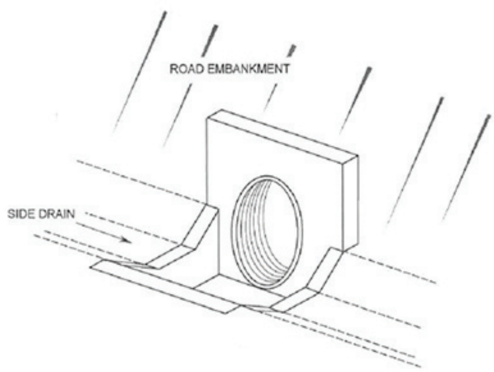


Figure 5.10 Culvert drop inlets

In all situations the road alignment standards and structure protection cover requirements should be complied with. Erosion, silting potential and maintenance implications should be seriously considered in all cases. Further guidance on culvert setting out is provided in chapter 9.

Although it is desirable for culverts to cross roads at 90 degrees to minimise the length and hence the cost of the culvert, it is not essential. However, it is important to avoid abrupt changes in stream flow direction at the inlet or outlet of the culvert as this will result in severe erosion risk for the channel (without suitable control arrangements such as a drop inlet or erosion protection).

It is not possible to achieve this requirement for relief culverts which transfer water across the road from the high side channel to the low side channel. These culverts will have an abrupt bend at the inlet and require careful protection to ensure that erosion does not occur. The design of these inlets is discussed in more detail in chapter 8. It is impossible to define the number of culverts required per km as this will vary according to the topography and weather conditions and must be determined by an investigation of the proposed route. However, as a guide there will typically be 1-3 culverts per km in arid flat or undulating land and up to 6 culverts per km in more severe terrain, high rainfall areas.

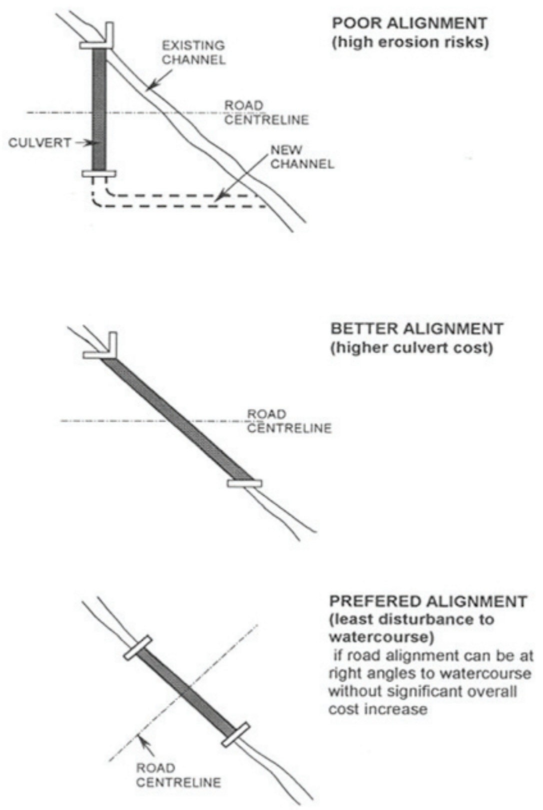


Figure 5.11 Culvert alignment options

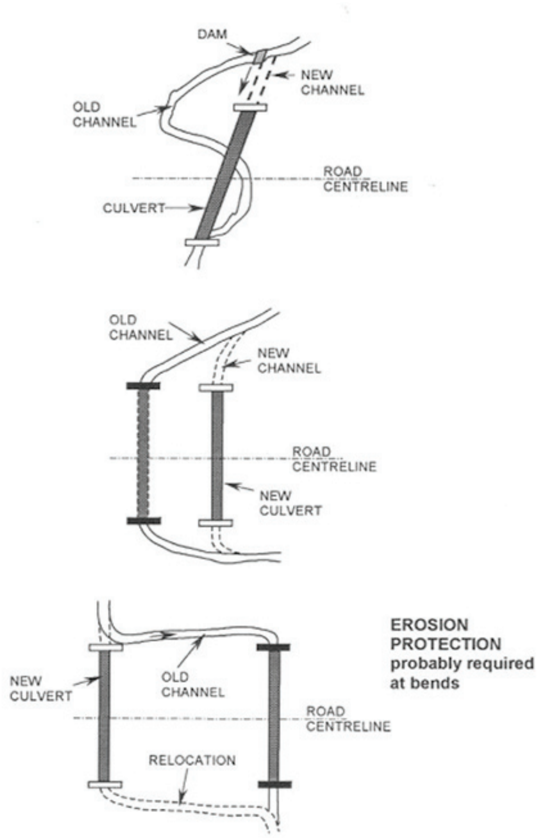


Figure 5.12 Culvert re-alignment options

Minimum recommended relief culvert spacing

Road gradient (%)	Culvert intervals (m)
12	40
10	80
8	120
6	160
4	200
2	>200

Culverts in hilly areas

In hilly areas on long steep gradients relief culverts will be required at regular intervals to transfer water from the uphill side drain to the downhill side of the road to prevent erosion from a large build up of water in the side drain. The adjacent table suggests intervals between relief culverts on long grades. Culverts will also be required at points where a stream or waterfall crosses the road. These culverts may also be used as relief culverts to transfer the water across the road.

Vented Fords

As vented fords are designed to be overtopped during flood periods it is necessary for the watercourse to be well defined both for normal flows and flood flows. During flood flows the watercourse will generally be wider but should still have clearly defined banks to enable the position and size of the structure to be identified.

A vented ford provides a constriction to the water flow, due to the solid fill between the pipes. The proposed location should allow sufficient pipes to be constructed to prevent normal flows overtopping the structure. In areas where the flow level regularly varies, it is desirable that there are sufficient pipes to only cause overtopping for larger flood flows.

The proposed site should require neither long approach embankments, as these increase the cost of the structure, nor steep approaches, which will make the structure difficult for larger vehicles to cross.

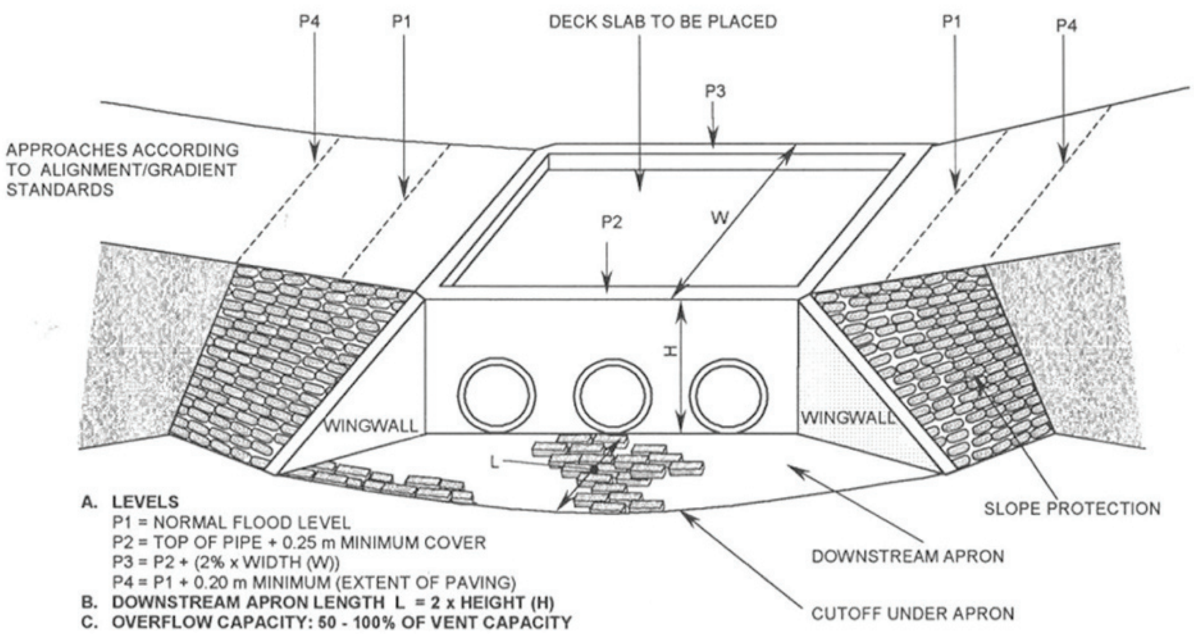


Figure 5.13 Key design criteria for a vented ford