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

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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 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

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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:

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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.

Figure 1.1 Steel lattice bridge for motorcycle traffic

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.

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.

Figure 1.2 Bailey Bridge

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.

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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

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.

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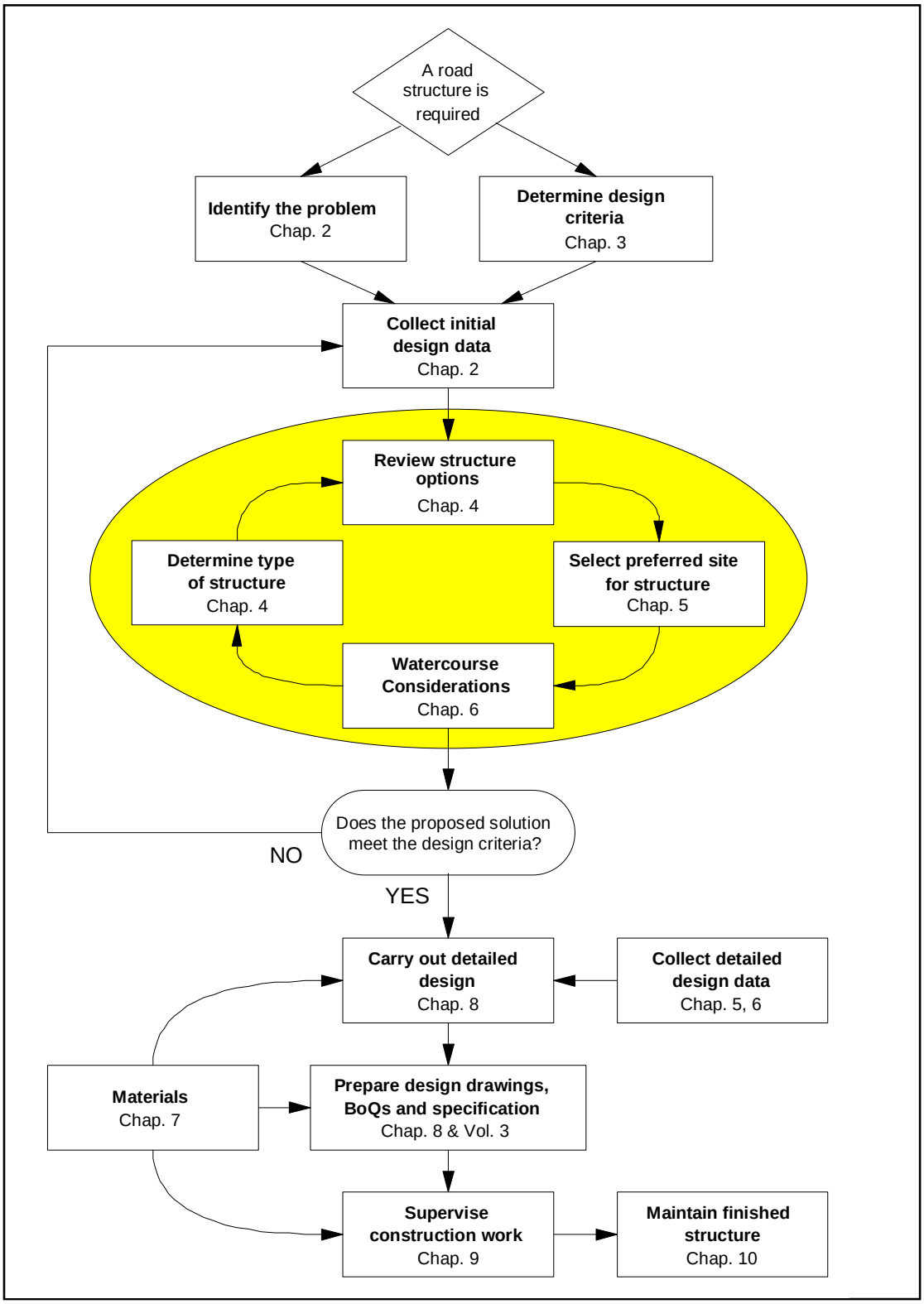
Figure 1.3 Flow diagram of the planning, design and construction process



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

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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 below 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	Length
1 hectare = 10 000 m^2 = 2.47 acres	1 mile = 1.61 km
100 hectares = 1 km^2	1 yard = 0.914 m
1 sq. mile = 2.59 km^2	1 foot = 0.305 m
	1 inch = 25.4 mm
Pressure or Stress	
1 kPa = 1 kN/ m^2	Volume
1 N/mm2 = 1 MN/ m^2	1 m^3 = 35.3 cubic ft
1 ton/in^2 = 15.44 N/ mm^2	1 m^3/s = 1000 litres/s
1 ton/ft^2 = 107.3 kN/m^2	
Velocity	k - kilo = x 1000
1 m/s = 3.6 km/h	M - Mega = x 1 000 000
1 m/s = 3.26 ft/s	

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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.

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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:

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- 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 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.

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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

- Labour

Is there an availability of trade skills in locality e.g. carpentry, stone masons?

What is the standard of workmanship available?

Options of:

1. Specialist skills vs. training local labour

2. Time/cost vs. skills transfer and ongoing maintenance potential

Labour wage rates

- 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?

- 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)

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 ?

- 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 the 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 ?

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Type of Structure (chapter 4)

Which types of structure would be acceptable ?

- 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)

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)

- 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 ?

- Catchment Details

Area of catchment ?
Shape of catchment ?
Permeability of soil ?
Rainfall intensity ?
Are sudden floods encountered ?
Gradient of terrain ?
Vegetation coverage and type ?
Is the vegetation coverage changing rapidly e.g.. Deforestation ?

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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 sites

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,

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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		Structural Condition	Remarks		Culvert Length* or bridge width* (m)	Culvert/ Bridge span (m)	Diameter/ Height		Proposed solutions
						Pipe Diam. (mm)	Height (m)						Pipe Diam. (mm)	Height (m)	
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

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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

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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

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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

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

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.

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 carriageway and 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

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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.

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.

Figure 3.4 Guide stones narrowing road width

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.

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.

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Figure 3.5 Culvert head stone outside main running lanes

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

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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.

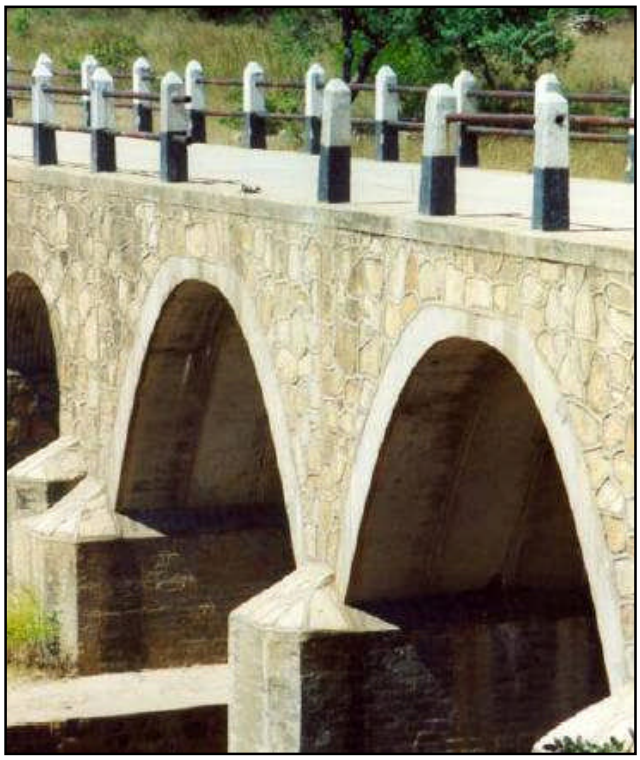

Figure 3.6 Pedestrian guard rails (in need of repair)

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

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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.

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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.

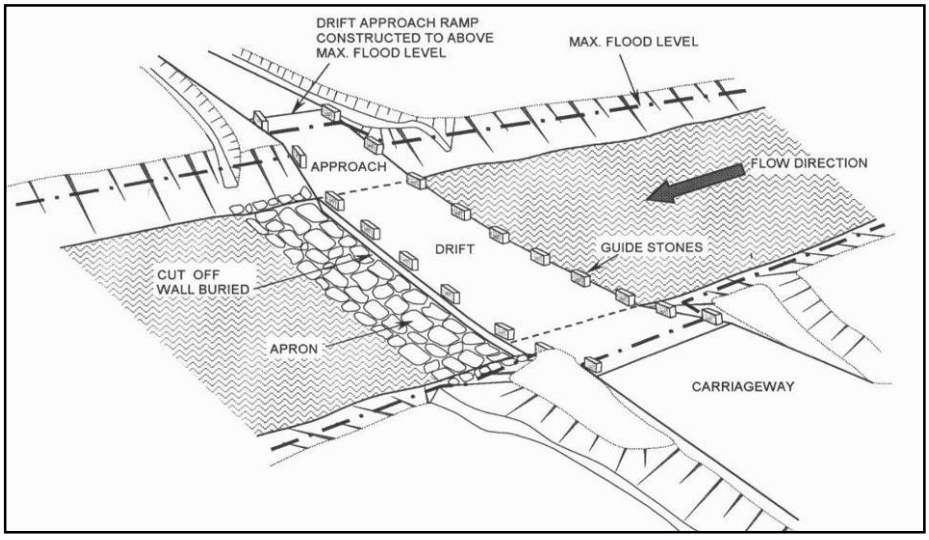

Figure 4.1 Key Features of a stream drift

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

Figure 4.2 A stream drift

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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.

Advantages	**Disadvantages**
Low cost: at the most basic level, can be constructed and maintained entirely with local labour and materials	Drifts require vehicles to slow down when crossing
Ease of maintenance and repair	The crossing can be impassable to traffic during flood periods
Volume of excavated material in most cases is minimal	Foot passage can be inconvenient or hazardous when water is flowing
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	

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Figure 4.3 A basic hand packed stone drift

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

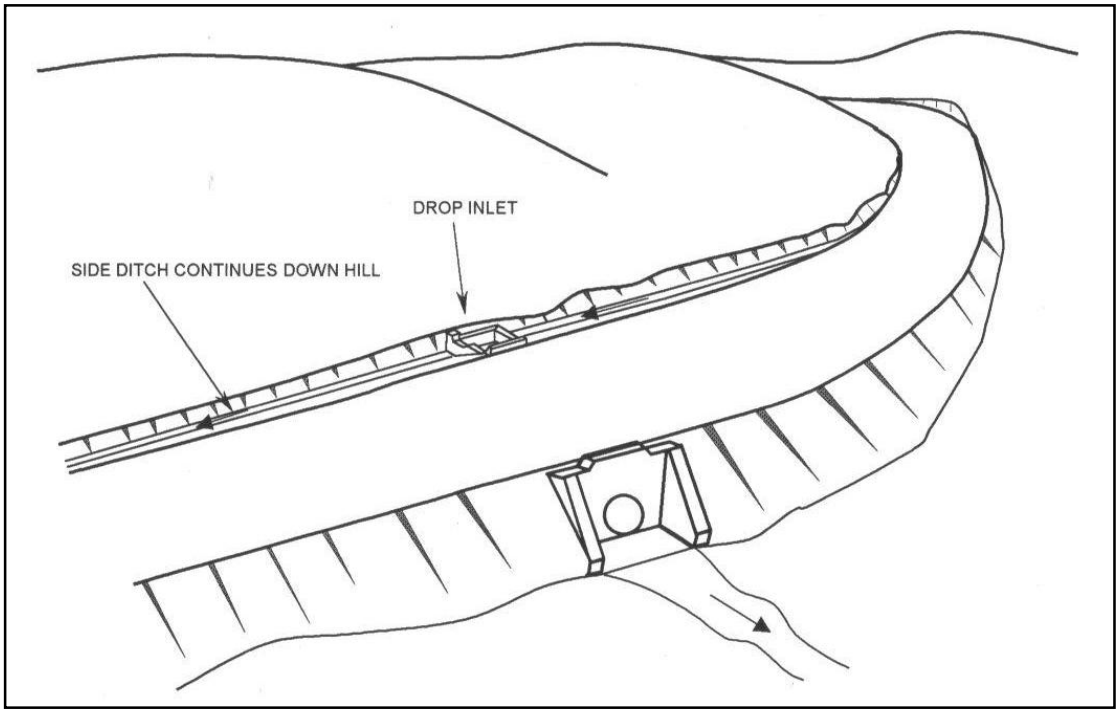

Figure 4.4 Key features of a relief culvert

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.

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- 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	Regular maintenance is often required to prevent the culvert silting up, or to remove debris blockage.
Can be constructed and maintained primarily with local labour and local materials	Culverts act as a channel, forcing water flow to be concentrated, so there is a greater potential for downstream erosion compared with drifts.
Culverts allow vehicle and foot passage at all times.	Culverts are not suited to occasional high volume flows
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	

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

Vented Fords and Causeways

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

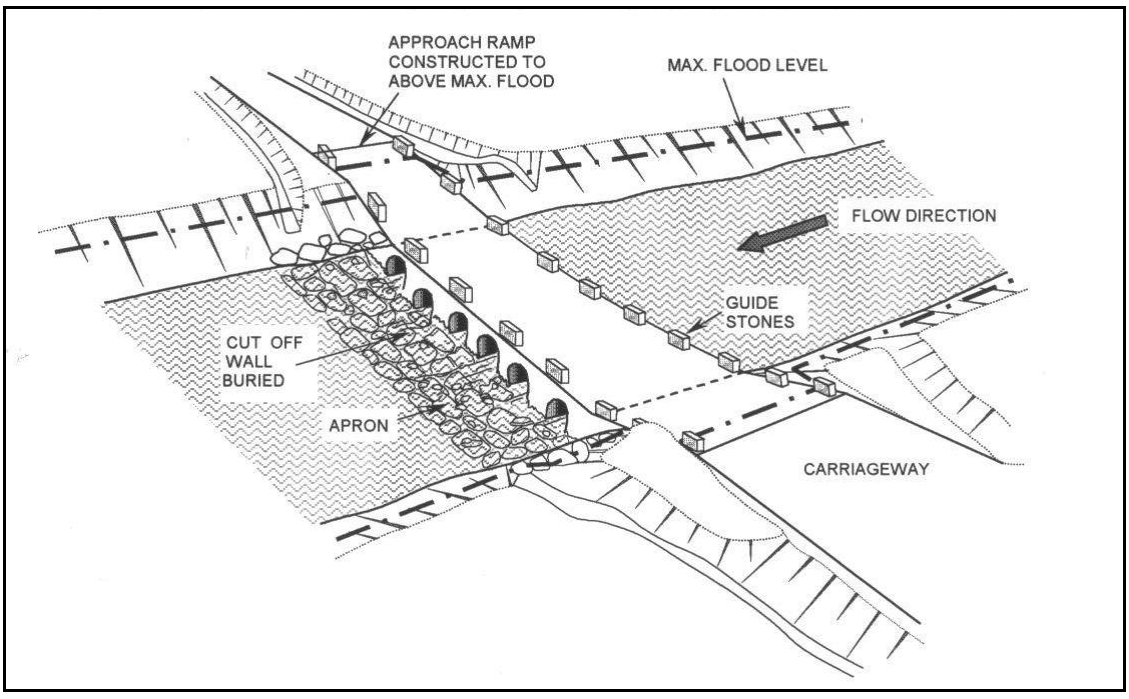

Figure 4.6 Key features of a vented ford / causeway

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

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and over the road, which may make the road impassable for short periods of time.

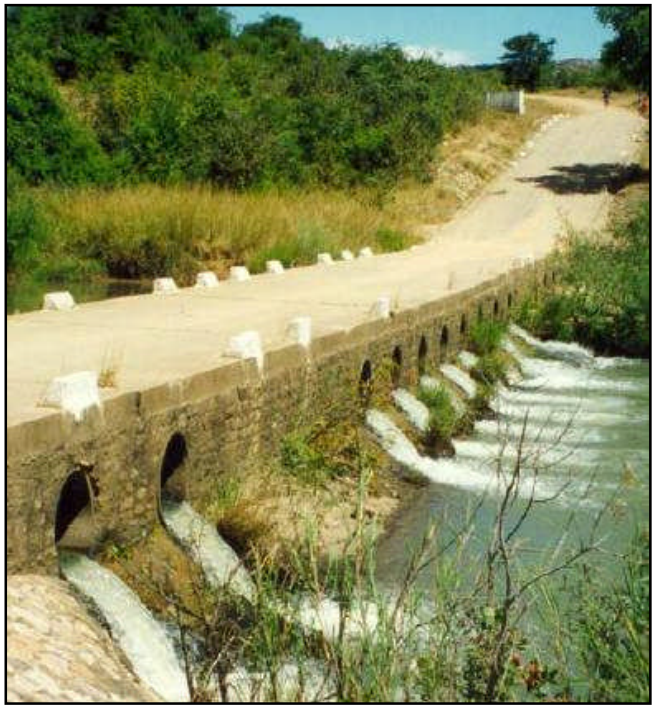

Figure 4.7 A vented ford

- 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 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

Figure 4.8 Downstream protection to a vented ford

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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

Figure 4.9 Concrete vented causeway

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Large Bore Arch Culverts

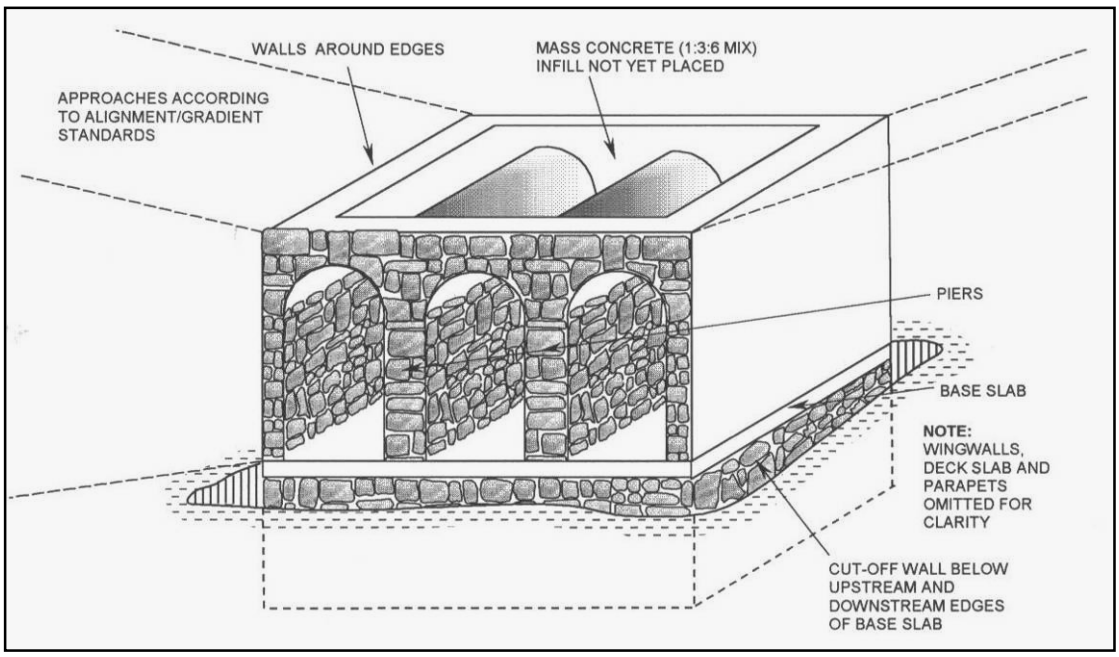

Figure 4.10 Key features of large bore culvert

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

Figure 4.11 Large bore arch culverts

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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.

Figure 4.12 Guide stones on large bore 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.

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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.

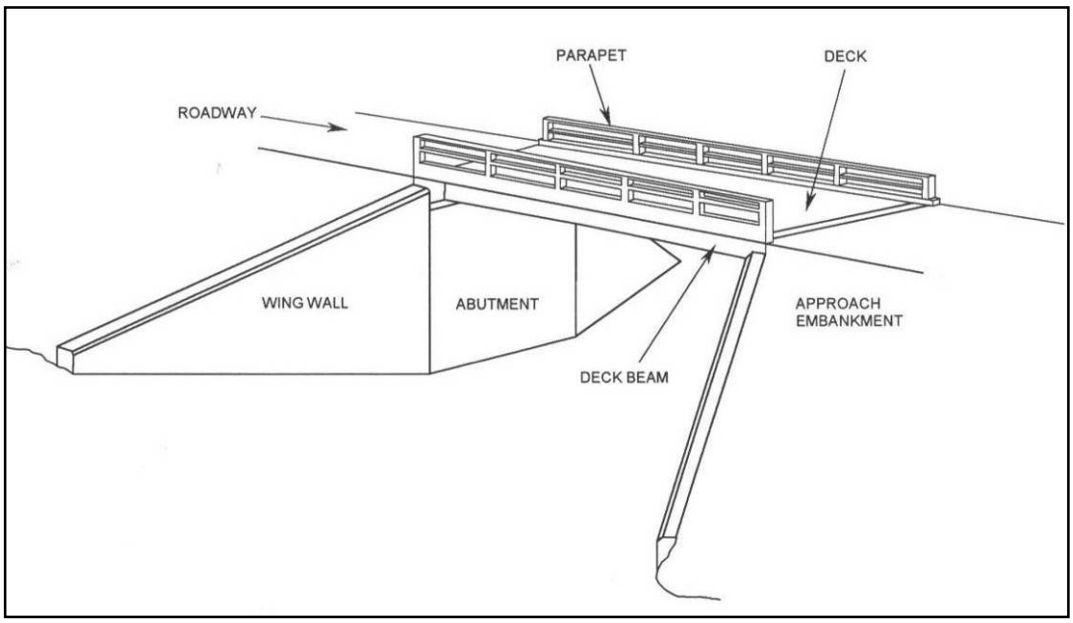

Figure 4.13 Key features of a simply supported deck bridge

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.

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- 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.

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Example comparison of timber and masonry bridge costs

Year	Timber Bridge		Masonry vented ford	
	Work Undertaken	Cost	Work undertaken	Cost
1	Construction	10000	Construction	15000
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		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.

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- 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.

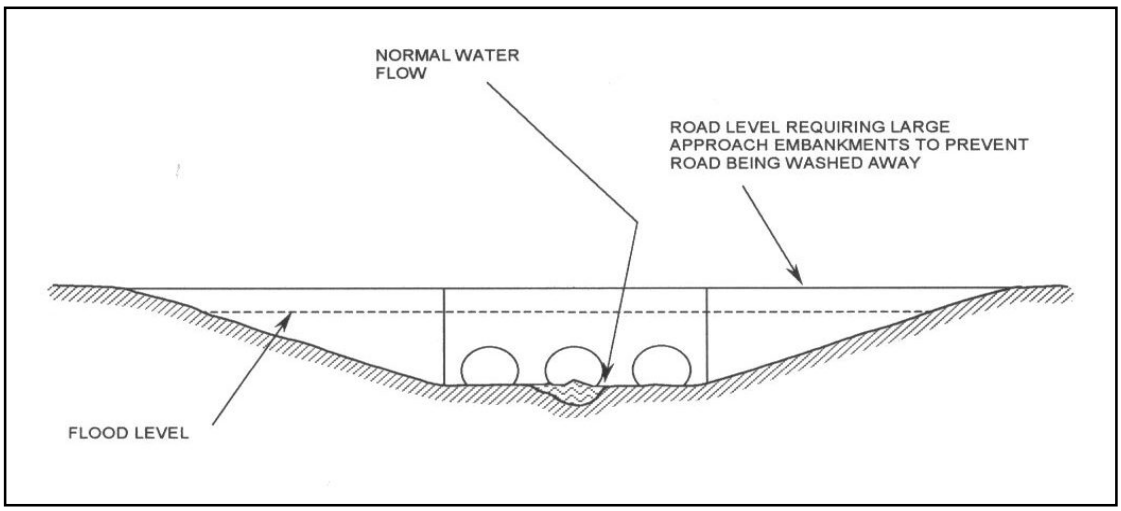
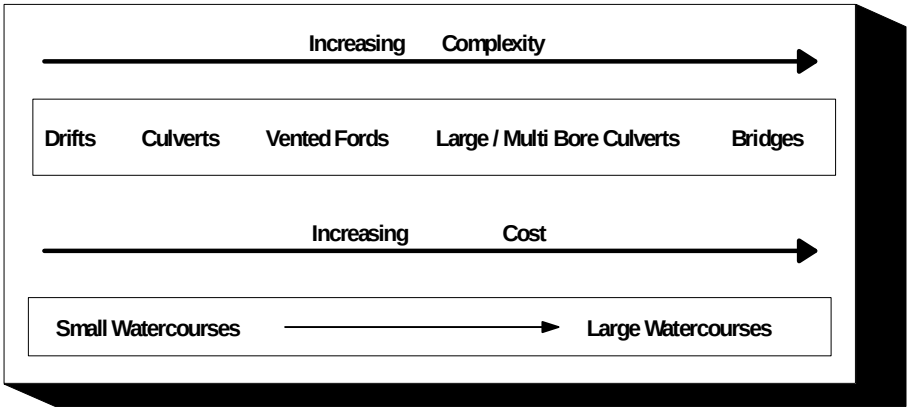


Figure 4.14 Large embankments required to prevent road flooding

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.

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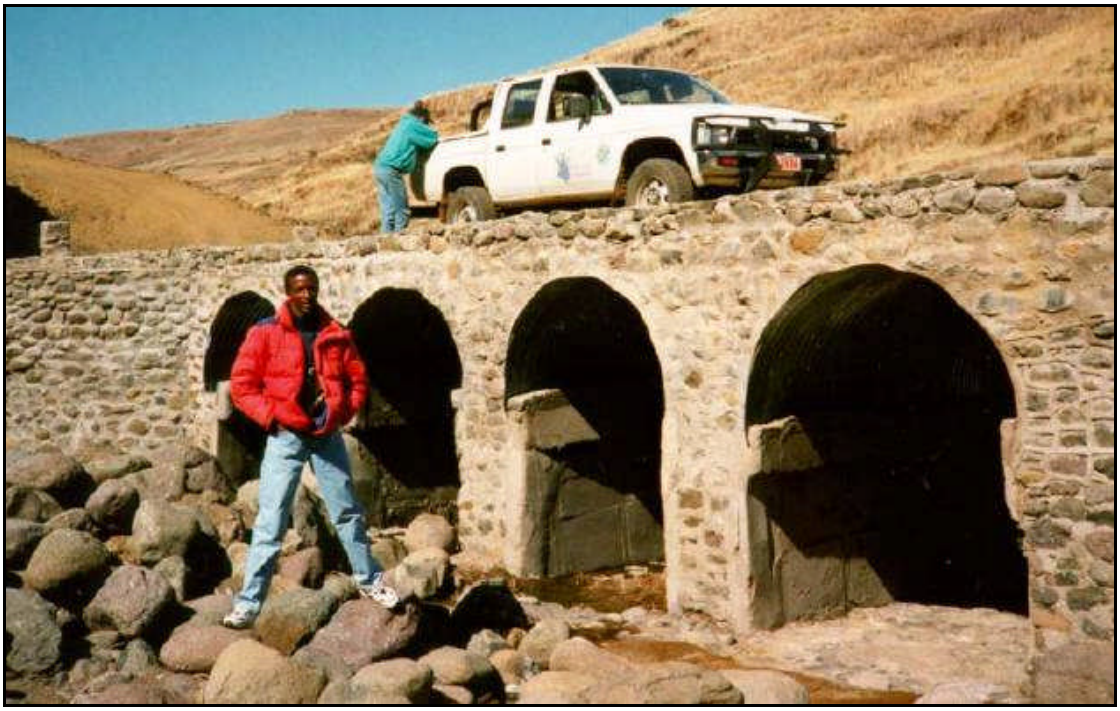

Figure 4.15 Is this a vented ford or a multi-bore culvert?

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.

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

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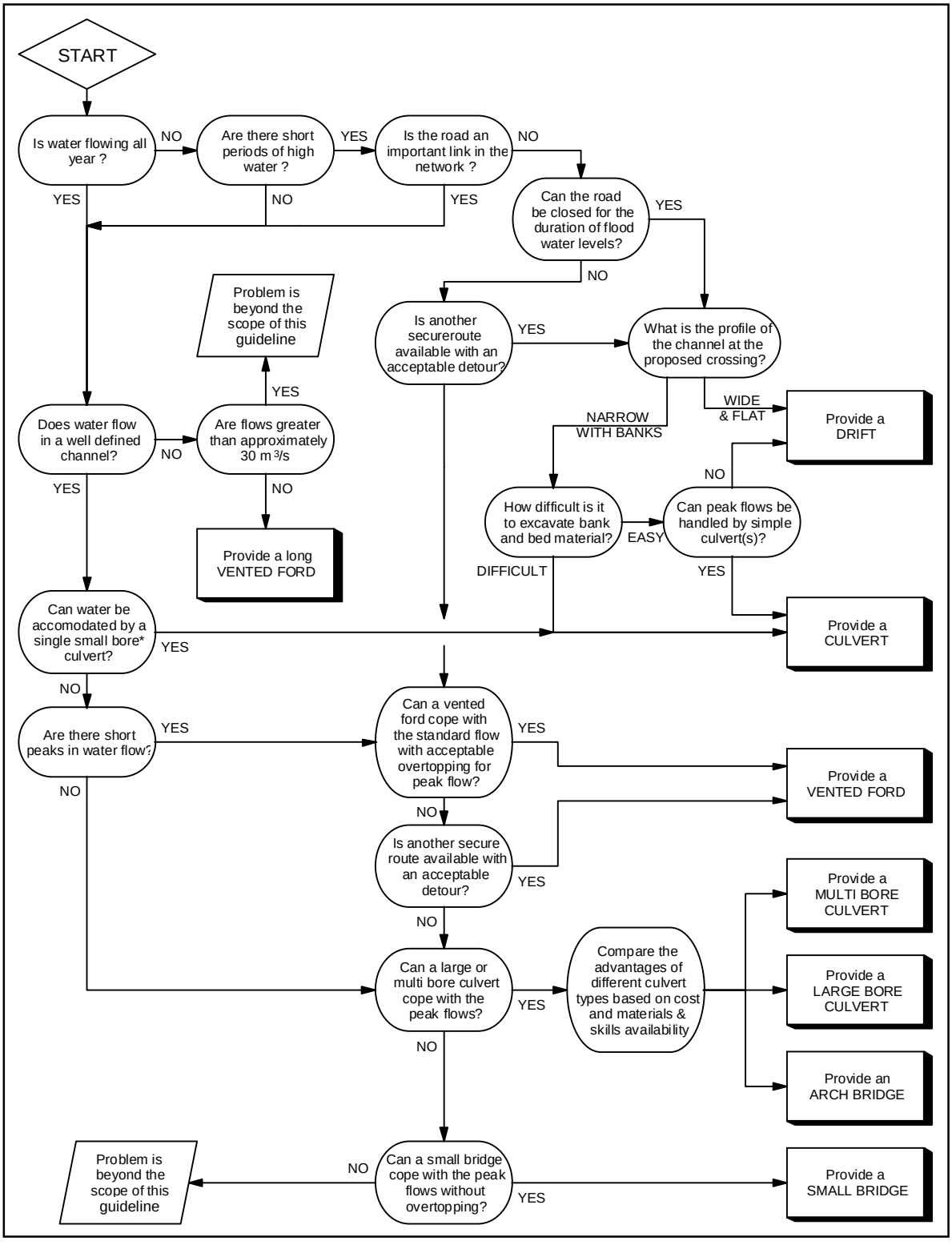
Figure 4.16 'Route map' for the selection of a suitable structure



*Small bore – diameters less than 900mm

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

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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.

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.

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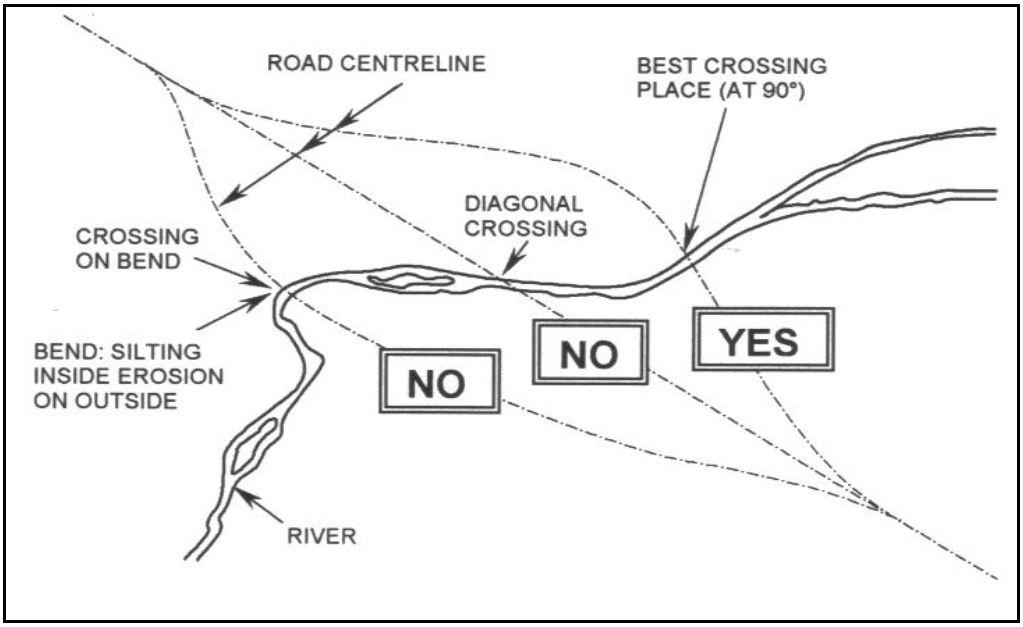

Figure 5.1 Suitable crossing points for larger structures

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.

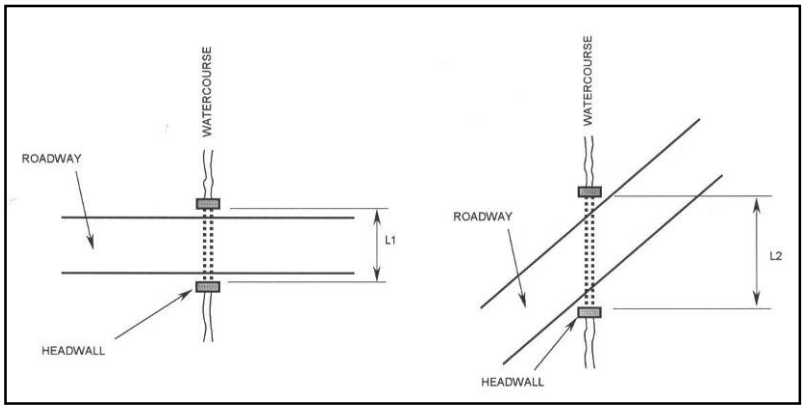

Figure 5.2 Right angle crossings reduce the length and cost of structure required.

- 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.

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- 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.

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.

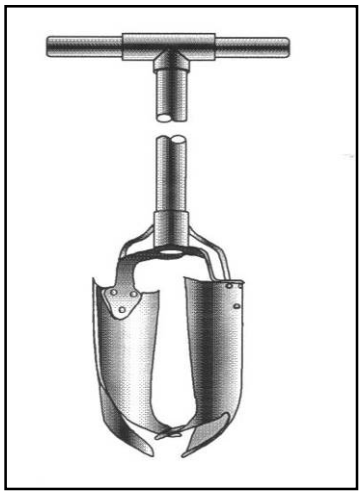

Figure 5.3 A hand auger

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

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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

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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/m^2)	Uniaxial compressive strength (MN/m^2)
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/m^2)	Undrained shear strength (kN/m^2)
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.

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.

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

Sands and gravels bearing capacity

Soil sample 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.

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- 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.

Figure 5.6 Flat arid area location of the low point

Culverts

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.

Figure 5.7 Ponding at culvert outlet

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

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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 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.

Figure 5.8 Long culvert outfall

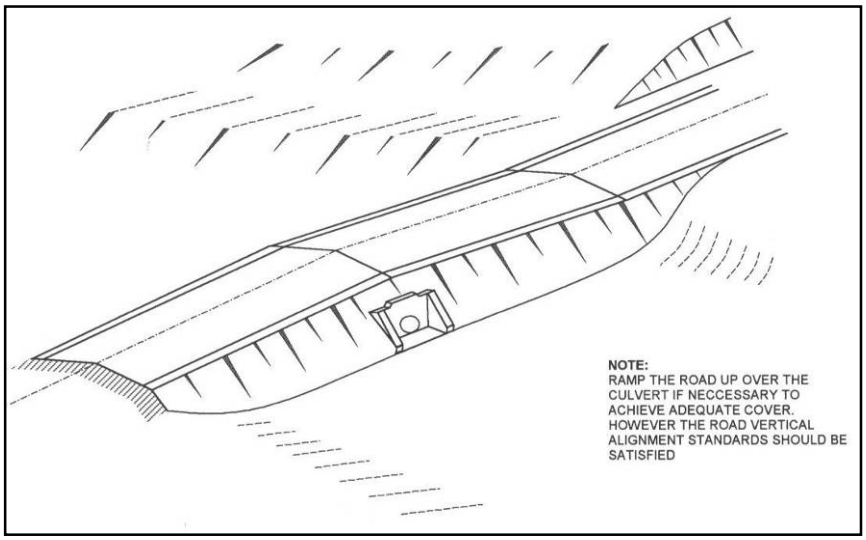

Figure 5.9 Road alignment raised over culvert

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

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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.

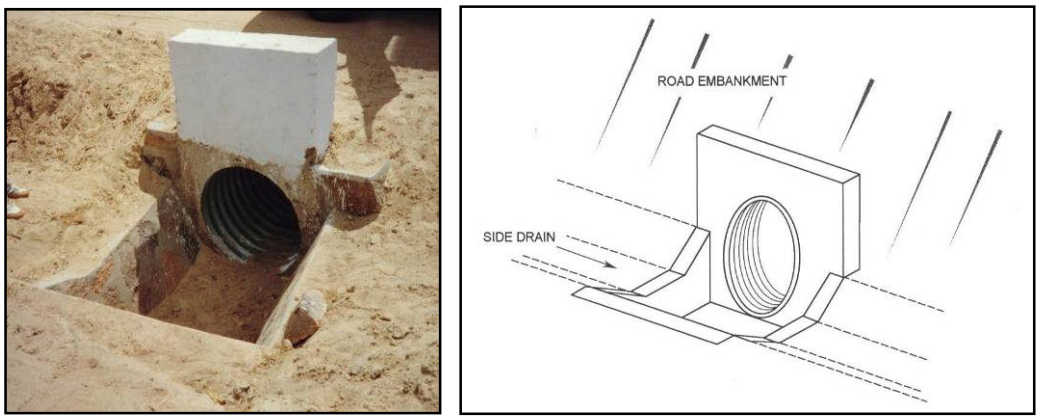

Figure 5.10 Culvert drop inlets

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.

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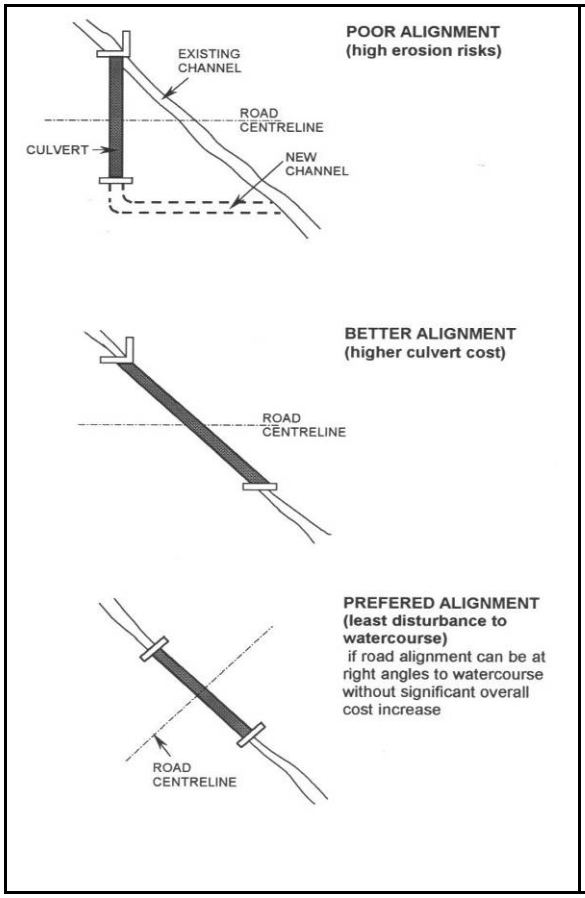

Figure 5.11 Culvert alignment options

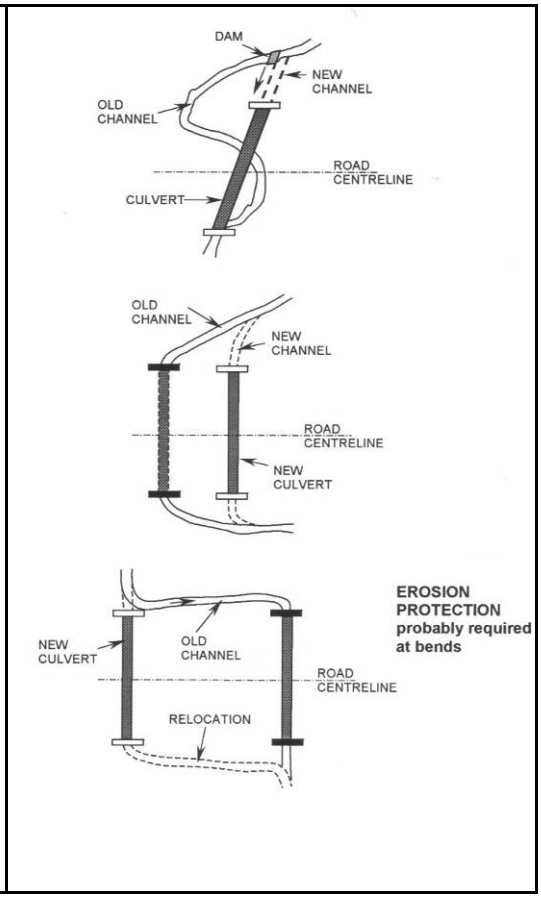

Figure 5.12 Culvert re-alignment options

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 table below 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.

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

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.

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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.

Vented fords can be built on relatively weak ground as their dead weight is spread over the whole area of the structure. However, the ground should not be susceptible to long term settlement under the dead weight of the fill material, as this could result in damage to the structure. To minimise the cost of the vented ford a suitable source for fill material should be available close to the proposed site.

If the volume of traffic using these structures cannot justify two way traffic, the proposed site should allow drivers to see the opposite end of the crossing and have waiting areas at each end to allow vehicles to pass each other safely. On road networks where there is a long detour to avoid the vented ford when it is impassable, the proposed site should have a waiting area on both sides of the structure sufficiently large enough for the expected number of waiting vehicles. This waiting area may consist of widening the carriageway or an area where vehicles can pull off the road.

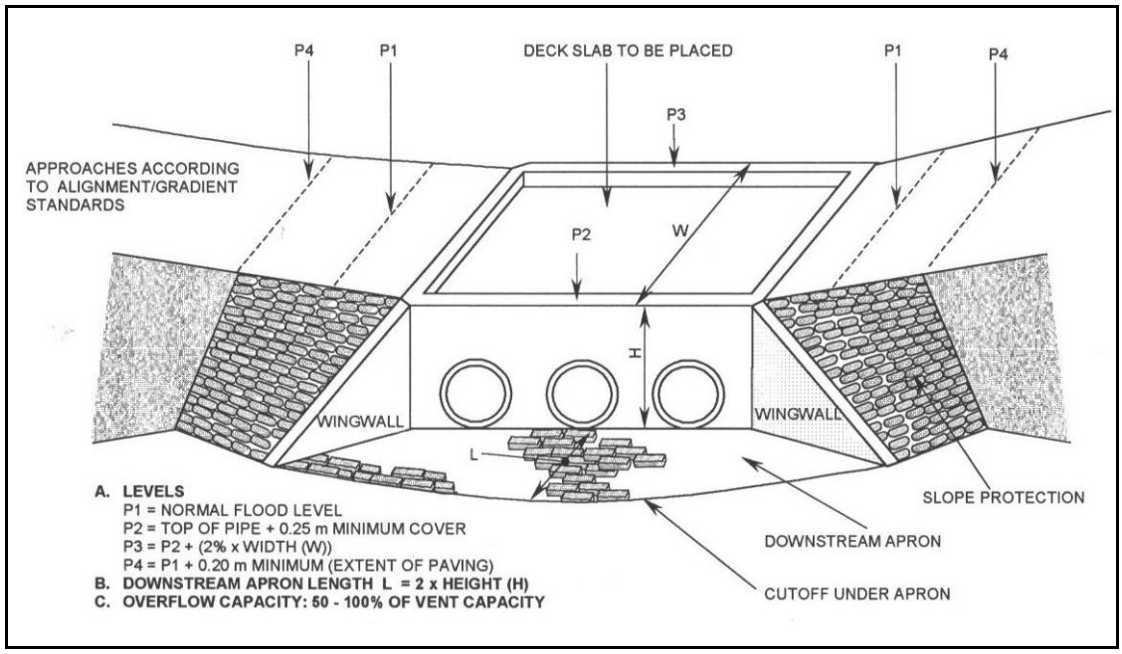

Figure 5.13 Key design criteria for a vented ford

Large Bore Culverts

Large bore culverts require the bed of the watercourse to be at least 2 metres below the proposed road level, to allow sufficient cover over the culvert barrel. Proposed sites for these culverts should have watercourse banks higher than two metres to prevent the need for long approach embankments which increase the cost of the structure.

If the crossing site will require more than one arch there should be suitable ground conditions to construct firm foundations for the piers as well as the abutments. Large arches can exert substantial forces on the ground at each end, and therefore usually require firm ground on each side of the watercourse. If the foundation strength is insufficient to support arch springing thrust blocks or pier foundations, it may be necessary to consider provision of a foundation slab across the entire structure.

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Large bore culverts are usually not expected to be overtopped. Consideration of the consequences of the high flood and its potential to overtop the structure should be made for the proposed site.

As a substantial amount of fill material can be required for a large bore culvert, the total construction costs can be reduced if suitable fill material is available near the crossing site.

Bridges

The site selection of bridges often involves detailed site investigations which are beyond the scope of this guideline. For further guidance refer to publications such as Overseas Road Note 9. For bridges up to 8 metre spans the guidelines given below should be followed.

The most common cause of failure of bridges is scour of the abutments or piers. In addition to the factors discussed for all structures above, a site which can avoid the use of piers and has firm ground for abutment foundations is the overriding criteria in selecting a suitable site for a bridge crossing.

Additional factors which should be taken into account:

- Artificial constriction of the watercourse due to the proposed position of the abutments should be minimised to reduce the depth of scour.
- The stream velocity should be modest - i.e. the watercourse should be on a shallow gradient to reduce the possibility of scour.
- The proposed site should require a minimal amount of work to be carried out underwater. Where work in the water is unavoidable a site which reduces the amount of underwater work either by a simple cofferdam or construction during a dry period is preferable.
- The bridge superstructure should be above the design flood level. Consideration should also be given to the possible consequences of a high flood on the bridge superstructure.

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6. Watercourse characteristics

Road structures are constructed not only to remove water from the road and side drains, but also to transfer water from one side of the road to the other where it crosses a natural watercourse. These natural watercourses transfer rainfall from higher ground to lowlands and eventually, usually, into the sea. The water flowing in a stream or river is called the runoff and will usually be expressed as mm per unit area or a total volume in cubic metres for a stated period of time. There are many factors which will affect the runoff, or amount of water in a watercourse, and hence the type of structure which will be required:

Rainfall
- Annual and seasonal variations
- Extent and duration of the rainfall
- Intensity and distribution

Geological features
- Type and permeability of the soil
- Natural water storage characteristics of the catchment area

Size of the catchment
- Intense rainfall only occurs over a small area at any point in time so runoff is not proportional to size of catchment
- Fan shaped catchment will give higher peak flows as runoff will arrive at the confluence of all streams at the same time. Long and thin catchment areas have the discharge spread over a longer period and have relatively smaller peak flows for a similar area.

Topography
- The relief of the ground
- Character of the area: smooth or rugged

Land use
- Natural drainage of the area
- Vegetation cover

A wide range of hydraulic information may be required for the design and construction of water crossing structures. The amount of information required and its accuracy will depend on the type and complexity of the proposed structure. The following table indicates hydraulic data and other information about the watercourse which is required for different structures, along with the potential inaccuracies that may be encountered.

The most important hydraulic factor for structures is the maximum peak flow (or runoff). Culverts and bridges must be capable of accommodating the peak runoff, after heavy rain, without overtopping, and vented fords or drifts must be able to pass the peak runoff without erosion or other damage to the watercourse or roadway. In the case of drifts and vented fords the normal runoff or average flow will also be important, to ensure that the drift will be passable or the pipes on the vented ford can accommodate normal flows.

Maximum peak flow

The maximum peak flow is the most important information to be collected as it is used to determine the size of the chosen structure. There are a number of methods which can be used to assess the maximum peak flow. These methods vary in complexity of calculation and accuracy. The option chosen will depend on the availability of topographical data and the accuracy required for the structure to be constructed.

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Hydraulic and watercourse data required to undertake design

Hydraulic Data	Drift	Culvert	Vented Ford	Large Bore Culvert	Bridge
Maximum peak flow	Use methods 1,2,4 described below, but see flood return period	Use methods 1,2,4 described below, but see flood return period	Use methods 1,2 & 4 as a cross check for method 3 described below	Use all methods described below and use worst case result. Accurate rainfall data is required	Use all methods described below and use worst case result. Accurate rainfall data is required
Duration of peak flow	Required	Not required	Required	Not required	Not required
Flow velocity	Desirable to know	Required	Required	Required	Required
Normal flow rate	Required	Not required	Required	May be required	May be required
Perennial / seasonal flow	Required	Not required	Required	Not required	Not required
Amount of debris in watercourse	Not required	Required	Required	Required	Required
Type of watercourse (alluvial/incised)	Required	Required	Required	Required	Required
Watercourse bank and bed characteristics	25m above and below crossing point	25m above and below crossing point	25m above & 50m below crossing point	100m above & 200m below crossing point	200m above and below crossing point
Catchment area & shape	May be required to calculate peak flow rate	May be required to calculate peak flow rate	Required	Required	Required
Cross-sections at crossing point	Required	Required	Required	Required	Required
Cross-section 100m above crossing point	Not required	Required	Required	Required	Required
Cross-section 400m above crossing point	Not required	Not required	Not required	Not required	Required
Cross-section 150m below crossing point	Not required	Not required	Not required	Required	Required
Hydraulic gradient up- and down-stream	50m above & 25m below crossing point	100m above and 50m below crossing point	100m above and 50m below crossing point	250m above and 100m below crossing point	250m above and 100m below crossing point
Permeability of soil	←	—	Desirable for determining peak flow	→	→
Rainfall intensity	←	—	Desirable for determining peak flow	→	→

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♦ Method 1 - Observation

It may be possible to observe previous high water marks from existing structures, trees or other vegetation near the watercourse. Small debris floating down the river will be caught on branches and twigs during floods and indicate the water level during a flood. The highest flood is the most likely to be visible as it will often 'rub off' smaller flood tide marks. The problem with this method is that there is often no indication of how old the flood level indicators are and hence what the return periods will be. There may in the past have been higher floods but these marks have been removed by natural weathering. This method will therefore give an indication of a recent high flood level but will not be guaranteed to be the highest expected flood level. The information gathered by observation may be supplemented by interviews with local residents.

Figure 6.1 Flood debris caught on vegetation

♦ Method 2 - Interviews

If there are people living near the proposed crossing point it would be possible to ask them how high the water level has risen in previous floods, as these occurrences tend to intimately affect their activities. If this method is adopted a number of people should be questioned as memories 'fade' over time and floods may 'get bigger' each time the story is told. It may be possible to ask people individually how high the biggest flood had been over the previous years and then take an average of the results obtained. Validation may be improved if enquiries are made for each bank independently and for different locations along the banks that provide information that can be correlated. Alternatively a group may be asked to collectively agree the maximum height of the flood water. It will also be necessary to ask how often floods of the maximum size occur in order to determine the return period.

Figure 6.2 Visual records of recent floods may be recorded

The two methods described above can often form a good cross check between the data obtained for each method.

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♦ Method 3 - Rational Method

This method is accurate for smaller catchments up to 10 km^2. The rational method may be used for larger catchments but the results obtained will tend to be larger than the actual floods encountered.

Q = 0.278 C I A

where
Q = flood flow in m^3/s
C = runoff coefficient (see tables below)
I = rainfall in mm/hr (rainfall intensity)
A = drainage area contributing to runoff in km^2

Runoff coefficient: Humid catchment

Average Ground Slope	Soil Permeability			
	very low (rock & hard clay)	low (clay loam)	medium (sandy loam)	high (sand & gravel)
Flat 0 - 1 %	0.55	0.40	0.20	0.05
Gentle 1 - 4 %	0.75	0.55	0.35	0.20
Rolling 4 - 10 %	0.85	0.65	0.45	0.30
Steep > 10 %	0.95	0.75	0.55	0.40

Runoff coefficient: Semi-arid catchment

Average Ground Slope	Soil Permeability			
	very low (rock & hard clay)	low (clay loam)	medium (sandy loam)	high (sand & gravel)
Flat 0 - 1 %	0.75	0.40	0.05	0.05
Gentle 1 - 4 %	0.85	0.55	0.20	0.05
Rolling 4 - 10 %	0.95	0.70	0.30	0.05
Steep > 10 %	1.00	0.80	0.50	0.10

Note: The soil permeability will also be affected by the type of cultivation; these values may be increased by 0.1 for cultivated land and decreased by 0.1 for forested land.

♦ Method 4 - Estimation

The main problem with the rational method is the requirement to have data available on the predicted rainfall intensity. In many regions this data may not exist or be incomplete. For catchments up to 15km^2 an approximate maximum flood flow can be calculated by assuming a discharge of 1 - 2 m^3/s per 25 hectares of catchment area.

Flood return period

Each flood will have a different size and intensity. Over a period of years the maximum flood experienced each year will vary. Chapter 3 indicated that the maximum design flood that a structure should be able to accommodate would depend on the type of structure and be related to a number of years. A 100 year flood (the largest flood expected in 100 years) will be much greater than a 5 year flood (the largest flood expected in 5 years). Data may be available for the size of flood, or rainfall intensity, which will be predicated over a particular period (12.5 years and 100 years are popular record assessment periods). However, designs for drifts and small culverts will suggest a shorter return period due to the less serious (physical and financial) consequences of storm damage and hence a smaller storm basis may be justified for their design. The

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table below provides factors to adjust the size of a given storm period to another period based on a 12.5 year flood.

Flood period	2	3	5	7	10	12.5	15	20	25	50	100
Adjustment factor	0.15	0.3	0.5	0.65	0.9	1.0	1.1	1.3	1.5	2.0	2.5

Example
The 12.5 year flood has a rainfall intensity of 35 mm/hour. What will be the rainfall intensity of a 5 year flood ?
From the table, the 5 year flood factor is 0.5. Therefore rainfall intensity = 35 x 0.5 = 18 mm/hour.

The table can also be used to adjust flood flows for other return periods.

Example,
The 25 year flood results in a flood flow of 12 m^3/s. What will the 10 year flood flow be?
From the table the 25 year factor is 1.5 and the 10 year factor is 0.9.
Therefore the 10 year flood flow = 12 x 0.9 / 1.5 = 7 m^3/s.

Duration of peak flow

The duration of peak flow will not usually affect the design of the structure, but will determine how long the crossing may be impassable. It is therefore necessary to collect this data if a drift or vented ford is proposed. The duration of the peak flow depends on the factors which affect the rainfall runoff described above, and may therefore be difficult to calculate. As this data is only required for simple structures it would be acceptable to rely on information gathered from the local population and/or the following rule of thumb.

For catchment areas less than $10km^2$ the designer can assume that the duration of peak flow will last no longer than twice the length of rainfall periods.

Flow velocity

The velocity of the water flow during peak floods is important to determine as it affects the amount of scour that can be expected around the structure, and hence the protective measures that may be required. The velocity can be measured in two ways.

- Direct observation in flood conditions

An object which floats, such as a stick or piece of fruit, may be thrown into the river upstream of the potential crossing point. The time it takes to float downstream a known distance (about 100m is a suitable distance) should be measured. The velocity can then be calculated by dividing the distance the floating object has travelled by the time taken. This exercise should be repeated at least 3 times, but preferably 5 times, to get an accurate result. Tests where the floating object is caught on weed or other debris in the water should be discarded. The opportunities for making such observations during flood conditions are obviously very limited.

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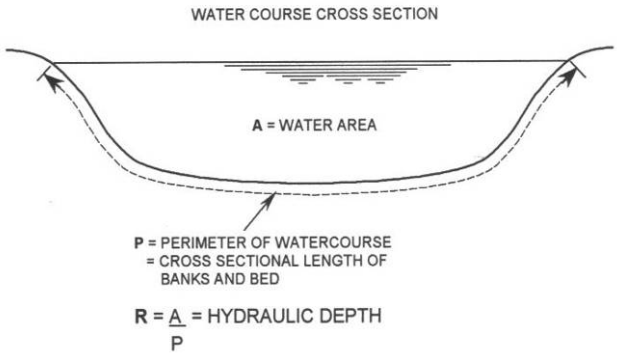
- Mannings formula

$V = 1/n \ R^{2/3} \ S^{1/2}$ V = velocity in m/s R = hydraulic depth (the area for the stream flow divided by the wetted perimeter) S = hydraulic gradient (the slope of the river bed over a reasonable distance either side of the crossing point) n = roughness coefficient (from the table below)	 Definition of hydraulic depth

It is difficult to define an exact value of n in tables. It is necessary for the engineer to relate the characteristics described above in relation to the watercourse being considered to interpret the value of 'n' to be used.

Roughness coefficient

Stream characteristics	Ranges of values of n
Streams in upland areas	
1. Gravels, cobbles and boulders with no vegetation	0.030 - 0.050
2. Cobbles and large boulders	0.040 - 0.070
Streams on plains	
1. Clean straight bank with no rifts or pools	0.025 - 0.033
2. Same as 1 but with some weeds and stones	0.030 - 0.040
3. Winding watercourse, some pools and shoals but clean banks	0.035 - 0.050
4. As 3 but straighter river with less clearly defined banks	0.040 - 0.055
5. As 3 but with some weeds and stones	0.035 - 0.045
6. As 4 but with stony sections	0.045 - 0.060
7. River reaches with weeds and deep pools	0.050 - 0.080
8. Very weedy river reaches	0.080 - 0.150
9. Stream out of channel flowing across grass	0.030 - 0.050
10. Stream out of channel flowing through light bush	0.040 - 0.080

Normal flow rate

The normal flow rate, like the peak flow rate, is linked to the total runoff and dependent on the rainfall in the catchment area. As the design of structures is primarily based on the peak flow rate it is necessary to know the normal flow rate for two reasons:

1. For the design of drifts and vented fords it is necessary to ensure that vehicles can cross the drift during the normal flow or that in the case of a vented ford the water passes through the pipes and the vented ford is not overtopped.
2. To check that there will be no long term damage to the structure due to erosion. The short period of peak flows may not damage erodable parts of the structure. However it is necessary to ensure that parts of the structure permanently in contact with the water flow are not damaged.

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Perennial / seasonal flow

An investigation into the variation in seasonal water flows is required if the proposed structure will be overtopped. It is necessary to determine the proportion of the year that higher flows will be experienced to estimate the number of days the structure may not be passable. It may be necessary to raise the running surface of the structure, such as a vented ford, to ensure that the structure is only overtopped during particularly rainy months. Unless detailed rainfall data is available for the area it is likely that the only suitable methods for collecting seasonal water levels and flows will be from the knowledge of the local population.

Amount of debris in water

Any debris, such as tree branches, carried in the water could cause blockages in the structural openings. A few small branches can quickly block the 600mm opening of a culvert pipe resulting in water backing up in the watercourse and potential damage to the culvert or road. Investigations must therefore be carried out to determine the amount of debris that is typically carried downstream during a flood, to determine if protective measures are required and/or determine the frequency of maintenance required to the completed structure to remove trapped vegetation. The funding, resources and likely responsiveness of the maintenance authority responsible for the route should be investigated to assess the risk of debris blockage and subsequent damage.

Type of river (incised or alluvial)

A stretch of river may be described as incised or alluvial . The upper sections of a river are classified as incised, where the river is eroding the sides and bed of the watercourse. Incised water flows are, in general, irregular with faster and slower flowing sections. The lower sections of a river are typically alluvial, with the watercourse meandering across flat plains. Each of the river characteristics provides challenges for the designer:

- Incised

This section of the river is particularly prone to scour, especially around piers and abutments, which requires careful consideration to protection measures.

- Alluvial

The lower reaches of a river normally flow at a steadier rate. There is an equal amount of erosion and deposition of material in the channel as the stream is already carrying a large amount of sediment. Although scour will still occur around abutments and piers an additional problem for a designer is that the watercourse is often unstable; changing its route. It may therefore be necessary to train the river to ensure that it continues to flow through the structure rather than breaking through the road alignment at an alternative point.

Watercourse bank and bed characteristics

Visual inspections of the watercourse bank and bed should be carried out to determine the type of soil and depth to a firm stratum or rock. The ground conditions will determine the size, depth and shape of the structures foundations. Watercourse characteristics will also determine the amount of protection required to the river bank downstream of the structure. It is not necessary to dig trial pits in the actual river bed unless piers are required in the watercourse. In this case a temporary cofferdam may be required to enable investigations if the bed does not dry out in the dry season. Pits in the sides of the watercourse around the site of the proposed structure foundations provide useful information.

Catchment area and shape

The size of the catchment will determine the maximum peak runoff that may be experienced after heavy rain. It may be determined from topographical maps, if they are

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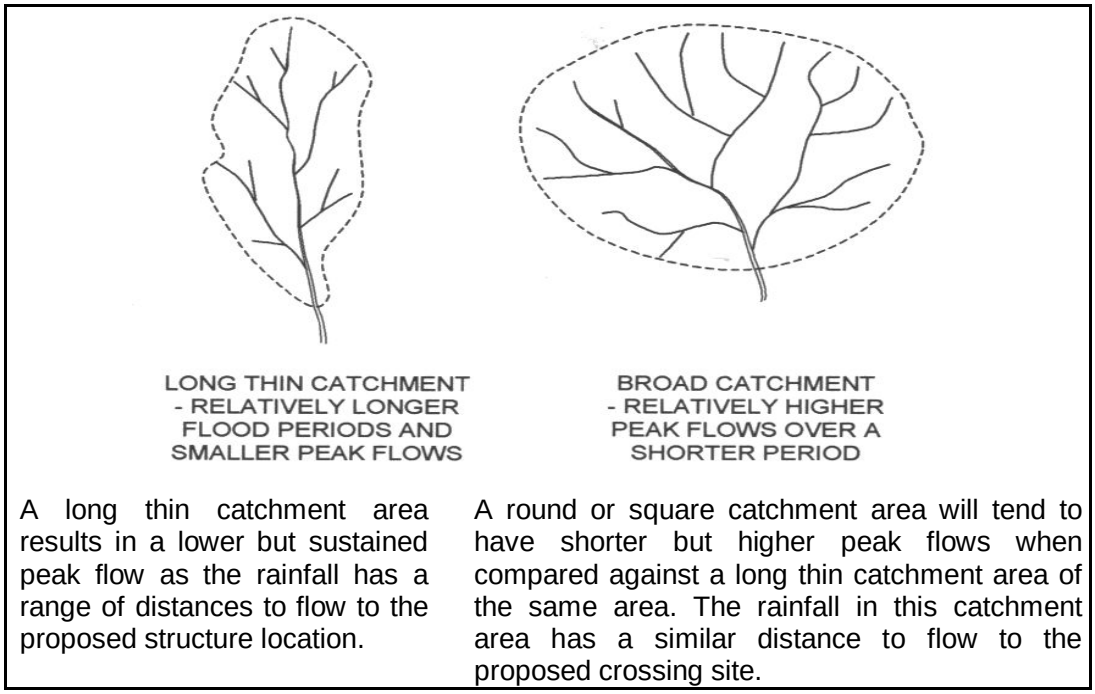
available, or from a simple field survey of the area. The shape of the catchment area may also be of interest to the designer as it will affect the size and duration of peak flows.



A long thin catchment area results in a lower but sustained peak flow as the rainfall has a range of distances to flow to the proposed structure location.

A round or square catchment area will tend to have shorter but higher peak flows when compared against a long thin catchment area of the same area. The rainfall in this catchment area has a similar distance to flow to the proposed crossing site.

Figure 6.3 Catchment characteristics

Cross-sections at crossing point

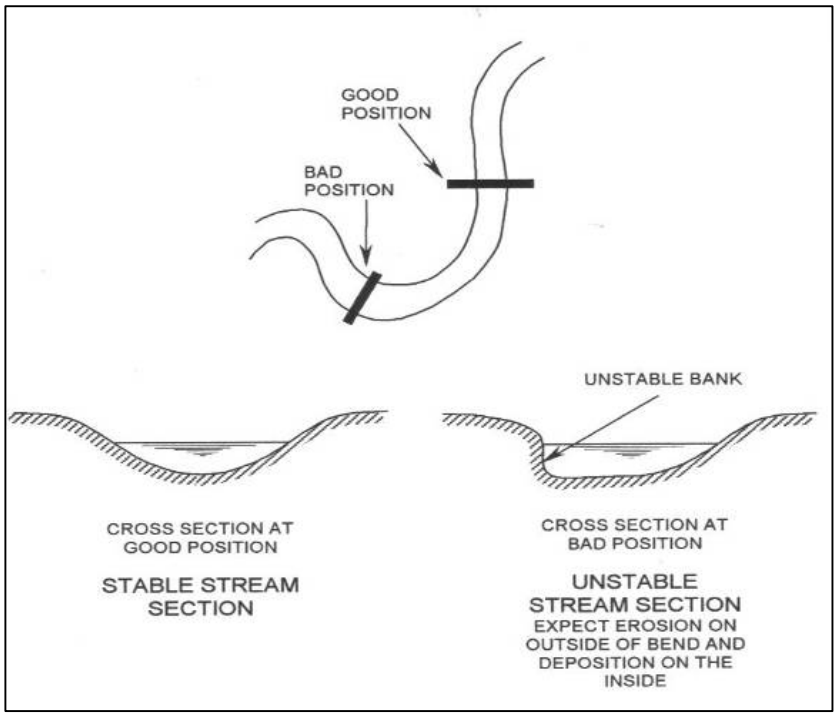


Figure 6.4 Stream crossing point cross sections

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The cross-section of the watercourse at the crossing point will affect the design of the structure. The watercourse should be surveyed and a section drawn with an exaggerated (5 or 10 times) vertical scale for the design process. It is also useful to know the cross-section of the watercourse above and below the crossing point, particularly in the case of incised rivers, as this information will give an indication of the 'movement' of the watercourse and possible additional erosion and training measures that may be required upstream of the structure.

Hydraulic gradient upstream and downstream

The hydraulic gradient is the slope of the river bed and is normally expressed as a fraction. The hydraulic gradient will determine how fast the water will flow and hence how much damage it can cause to the structure and river bed. It will also help to determine how much downstream protection is required for the watercourse. Some simple surveying is required to determine the slope of the watercourse around the proposed crossing point. The extent of the survey would depend on the type of structure proposed.

Permeability of soil

The permeability of the soil in the whole catchment area will affect the peak water flow after heavy rain. See the section on peak flow rate above. The permeability of the soil in the river banks at the proposed structure site will also affect the bearing capacity of the soil and hence the design of the structural foundations.

Rainfall intensity

The rainfall intensity in the whole catchment area will affect the peak water flow after heavy rain. See the section on peak flow rate above.

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