COSTING EARTHWORKS

7.34 Standard engineering methods should be used to prepare preliminary alignment designs based on the range or geometric standards recommended here. Computer programs are available to assist with this process from a variety of sources including:

Highways Directorate
Department of Transport
2 Marsham Street
London SW1P 3BB
United Kingdom

7.35 For feasibility study purposes, alignments designed on the basis of available contour maps are adequate to provide the level of detail required to make cost estimates to an acceptable order of accuracy. For design studies, more detailed terrain information is needed as described in Section 5.

7.36 A significant proportion of the cost of building or realigning a road is the cost of earthworks. This is made up principally of the cost of excavating cuttings, building embankments and hauling material between the two. Additional material may also need to be brought in from pits, and any surplus or unsuitable material will need to be dumped. Standard engineering methods should be used for determining earthworks quantities and costs. Computer programs are available to assist with these calculations including the construction cost submodel of micro-RTIM2 which has been developed specifically for use in feasibility studies in developing countries. Details of how to obtain copies of this program can be obtained from:

Overseas Unit
Transport and Road Research Laboratory
Crowthorne Berkshire RG1 6AU
United Kingdom

7.37 Methods of costing based on those in Section 4 should be used.

8. DRAINAGE AND STRUCTURES

8.1 Consideration of drainage is important in a road project analysis because the cost of providing structures can represent a significant proportion of the construction cost of a new road.

THE DRAINAGE SYSTEM

8.2 One of the most important aspects of the design of a road is the provision made for protecting the road from surface water or ground water. If water is allowed to enter the structure of the road, the pavement will be weakened and it will be much more susceptible to damage by traffic. Water can enter the road as a result of rain penetrating the surface or as a result of the infiltration of ground water. The road surface must be constructed with a sufficient camber or crossfall to shed rainwater quickly and the formation of the road must be raised above the level of the local water table to prevent it being affected by ground water.

8.3 Water can also have a harmful effect on shoulders, slopes, ditches and other features. High water velocities can cause erosion which, when severe, can lead to the road being cut. Alternatively, low velocities in drainage facilities can lead to silt being deposited which, in turn, can lead to a blockage. Blockages often result in further erosion.

8.4 A good road drainage system, which is properly maintained, is vital to the successful operation of a road. It has four main functions:

- to convey rainwater from the surface of the carriageway to outfalls
- to control the level of the water table in the subgrade beneath the carriageway
- to intercept ground and surface water flowing towards the road
- to convey water across the line of the road in a controlled fashion.

The first three functions are performed by side drains and the fourth by culverts, drifts and bridges.

SIDE DRAINS

8.5 The cost of side drains will normally be calculated as part of the cost of earthworks (see Figs 6.3 and 7.3, and Section 7). Side drains should be flat-bottomed if they are to be maintained by hand (Fig 7.3), or ‘v’-shaped if they are to be maintained by machine (Fig 6.3). Wide flat drains, known as ‘meadow drains’, can be used with advantage if there is room. The longitudinal gradient of
side drains should always exceed 0.5 per cent to reduce the possibility of silting up. In hilly terrain, providing side drains with the same gradient as the road may result in water velocities that are too high. It may therefore be necessary to reduce the maximum gradient to an acceptable level by the provision of shallow dams or scour checks. These are often constructed of masonry, but can also be constructed in concrete or even timber. Wide drains are preferred to reduce the velocity and so minimise erosion. The provision of turnouts or cut-off drains should also be considered to reduce or control the amount of water in the side drains. Costing may need to take account of these and the need to line drains with masonry or concrete in highly erodible soils.

REQUIREMENTS FOR CROSS DRAINAGE

8.6 In order to determine requirements for cross drainage, information must be collected and predictions made about the level of traffic and the likely flow of water passing under the road. This enables decisions to be made about the types of structure that will be necessary and the number required.

8.7 The following types of structure should be considered:

- **Ford.** This utilises a suitable existing river bed and is appropriate for shallow, slow moving watercourses with little probability of flash floods: traffic volumes up to about 100 vehicles per day.
- **Drift.** This is sometimes known as an 'Irish bridge' and consists of a concrete slab constructed in the river bed which would otherwise be unable to carry vehicles and is suitable as a crossing for rivers that are normally fordable but are prone to flash floods; where the river is running most of the year, culverts can be placed in the drift to reduce the frequency and depth of overtopping during flash floods: traffic volumes up to about 100 vehicles per day.
- **Culvert.** This usually consists of a concrete or steel pipe, or a reinforced concrete box, placed under the road within an embankment to provide a suitable means of conveying streams, or the contents of side drains, under the road with no restrictions on traffic.
- **Bridge.** This may have a superstructure of timber, concrete and/or steel on masonry, concrete, or timber abutments and will be required for crossing streams or rivers where culverts would provide insufficient capacity, or where the road crosses an obstruction such as a railway or canal. There is no restriction to traffic unless the width of the structure is less than the road width.

8.8 Traffic requirements should be determined using the methods described in Section 3.

8.9 In order to determine the maximum likely flow of water to be accommodated by the chosen structure, information may be needed on:

- water catchment area
- rainfall characteristics
- topography
- vegetation and soils
- catchment shape
- available storage in lakes and swamps
- urban development (if any).

Peak flood volumes can then be estimated using standard hydrological techniques such as those described by Watkins and Fiddes (1984).

8.10 In order to determine the type of structure, consideration may need to be given to the cost of delays to traffic if, for example, a concrete drift is impassable for several days or if a single lane bridge is being considered instead of a two lane structure. Thus, the choice of structure may need to be determined by appraisal. The value of time is discussed in Section 12.

FORDS AND DRIFTS

8.11 The simplest river crossing is a ford. Large stones with flat tops can be placed at the upstream and downstream sides of the ford so that pedestrians can use them as stepping stones rather than having to wade across the river. Gravel or stones can be used to line the bottom of the ford to provide a firm footing for vehicles. Fords should normally only be used for rivers that do not flood as this may cause the ford to be washed away. However, repair or replacement is cheap and this may still provide an acceptable solution. The cost of providing fords is small and can usually be ignored for project analysis purposes, although some additional earthworks costs may be incurred to ensure that the road gradient on either side is acceptable to traffic.

8.12 An improvement on a ford is a concrete drift. This provides a permanent running surface for traffic, although delays may still occur when stream levels are above the level of the carriageway. The gradient of the road on either side of the drift should be not more than about 10 per cent, or 4 per cent where animal drawn traffic is expected. It may be necessary to surface the road where such gradients are unavoidable, even where a gravel surface is otherwise adequate. The width of the drift need be no more than 3.5 to 4 metres, but should be delineated by graduated marker posts to show both the edge of the road and the depth of the water during floods. Culverted drifts may be used to cross perennial streams. Culverts should normally be at least one metre in diameter to reduce the likelihood of blockage and to make them easier to maintain. The cost of drifts can be
estimated from the volume of concrete required for construction, but allowances must be made for engineering work required to ensure that the pavement is not eroded or undermined. These costs may be significant. Cost estimates for culvert pipes are made on the basis of the length of pipe required. Unit prices for concrete and for culvert pipes of various diameters which are appropriate to the road being analysed should be readily available.

CULVERTS

8.13 The use of culvert pipes to convey surface water under a road alignment is common, and provides a relatively cheap and durable solution. Most countries make concrete pipes of up to one metre diameter and these may be cost effective provided that they can be transported and handled. Corrugated galvanised steel pipes, often known by the trade name 'Armco', are available in larger diameters and are usually more expensive, but lighter and easier to handle. There should be little maintenance required for either material other than an annual inspection and clearing of accumulated silt or debris, although corrosion may occur to metal pipes in some circumstances. Culvert pipes require headwalls to protect the ends of the pipe and to direct water either towards or away from the culvert. The outfall of the culvert must be protected against scour and environmental damage downstream.

8.14 For larger volumes of water, it is possible to use several pipes in parallel under the road. Multiple pipes can also be used where the planned embankment height is insufficient to cover a single pipe of sufficient diameter adequately. However, pipes of less than one metre diameter are not recommended since they are difficult to maintain.

8.15 Reinforced concrete box culverts may also be used either singly or in parallel where relatively large volumes of water must be carried. These are normally cast in place, although smaller sizes may be precast.

8.16 Costs for culverts and for mass and reinforced concrete should be based on final achieved contract costs rather than current contract rates (see Section 4). Culvert pipes are normally costed per unit length, depending on diameter, whereas headwalls and box culverts are normally costed on the basis of volume of concrete used. Local advice on costs should always be sought to ensure that all reasons for cost differences are taken into account.

BRIDGES

8.17 Bridges will be needed over rivers where high level crossings are essential, where several culverts in parallel do not have sufficient capacity to carry the flow, or where drifts are not suitable because of safety considerations, or because resulting traffic delays are unacceptable. The following gives a brief survey of the main issues and choices. Specialist engineering advice should be sought whenever possible.

Bridge design

8.18 Most countries have established bridge design codes which specify the size, type and configuration of loads which the structure must be able to carry safely. Such codes are usually based on, or similar to, codes adopted in the USA (AASHTO 1983) or the United Kingdom (BSI 1972, 1978). It is normally advisable that new structures are designed to the code adopted by the country concerned. This avoids the need to impose weight restrictions, which may be difficult to enforce or, conversely, the provision of a structure which will safely carry loads which cannot be permitted elsewhere on the network. An exception may be made where:

- A temporary structure is envisaged
- Provision must be made for known exceptional loads, e.g. access to a power station or other structures known to require exceptionally heavy plant or equipment.

8.19 The width of a proposed bridge can significantly affect the cost of construction. If two lanes are provided instead of one, material costs will more than double as heavier construction will be required to accommodate the additional traffic loads. Particularly where a long bridge is required, careful consideration should be given to the relative cost of the provision of two lanes and the delays to traffic that would otherwise occur over the life of the structure. The proportion of pedestrians, bicycles, and animal-drawn vehicles should also be considered. In such cases, it may only be necessary to widen the carriageway sufficiently to ensure that motor traffic is unimpeded rather than provide two standard traffic lanes. A cheaper solution may be to provide light footways cantilevered out from the main structure. It is very unlikely that more than two lanes will be required in rural areas in developing countries.

8.20 A significant reason for bridge failure and high maintenance costs in tropical countries is erosion and scour leading to foundation failure. Even at the analysis stage, it is worthwhile to make sure that these aspects have been considered and appropriate protection provided.

Site conditions

8.21 Temporary structures apart, bridges are normally designed to operate without major structural alteration for very long periods, typically fifty years. It is therefore
particularly important that the design takes into account all factors that can reasonably be foreseen and that may affect performance. Such factors must include the characteristics of the river, which will determine the location and design of abutments and piers, and the elevation of the deck or superstructure. Other factors include the extent of river training and scour protection measures that are needed. Of equal importance, will be a knowledge of ground conditions at the selected site. No reasonable estimate of cost can be made without this information and a site investigation should always be undertaken to determine the strength and other characteristics of the soils on which the structure will be founded.

8.22 The cost of providing river training works is often high and, where there is evidence of the river changing its course, it may be preferable to reduce the design life and the cost, and accept the need to rebuild the bridge at a later date. It is also important to consider what the cost of disruption or damage would be if the river were to overtop the bridge. An understanding of the river characteristics, the construction cost and the risk of structural failure is crucially important in deciding the optimum choice of materials and design for the structure.

Abutments and piers

8.23 Abutments and intermediate piers distribute the vertical and horizontal loads on the bridge to the foundations. Abutments must also resist the horizontal forces of the soil which is constrained.

8.24 Where the ground conditions at a reasonable depth are adequate to support the bridge and traffic loads, it is normal to support abutments on narrow reinforced concrete slabs or footings. Where the soil is too weak to support this type of foundation, piles will be needed to support the abutments and piers. Normally piles are more expensive than concrete footings and require specialist design and construction skills.

8.25 Abutments and piers are usually constructed of reinforced or mass concrete, masonry, brick or timber. The choice between concrete, masonry or brick will be determined by the cost and availability of materials and the skill and experience of the available labour force. Timber should be considered with care because, although accommodating considerable movement without distress, it is prone to rot and insect attack, particularly when used in abutments and retaining soil. Careful selection of species and treatment will help, but maintenance costs may be high and regular monitoring of condition essential.

Timber decks

8.26 In many rural areas which are close to forests, the cheapest construction option for the superstructure of bridges may be parallel timber logs. Cutting and squaring timber for such crossings is expensive and not normally worthwhile. Ideally, timber should only be used where there is little or no problem with wood-boring insects and a naturally durable species should be selected, or else some form of chemical treatment, such as creosote, applied. To be effective, timber preservation must be done thoroughly and may significantly increase costs. On top of the logs, cross beams should be used to support longitudinal running boards.

8.27 The maximum span that can be used will depend on the species and height of available trees, but spans of up to about 15 metres are feasible.

8.28 Modular timber bridges have been developed for use in developing countries (ARRY 1981, UNIDO and TRADA undated). These are suitable for spans of 12 to 24 metres and have the following advantages:

- relatively cheap to build
- the materials and skills required to build the bridge are available locally in most developing countries
- the modular design permits prefabrication of the frames in local workshops
- the frames may be stored for emergency use, and can be assembled to make a bridge on prepared abutments very quickly
- the bridge components are small enough and light enough to be transported to a remote site if a bridge is required urgently.

Although such bridges have some disadvantages, they should be considered for use in appropriate situations.

Concrete decks

8.29 Concrete superstructures are now common practice in most developing countries. Local contractors may be capable and experienced in some of the simpler forms of reinforced concrete. Where cement is locally produced, it may be economic to set up a precasting factory for standard bridge beams. Where these are available, they will often be cheaper and more suitable than steel. Alternatively, the beams may be cast in-situ but, in either case, a concrete slab needs to be cast to provide a running surface. A bituminous wearing course may also be added. An alternative to a beam and slab design would be either a solid concrete slab without beams, or a slab cast with voids to reduce the weight, also without beams. The most cost-effective configuration will depend on the span, width, available reinforcement, concrete strength achievable, and many other factors which the bridge designer should take into account.

8.30 Other, more sophisticated techniques of pre-stressing may be considered.
8.31 **Post tensioned beams and slab.** The deck is constructed in-situ in a similar way to above, but incorporating accurately located steel ducts to accommodate separate wires, strands, or high strength steel bars. When the concrete has hardened, the wires or strands are tensioned by jacks bearing against the concrete faces. The tensile force in the wires imposes a compressive force on the concrete. This condition is maintained by specially designed anchors attached to the ends of the wires.

8.32 **Pretensioned beams.** This method is applicable mainly to precast elements. Prior to casting the concrete, wires, strands or high strength steel bars are located in the mould and loaded to the required tensile stress. After the concrete has hardened, the load is removed and the tensile stress in the reinforcement applies an equal compressive stress in the concrete through the bond between the materials.

8.33 Both forms of pre-stressing offer advantages over conventional reinforced concrete. A pre-stressed beam or slab is generally free from cracks and is therefore more durable. Much less steel is required, since the weight of high-strength steel in the tendons is only a fraction of the weight of the reinforcement it supersedes. The cross-section is smaller since the concrete is used more efficiently and resistance to shear stress is substantially increased. However, pre-stressing demands high quality concrete, special steels, specialist equipment, and experienced and knowledgeable contractors and designers. Pre-stressing should not be considered if any of these requirements cannot be met.

8.34 **Segmental box girder units.** This is a technique for use on longer spans. Each separate unit is manufactured using industrial processes either at site or in a factory. High quality concrete is therefore achievable, but specialist construction skills and equipment are required and, in general, this design is unlikely to be appropriate where local contractors are employed.

### Steel decks

8.35 Steel superstructures are of three types.

8.36 **Rolled steel beams** provide the simplest design consisting of a number of parallel T beams spanning from one fixed abutment to the other, or to intermediate piers. The length is usually limited by handling and transport constraints to about 18 metres but, in many countries, the size of beam available limits the span to about 8 or 10 metres. A timber or reinforced concrete deck is constructed on top of the beams. If a concrete deck is used, this can be more efficient if the steel beam and concrete are designed to act compositely, ie are effectively bonded together.

8.37 **Panel bridges** are made of steel sections fabricated at a factory to form trusses and may be either part or fully assembled before delivery to site. In the UK, these are fabricated and designed by Callender-Hamilton and Mabey, who produce both their own ‘Universal’ design and the ‘Bailey’ type. Bailey bridges are also available from Messrs Thomas Storey. By varying the number of panels, various spans can be constructed. Although relatively expensive, the panel system is also excellent for the quick erection of bridging at temporary sites. Pontoon type crossings have also been effective on many rivers using standard panel units.

8.38 **Box girder bridges** are sophisticated structures used for long spans. They require specialist design and construction skills, but are technically very efficient in that they have a high strength to weight ratio. Suspension bridges often incorporate prefabricated box girders.

### Arch bridges

8.39 Masonry and brick arch bridges are a traditional form of construction in some countries and may well be competitive where skilled bricklayers or masons are plentiful, and where appropriate materials are available. Despite this, the use of this type of structure is often overlooked in road projects where design is done by engineers from countries where there is little experience of their construction because labour costs make them uncompetitive. Structural analysis of this type of structure is less precise than that possible for steel or concrete, but arch bridge are capable of carrying exceptionally high loads without distress. There is thus more scope for the use of arch bridges in road projects and they should be considered as an alternative to steel and concrete structures in appropriate situations.

### Replacement of existing bridges

8.40 If the project is to replace an existing bridge, a technical appraisal should be carried out to ascertain the need. If load restrictions are in force, the benefits of replacing or strengthening will be derived from more efficient freight operations. The age of a bridge should not be the sole criterion for replacement. Replacement should be based on a technical assessment of the bridge’s ability to carry the required loads in the future. In many cases, deck reconstruction will be more cost-effective than replacement, particularly where piers and abutments are sound. However, the costs of disruption to traffic should be included in the analysis. In many cases, old bridges, especially stone or brick arches, will carry legally permitted traffic loads even though they were not originally designed for them. A sub-standard bridge located in an important route can have a considerable effect on goods throughout the network and thus reconstruction/replacement may have benefits beyond the immediate vicinity of the bridge which should be considered in the analysis of a project.
8.41 Another common problem arises where a two lane road includes a series of narrow single lane bridges. Often these have short spans and are of adequate strength, but because of their width, they represent a safety hazard and traffic is delayed by giving way to oncoming vehicles. A widening or replacement programme may be appropriate, but should be tested by the economic analysis.

8.42 Many large rivers in developing countries have an existing railway bridge but no equivalent road crossing. Where both rail and road traffic is light (say up to 10 trains and 250 vehicles per day), the economic feasibility of converting the rail bridge into a rail/road bridge should also be considered.

Costing bridges

8.43 There are many factors which affect the design choice and the cost of the structure, and these will vary at each site. In general, the simpler designs will be easier to construct, and hence cheaper, for short span bridges.

8.44 The availability of materials and local expertise will tend to govern the choice between concrete and steel structures. Local contractors may construct reinforced concrete competently; pre-stressed or post-tensioned concrete may be beyond their capability. The cost of concrete bridges, in general, will be relatively insensitive to the load carried whereas, for steel panel bridges, the load at certain span lengths determines the number of units that are needed and hence the cost. For some timber bridges, the load carried may be extremely critical on particular spans as this will determine whether locally available timber is strong enough.

8.45 The choice of optimum span for a large bridge is an important decision since the longer the span, the more expensive and difficult construction becomes, but there is a corresponding saving in cost of foundations and piers. Where the river is permanent, fast flowing, and carrying considerable debris in flood, then the cost of building adequate intermediate supports for the bridge is likely to be high. There will be physical limits on the maximum length of span for a given design that can be constructed, and these will have to be carefully balanced with the river conditions and foundation problems.

8.46 The alignment of a structure is usually determined by the geometry of the approach road. This may result in the bridge being 'skewed' in relation to the river. Both design and construction costs will be higher for a skewed structure than for one at right angles to the river. Local realignment of the approach road should be considered as an alternative to a skewed structure if adequate sight distances can be maintained.

8.47 A major cost may be the transport of materials to the bridge site. In inaccessible areas where existing roads or tracks are non-existent, this problem becomes more acute and the use of construction materials near to the site becomes very economic. On low volume roads, the use of whole timber logs may be appropriate as the timber can normally be obtained virtually 'free' whilst cement and other conventional materials are expensive or unobtainable.

8.48 Costs do not rise gradually, but in a series of steps at particular loadings and spans. Single lane bridges can still be suitable for main roads if the capital cost advantage of doing this is substantial. This will usually be the case on long span bridges where the traffic flow is less than about 250 vehicles per day.

8.49 It is not possible to give definitive rules on which design is 'best' for a particular situation since much will depend on the terrain, river regime, materials, local skills and available plant.

8.50 Bridges can represent a significant proportion of the cost of a construction project and, if large structures are needed, they can outweigh other costs. Thus, even at the project feasibility stage, considerable attention must be paid to bridge costs and this cannot be done unless preliminary designs and a site investigation have been carried out. This design and costing should always be carried out by a structural engineer on the basis of prices obtained locally.

MAINTENANCE

8.51 If a structure is to perform adequately over its design life, it must be regularly inspected and maintained. The resources and capabilities of the department responsible for upkeep of the structure should be considered at the design stage if a truly cost-effective solution is to be found. Care taken to ensure that such critical details as bridge bearings and expansion joints are both maintenance-free as possible, and easily accessible, will ensure that expensive repairs are less likely to be required later. Steel components will require regular painting and the performance of timber will be radically affected by both the quality of the initial treatment and the avoidance of traps for moisture and debris in the design.

8.52 A cost-effective design will be that which most successfully takes account of local skills, materials, location, safety and maintenance capabilities.

FERRIES

8.53 Rivers do not have to be crossed by bridges. Another option is to improve or provide a ferry service. These are particularly applicable where the river channel is constantly changing. Where traffic levels are low and the river wide and slow-moving, they can be a cost-effective alternative and several designs of flat bottomed ferry are available. However, appraisals should take account of the delay to traffic introduced by the utilisation of ferries and both their capital and maintenance cost.