FOOTBRIDGES

A Manual for Construction at Community and District Level

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by I.T. Transport Ltd.

Consultants in Transport for Development

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ABBREVIATIONS AND GLOSSARY OF TERMS

ABBREVIATIONS

ADV Animal Drawn Vehicle
DFL Design Flood Level
IMT Intermediate Means of Transport
KN Kilo-Newton (Approximately 100kg)
NMT Non-motorised Transport
RCC Reinforced Concrete
USD United States Dollars
VARBU Village Access Roads and Bridge Unit (Malawi)

GLOSSARY OF TERMS

Abutments Supports at each end of the footbridge
Dead loading The self-weight of the footbridge resting on the abutments and piers
Deck The surface of the footbridge that users walk or ride on
Live Loading The load imposed on the footbridge by users
Piers Intermediate supports for the footbridge superstructure between the abutments
Shuttering Boards, usually timber, making up the box-work into which concrete is cast
Stringers Beams that support the deck. May be timber or steel
Substructure Abutments and piers that provide the structure supporting the footbridge
Superstructure The upper part of the footbridge structure comprising the deck, the structure supporting the deck and safety railings
1. **INTRODUCTION**

Much rural travel takes place on local paths, tracks and village roads. These provide essential access to water, firewood, farm plots and the classified road network. Communities and/or local government are generally responsible for this network of paths and tracks. One of the main problems they face is in providing effective water crossings. Particularly in the rainy season, the lack of an adequate crossing can prevent access to services, or detours of many km or taking risks, especially by women and children, on an unsafe crossing.

To provide safe and sustainable crossings, those providing technical assistance to local government and communities need simple, easily applied guidelines on the selection and construction of effective water crossings. A manual, ‘Construction and Improvement of Footpaths and Tracks’\(^1\), contains information on simple water crossings and an introductory chapter on footbridges but within the context of the manual it was not possible to provide the comprehensive guidelines needed for selecting and constructing footbridge designs for specific applications.

This follow-up manual deals specifically with the construction of simple but effective footbridges for spans up to about 20m and is targeted at local technical persons from district council staff, NGOs, local consultants etc. who are involved in providing technical assistance to communities and small contractors in the construction of footbridges. Although the bridges covered in the manual are termed ‘footbridges’, the designs also allow for use by livestock, IMT (Intermediate Means of Transport) such as oxcarts and the occasional light motorised vehicle, for instance a pick-up.

Before beginning the selection process it is necessary to confirm that a footbridge is the best option for the water crossing. Other options are:

- For shallow crossings, simple stepping stones may be adequate
- For narrow crossings, a culvert may be a better option
- For wide crossings, a ferry may be the most practical option
- For low pedestrian traffic, a cable way may be the cheapest option

Installation of a footbridge is usually a considerable undertaking, particularly for communities, and it is essential to make sure that it is really needed and is a top priority and commitment for the communities involved.

If it is decided that a footbridge is the best option the first step is to carry out a site survey to decide on the alignment of the footbridge and determine its specifications in terms of span (length between supports) and the traffic to be carried. The manual starts from this planning process and works through the process of selecting the most appropriate design of footbridge to meet the specifications. Detailed construction and installation guidelines are then provided on a number of options that are considered the most appropriate. The information is presented largely through pictorial sketches with brief notes of explanation. An understanding of engineering drawing practice is therefore not needed. Text is kept to a minimum.

\(^1\) *Footpaths and Tracks – a field manual for their construction and improvement*: produced by I.T. Transport Ltd. for the UK Department for International Development (DFID), published by ILO/ASIST as RATP No.6, Geneva, 2002.
A considerable volume of information already exists on footbridges but it is spread around and difficult to access. A major aim of the manual has therefore been to bring this information together and present it in a form suitable for the target users. 5 case studies were carried out in – Nepal, Laos and Indonesia in Asia and Malawi and Ethiopia in Sub-Saharan Africa – to collect data on specific types of footbridges. Library and Internet searches were also carried out, yielding useful information from USA, Australia and the UK. Good information and manuals already exist on certain types of bridges such as cable bridges in Nepal. In these cases the reference sources are given and detailed design information is not included in the manual.

Standard design data is included for the common types of footbridges found in rural areas – bamboo, timber log and sawn timber beam footbridges. These are suited to spans up to 10 to 12m and longer if intermediate pier supports can be used. It is considered that the most appropriate design for longer spans from 10 to 20 or 25m is a steel truss bridge. Standard designs for a version requiring full assembly on site are available from Nepal but no standard designs were found for a modular type which is simpler to construct and assemble on site. A design of the latter type was therefore developed and field-tested in Sri Lanka. An important aspect of the field-test was to test and improve the presentation of data in the manual. Details of the construction and testing of the footbridge are available in a separate publication.

The content and layout of the manual are described in more detail below:

**Chapter 2: Footbridge Specifications**

This chapter covers the planning stage to determine the specifications and layout of the bridge, including the location and alignment of the bridge to specify span, and identification of users to specify width and loading.

The design loading and criteria used in the manual are derived and compared with other footbridge standards

**Chapter 3: Selecting a Footbridge Design**

The range of design options for footbridges is outlined covering characteristics, applications, advantages and disadvantages. Typical examples of each type are illustrated by photographs or drawings, showing basic details of construction. Further sources of information are provided.

The types of designs included are:

- Bamboo bridges
- Timber log and timber pole bridges
- Sawn timber, beam and truss types – glue-laminated designs are also briefly described but are not considered appropriate for this manual
- Steel beam and truss types
- Reinforced concrete footbridges
- Suspended and Suspension bridges

The criteria for selecting a footbridge type are discussed and the above range of options compared against these criteria. The types of footbridges to be covered in detail in the manual are selected.
Chapter 4: Design of Timber Footbridges

Detailed designs and examples are given for 3 types:

- Bamboo footbridges
- Timber log footbridges
- Sawn-timber beam bridges

Chapter 5: Design of Steel Footbridge

A standard design for a modular steel truss bridge for spans up to 20m is described. Maintenance requirements are outlined.

Chapter 6: Design of Reinforced Concrete Footbridges

Design details are given for a simple slab type of reinforced concrete (RCC) footbridge and the steps in construction are outlined.

Chapter 7: Installation of Footbridges

Details of the construction of abutments and piers are given, covering both timber and masonry types. Procedures for installing and fixing footbridges in position are described.

Appendix A: Site Survey and Layout of Bridge

This outlines the steps in carrying out the site survey with a questionnaire to collect the required information for planning the bridge installation.

Appendix B: Construction of Steel Truss Footbridge

Detailed step by step instructions are given for the manufacture of the modular steel truss footbridge that was described in Chapter 5.

Appendix C: Construction of a Footbridge using a Scrap Chassis from a Truck or Bus

Details are given of a footbridge constructed using a scrap truck chassis to span the crossing and support the deck. It is based on information provided by the Kisii Training Centre in Kenya.

Appendix D: Contact Details for Sources of Further Information

Contact details are given for the sources of further information referred to in the manual.
2.  FOOTBRIDGE SPECIFICATIONS

2.1  PLANNING

This section summarises the factors that need to be considered in the planning of the design and installation of the footbridge.

2.1.1  Location

The choice of location should try to minimise the cost of the footbridge and the work involved in installing it and maximise the benefits to the communities that will use it. The selection process should consider the overall installation covering both the bridge and the approach paths or tracks. The following factors should be considered:

- Use the shortest possible span (length) of the bridge taking into account the factors below
- The footbridge should be on a straight section of the river or stream, away from bends where erosion can occur.
- Select a location with good foundation conditions for the abutment supports for the footbridge
- The location should be as close as possible to any existing path or track alignment
- The location should provide good clearance against flooding and should minimise the need for earthworks on the approaches to raise the level of the bridge
- The stream/river should have a well defined and stable flow path with little risk of this changing due to erosion of the banks
- The approaches should be across well-drained ground to minimise problems of water-logging and erosion
- The location should be as sheltered as possible to minimise wind problems
- The site should allow good access for materials and workers.
- It is helpful if there is a good local supply of materials that might be used in the construction such as sand and stones.
- The site should be agreed with the local communities

2.1.2  Layout of the Footbridge

A bridge is made up of 2 assemblies:

1.  *The superstructure* that provides the crossing for users, comprising the deck (carriageway surface), the structure which supports the deck such as beams or trusses, and railings that provide safety for users. Various superstructure designs are presented in Chapters 4, 5 and 6.
2. The substructure that supports the superstructure, comprising abutments that support the ends of the bridge and in some cases piers that provide intermediate supports for longer span bridges. The design of substructures is presented in Chapter 7.

The layout of the bridge is set primarily by the surrounding terrain and the height needed for the superstructure. Three main factors need to be considered in deciding this:

1. The clearance of the deck above the Design Flood Level (DFL) to provide acceptable access during flood periods (note that the approach paths/tracks will also need to provide the same level of access) and to minimise potential damage to the superstructure from water and debris washed along in flood waters.

2. The height of the superstructure needed to provide clearance for floating debris and any boats using the stream or river in normal operating conditions (it has to be decided up to what water level it is reasonable to provide access for boats).

3. The height on the banks where it is suitable to locate the bridge abutments in regard to appropriate soil conditions, minimising erosion from flood waters and minimising the difference in elevation between the bridge deck and approach paths/tracks (see Chapter 7).

Figure 2.1 shows the basic layout of a footbridge. Simple, relatively low-cost footbridges using beam structures such as timber log or sawn timber are limited to spans of about 8 to 10m by the available lengths of the beams. For longer spans an important initial decision to be made is whether piers can be used for intermediate supports to allow beam structures or whether it is cheaper to use more complex truss structures to avoid the use of piers. The maximum span of truss type structures is 20 to 25m and above this a decision has to be made whether to use piers or suspension type bridges that are suitable for longer spans. More guidelines on the selection of bridge types are given in Chapter 3 of the manual.

2.1.3 Height of Deck

A Design Flood Level (DFL) needs to be defined. It may be an ‘average’ level (the maximum level that occurs in an ‘average’ year) or a higher level that occurs in 1 in ‘n’ (10, 20 etc.) years.

It is suggested that the average upper level over a 5 year period is used and the height of the deck is set so that there is clearance under the superstructure to allow for some excess flooding and for debris carried in flood waters. Recommended clearances are:

- In fairly flat areas where flood waters can spread to limit rises in water level a minimum clearance of 1m is recommended.
- As the terrain becomes more hilly and banks are steeper so that flood waters are more confined the clearance should be increased because of the greater variation in flood level. A clearance of up to 5m is recommended for hilly areas with streams/rivers running in steep-sided gorges.

The other critical factors of clearance for boats and the location of abutments also need to be checked to see which criteria sets the minimum height of the deck.

The average flood level can be checked by:
2. FOOTBRIDGE SPECIFICATIONS

Deck supported by superstructure, suitable for footbridge users

Safety handrail is advisable For spans over 3m

Fill up to level of approach path, track or road

Beam type superstructure

Flood Level

Normal Level

Piers allow longer spans but bed needs to be dry or stream diverted to allow excavation of footings

Abutments support ends of superstructure. May be timber, masonry or concrete. Wingwalls may be needed for protection

(i) Beam Type Superstructure

Truss type superstructure suitable for longer spans than beams

(ii) Truss Type Superstructure

Note:
Careful consideration needs to be given for the location of abutments and piers to limit their impact on the flow of water and to minimise the erosion they may cause. For example, a central pier is at the point of highest water velocity and is best avoided where the water flow is high. An off-set pier is better if spans allow it. If not 2 piers should be considered.

Figure 2.1: Layout of Footbridge
• Site observations – signs of debris caught on vegetation, tide marks, sand/soil deposits

• Discussions with the local population

Setting out the level of the bridge deck is shown in Figure 2.2. Guidelines for survey of the site and locating the positions of the abutments are given in Appendix A.

Note:

Increasing the height of the deck will usually lead to increasing its length and cost. However, it is likely to increase the security of the abutment against instability and erosion and reduce the risks of the deck being damaged or washed away by flood waters.

It is therefore necessary to carefully balance the increased cost against the reduced risks. Minimising the risks will be increasingly important as the cost and predicted life of the footbridge increase.

2.2 FOOTBRIDGE USERS AND LOADING

2.2.1 Users

The users of the bridge and expected traffic levels must be clearly identified as these will determine the required deck width of the bridge and the 'live' loading on the bridge.

Although termed “Footbridges”, in developing countries these bridges may be required to also carry livestock, pack animals and a range of simple vehicles (Intermediate Means of Transport, IMT) such as bicycles, handcarts, animal-drawn vehicles (ADVs), and motorcycles. This need must be clearly defined.

It may also be desirable for the bridge to carry an occasional light motorised vehicle such as a pick-up. For instance if the bridge is on an access track to a village and there is no road to the village.

If the bridge is to allow access for ADVs then it will be difficult to exclude cars and pick-ups. However, the deck width should only just allow access for these vehicles and should prevent access of any heavier vehicles.

Figure 2.3 shows recommended widths for paths and tracks for different types and levels of traffic. Because of the relatively short lengths of footbridges and the significant costs of construction it is considered that deck widths can be slightly less than those shown in the figure. Two standard widths are therefore recommended in this manual:

• 1.4m for pedestrians, bicycles, livestock, pack animals, wheelbarrows and handcarts, and motorcycles

• 2.1m to also include ADVs and occasional light motorised vehicles

These widths will only allow one-way access of some types of traffic and appropriate warning notices should be put up at each end of the bridge. Also for heavier vehicles such as ADVs, cars and pick-ups, only one vehicle should be allowed on the bridge at a time in order to avoid the need to over-design the bridge for just a few users.
2. FOOTBRIDGE SPECIFICATIONS

**Figure 2.2: Level of Bridge Deck**

Use clinometer to set up level reference line

Mark on post

Base level of bridge deck

Clearance, see 2.1.3

Height of maximum flood level

**Note:** Wherever possible the bridge should be perpendicular to the river/stream

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**Note:**

It is important to consider the stability of the banks when choosing the locations for the abutments. The abutments should lie outside a slope line of Angle $A^\circ$ which will depend on soil conditions.

- For stable rock, $A$ can be up to $60^\circ$
- For firm soil $A$ should not exceed $45^\circ$
- For loose sand, gravel and soft soil $A$ should not exceed $35^\circ$

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**Figure 2.2: Level of Bridge Deck**
2. FOOTBRIDGE SPECIFICATIONS

Standard Widths for Different Paths and Tracks

- **Two-Way Footpath**
  - pedestrians
  - low traffic
  - 1.0m wide

- **Two-Way Footpath**
  - pedestrians
  - 1.2m wide

- **One-Way Bicycle Track**
  - bicycles
  - low traffic
  - 1.2m wide

- **One-Way Track**
  - pedestrians
  - pack animals
  - low to medium traffic
  - 1.4m wide

- **Two-Way Track**
  - pedestrians
  - pack animals
  - high traffic
  - 2.0m wide

- **Two-Way Bicycle Track**
  - bicycles
  - 2.0m wide

- **Two-Way Footpath**
  - pedestrians
  - low traffic
  - 1.0m wide

- **Two-Way Track**
  - pedestrians
  - pack animals
  - high traffic
  - 2.5m wide

- **Motorable Track**
  - carts
  - 4WD vehicles
  - low traffic (passing places required)

**Guideline** for level of traffic for walkers and bicycles:

- **Low**: less than 50/day
- **Medium**: 50 to 500/day
- **High**: over 500/day

Standard Widths of Footbridges Recommended in Manual

Two-Way: pedestrians
- 1.4m wide

Two-Way: livestock
- 2.1m wide

One-Way: pack animals
- bicycles

One-Way: animal-drawn carts
- Light motor vehicles

**Note:**

Footpaths allow comfortable clearance. Because of their short lengths footbridges need provide only minimum clearance.

Figure 2.3: Proposed Standard Widths for Footbridges
Selection of width – this needs to be considered carefully. The potential loading on a 2.1m wide bridge is 50% greater than on a 1.4m wide bridge and therefore it has to be made substantially stronger, increasing cost in about the same proportion. If an ADV or motor vehicle is only expected to want to use the bridge occasionally, say 2 or 3 times per month, then the need for access has to be critically assessed with the local communities to make sure the extra cost is justified.

Restriction of vehicle size – it is recommended that masonry columns are built at each of the bridge with an opening of 1.9m. These will allow access for a Landrover and medium-size pick-up but prevent larger vehicles from damaging the bridge.

2.2.2 Design Loads

Footbridges have to be strong and rigid (without undue flexibility or deflection) to withstand the following forms of loading:

Vertical loading - (i) Dead loading from the weight of the bridge itself (snow loading is not usually considered for footbridges as it is unlikely to be significant when the bridge is being heavily used).

(ii) Live loading from the users of the bridge

The vertical design load is the combination of dead load and the highest live load anticipated from the users of the bridge. The dead load is the distributed weight of the superstructure including decking and can readily be evaluated. The highest live load is more difficult to estimate and is discussed below.

Side loading - (i) From wind pressure

(ii) Due to users leaning on or bumping against the safety railings

(iii) Due to the possibility of debris carried by the river/stream impacting against the bridge. Note: that it is only feasible to design against relatively light impacts. If heavy impacts are possible from larger objects in fast flowing water then the deck clearance (2.1.3) should be increased to reduce the risk of impact and damage.

Side loading to be considered in the design is wind loading acting on the exposed side faces of the bridge members and loads applied by users leaning on or bumping against the safety rails and support posts. Significant impacts from debris will not occur if there is adequate clearance below the bridge.

Design standards for footbridges consider wind velocities up to 140 to 160 km/hr. This imposes a uniform pressure on the exposed side faces of the bridge members of 130 to 140kg/m². The upper figure is used in the designs in this manual. Since there is unlikely to be traffic on the bridge in these high winds, the wind loading is considered separately from vertical live loading.
**Live loads** – two aspects of live loading need to be considered:

(i) The point load applied to the bridge deck by a person’s or animal’s foot or the wheel of a vehicle, to check the strength of the decking

(ii) The load transferred from the decking to the structural members of the superstructure which then transfer it to the bridge supports. These loads will act as a series of short distributed loads or as a continuous distributed load spread along the longitudinal members that support the decking.

The most critical live loads assumed for users of footbridges are shown in Table 2.1. Live loading by other types of users is considered to be less than these cases as explained below:

- **Bicycles and motorcycles** – the point loads will be less than those assumed for livestock and because of the space they take up the load per unit area will be less than for pedestrians

- **Pack animals** – these are assumed to be donkeys, mules, horses or camels. The maximum loading is assumed to be similar to that of livestock which may include oxen.

The design live loads used in this manual are summarised at the bottom of Table 2.1. It is considered that the **point load of 500kg** (5kN) and **distributed load of 400kg/m²** provide an adequate margin of safety for all normal users of footbridges. The live load specifications for the two bridge widths are summarised in Table 2.2. Table 2.3 compares these specifications with those from other manuals.

### 2.2.3 Design Criteria

Bridge design standards specify the following design criteria which need to be considered to ensure that footbridges are safe and convenient for anticipated users.

1. **Strength:** the bridge members need to be strong enough to withstand the live and dead loads identified above with an adequate margin of safety to allow for uncertainties in loading, material properties and quality of construction and maintenance.

2. **Deflection:** the footbridge should not deflect to an extent that might cause concern or discomfort to users or cause fixed members to become out of plane. Maximum limits for beam and truss footbridges range from span/180 (5.5mm per m of span) to span/360 (2.75mm per of span). A middle value of span/250 (4mm per m of span) is used in this manual. The limit is the maximum deflection at the centre of the footbridge when loaded by the above live loads.

3. **Dynamic Loading:** it is possible that a footbridge might be set vibrating by winds or by people walking over the bridge. However, this is not usually considered a problem for rural footbridges of the span range covered in this manual.
### Table 2.1: Assumed Live Loads on Footbridges

<table>
<thead>
<tr>
<th>Type of User</th>
<th>Point load on deck</th>
<th>Distributed load on bridge structure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pedestrians</strong></td>
<td>WEIGHT OF PERSON 80KG + LOAD CARRIED 20KG = TOTAL 100KG</td>
<td>ASSUME CROWDED BRIDGE WITH 4 PERSONS/M²</td>
</tr>
<tr>
<td></td>
<td>POINT LOAD ASSUME ALL LOAD ON 1 LEG X IMPACT FACTOR OF 1.2 = 120KG</td>
<td>DISTRIBUTED LOAD = 400KG/M²</td>
</tr>
<tr>
<td><strong>Livestock</strong></td>
<td>ASSUME UPPER WEIGHT OF 800KG</td>
<td>ASSUME WEIGHT SPREAD OVER 2X1M AREA</td>
</tr>
<tr>
<td></td>
<td>POINT LOAD ASSUME NORMAL WALKING WITH TOTAL WEIGHT ON 2 LEGS X IMPACT FACTOR OF 1.2 = 400X1.2 = 480KG</td>
<td>DISTRIBUTED LOAD = 800/2 = 400KG/M²</td>
</tr>
<tr>
<td><strong>Oxen and cart</strong></td>
<td>UPPER WEIGHT OF EACH OXEN 800KG + WEIGHT OF LOADED CART 1200KG = TOTAL 2800KG</td>
<td>ASSUME TOTAL WEIGHT SPREAD OVER AREA OF 4.5X2M</td>
</tr>
<tr>
<td></td>
<td>POINT LOADS FOR OXEN, TOTAL WEIGHT ON 2 LEGS X IMPACT FACTOR OF 1.2 = 400X1.2 = 480KG</td>
<td>DISTRIBUTED LOAD = 2800/9 = 310KG/M²</td>
</tr>
<tr>
<td></td>
<td>FOR CART, WEIGHT PER WHEEL = 600KG</td>
<td></td>
</tr>
<tr>
<td><strong>Light motor vehicle</strong></td>
<td>ASSUME MAXIMUM LOADED WEIGHT OF 3000KG WITH 1800KG ON REAR WHEELS</td>
<td>ASSUME WEIGHT SPREAD OVER AREA OF 4X2M</td>
</tr>
<tr>
<td></td>
<td>POINT LOAD LOAD PER REAR WHEEL = 900KG</td>
<td>DISTRIBUTED LOAD = 3000/8 = 375KG/M²</td>
</tr>
<tr>
<td><strong>Design Loads</strong></td>
<td>PEDIESTRANS AND LIVESTOCK ONLY = 500KG</td>
<td>ALL CASES – 400KG/M²</td>
</tr>
<tr>
<td></td>
<td>OXCARTS BUT NO MOTOR VEHICLES = 600KG</td>
<td></td>
</tr>
<tr>
<td></td>
<td>MOTOR VEHICLE = 900KG</td>
<td></td>
</tr>
</tbody>
</table>
### Table 2.2: Summary of Live Load Specifications

<table>
<thead>
<tr>
<th>Type of loading</th>
<th>1.4m wide footbridge</th>
<th>2.1m wide footbridge</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Point load</td>
<td>Distributed load</td>
</tr>
<tr>
<td><strong>Vertical</strong></td>
<td>1 animal, 500kg (5kN) at any position</td>
<td>560kg (5.6kN) per m length</td>
</tr>
<tr>
<td><strong>Constraints</strong></td>
<td>No oxcarts or motor vehicles</td>
<td>1 Limited to light motor vehicles of maximum loaded weight of 3 tonne</td>
</tr>
<tr>
<td><strong>Side load:</strong></td>
<td>check wind load applied to full length of bridge and point loads from users applied to side structures (railings)</td>
<td></td>
</tr>
<tr>
<td><strong>Wind load</strong></td>
<td>140kg/m² x side area of bridge elements</td>
<td>140kg/m² x side area of bridge elements</td>
</tr>
<tr>
<td><strong>Other side loads from users</strong></td>
<td>Point load of 130kg at height of 1.25m above deck</td>
<td>Point load of 130kg at height of 1.25m above deck</td>
</tr>
</tbody>
</table>

### Table 2.3: Load Specifications for other Codes

<table>
<thead>
<tr>
<th>Details of Code</th>
<th>Vertical loads</th>
<th>Side loads</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Point</td>
<td>Distributed</td>
</tr>
<tr>
<td><strong>Short-Span Trail Bridge Standard, Nepal</strong></td>
<td>None</td>
<td>400kg/m² up to 50m span</td>
</tr>
<tr>
<td><strong>Light Bridge Manual, Outdoor Structures Australia</strong></td>
<td>450kg normal 2000kg for small tractors Not specified for livestock</td>
<td>500kg/m² for severe crowding 300 to 400kg/m² for rural locations</td>
</tr>
<tr>
<td><strong>Footbridges in the Countryside, Countryside Commission for Scotland</strong></td>
<td>812kg for horse and rider (1) 612kg for cattle (1)</td>
<td>230kg/m² for normal pedestrian traffic and livestock</td>
</tr>
<tr>
<td><strong>Specifications for Design of Pedestrian Bridges, American Association of State Highway Transportation Officials (AASHTO)</strong></td>
<td>450kg for horse</td>
<td>405kg/m² for pedestrian load</td>
</tr>
</tbody>
</table>

**Note:**
1. These assume a trotting animal with total weight on one leg. This loading is considered excessive for the applications of this manual which assumes the weight shared between 2 legs.
2. This apparently assumes a much higher drag coefficient than other codes as it is based on the same wind speed of 160km/hr.
3. SELECTING A FOOTBRIDGE DESIGN

This chapter gives details of a range of footbridge designs, covering basics of construction, applications, advantages and disadvantages and providing sources of further information. The types of designs included are:

- Bamboo bridges
- Timber log and timber pole bridges
- Sawn timber, beam and truss types – glue-laminated designs are also briefly described but are not considered appropriate for this manual
- Steel beam and truss types
- Reinforced concrete footbridges
- Suspension bridges

The Chapter then goes on to discuss the criteria for selection of an appropriate design and on the basis of these selects designs from those above for presentation in more detail in Chapters 4, 5 and 6 of the manual.
3.1 BAMBOO BRIDGES

3.1.1 Characteristics and Applications

Bamboo grows locally in many rural areas, especially in Asia, and is therefore particularly suited to community construction of footbridges because of its ready availability at little or no cost. This is its main application, few bamboo footbridges are ‘technically’ designed and constructed.

Because of its hollow structure, bamboo is a considerably more efficient structural material than timber, with strength to weight and stiffness to weight ratios of at least double those for most timbers. Although it can be obtained in lengths of up to 8 to 10m, only sections above about 12cm in diameter are suitable for footbridge beams and therefore bamboo can only be used for short spans of 3 to 4m. Longer bamboo footbridges therefore need intermediate supports at a spacing of 4m or less.

Two types of design are common:

1. Suspended bridges for short lengths up to about 10m in which the deck is supported at its centre by poles or ropes from tall posts at the ends of the bridge or from an ‘A’ frame built above or below the bridge. Figure 3.1 shows an example of the first method but in this case using trees conveniently located on the banks rather than posts.

2. Footbridges with piers made from bamboo posts. Figure 3.2 shows an example of this type. It has a total length of 54m with 13 intermediate support piers. In this case the pier piles are supported by rocks in baskets because of their relatively short length but for higher decks they would need to be driven into the ground and braced (see Chapter 4).

In both the examples shown the deck is made from woven bamboo strips. This is satisfactory for pedestrians and bicycles but would not be strong enough for livestock or ADVs. For the latter, larger diameter bamboo is needed or preferably timber planks although these would substantially increase cost.

Further design details of these types of bamboo bridges are given in Chapter 4. It may also be possible to construct a truss type of bridge similar to that shown in Section 3.2 for timber logs with steel pipe connectors, but as far as is known this has not been attempted. This type of design would be substantially more costly than the types described above.

3.1.2 Advantages and Disadvantages

Advantages:
- The hollow structure gives good strength and stiffness relative to weight
- The surface is hard and clean. There is no bark to remove as with timber
- It is often locally available at little or no cost so communities can build footbridges with little outlay of funds
3. SELECTING A FOOTBRIDGE DESIGN

Bridge is suspended mainly by lengths of bamboo bound to branches of trees growing on the river bank.

Cross-members are bound to the suspension members to support the deck.

The deck is made from woven strips of bamboo.

Figure 3.1: Suspended Bamboo Footbridge
3. SELECTING A FOOTBRIDGE DESIGN

Section of bridge
Total length is 54m
Comprising:
  12 x 4m spans
  2 x 3m spans

Pier supports comprise a cross-member supported by 2 posts
Posts are held in place by rocks within a bamboo basket

The deck is a woven bamboo mat that is held in place by bamboo cross-pieces at 1.2m intervals bound to the longitudinal stringers

Figure 3.2: Bamboo Footbridge with Pier Support
3. SELECTING A FOOTBRIDGE DESIGN

Disadvantages:

- Because of the limited cross-sectional size of bamboo the maximum bridge span is only about 4m and more intermediate supports are needed for longer bridges than for timber.
- Bamboo has a low natural durability, particularly in soil. Effective application of preservatives is difficult because of the hard surface skin and is likely to be beyond the capability of most communities. Untreated bamboo will last less than 2 to 3 years and therefore bridges need regular maintenance to replace decayed members if they are to last for a reasonable time.
- Bamboo has poor resistance to termites.
- Joints are often made of natural fibres and have a limited effective life. Binding of joints with galvanised wire increases life but also cost.

3.1.3 Sources of Further Information  


   This publication has good information on the characteristics of bamboo and on methods of preservation. There is one chapter on footbridges. The designs included are taken from publication 2 below but are presented in a clearer format.


   This publication provides the source of much of the information presented in (1) above. In addition it provides details on floating bamboo and canvas bridges developed by the British Army in India for transport of army vehicles.

3. Timber Research and Development Association (TRADA); High Wycombe, UK

   TRADA is developing designs of bamboo footbridges in the range of 3 to 30m span for applications in India. These are of a more advanced technical design than those presented in this manual.

4. *Bamboo as a building material*: see –

   [www.bambus\new\eng\reports\buildingmaterial\buildingmaterial.html](http://www.bambus\new\eng\reports\buildingmaterial\buildingmaterial.html)

   This report has useful information on the characteristics of bamboo and its treatment. There is a short section on footbridges but with limited detail.

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2 Contact details of all organisations mentioned in the manual are given in Appendix D
3.2 TIMBER LOG FOOTBRIDGES

3.2.1 Characteristics and Applications

These are made from logs or large branches cut from trees. Timbers should be chosen from those that are locally used for structural purposes. Hardwoods are preferred for higher strength, durability and resistance to termites.

The simplest form of timber-bridge is for the logs to be used as stringers (beams) spanning the river/stream. Maximum spans depend on the sizes of logs available and are likely to be in the range 8 to 12m. However, in some locations logs of 15 to 20m length may be available. 2 to 4 logs are usually used depending on traffic using the footbridge and the span of the bridge. For longer spans, log sizes of at least 40 to 45cm in diameter will probably be needed. This is the diameter needed over the middle one third of the length of the log. It is with the bark removed and should not include sap wood.

Simple, low-cost footbridges for limited traffic, mainly pedestrians, can be made by nailing timber poles of about 7 to 10cm diameter across the log stringers to make a deck. However, for heavier traffic or a range of users, a proper deck of sawn wooden planks will be needed. For spans of over 3 to 4m handrails will be needed for safety and kerbs will be needed if carts or motor vehicles will use the bridge.

Figure 3.3 shows a fairly basic timber log bridge of 13m span installed in Malawi, while Figure 3.4 shows a more ‘finished’ bridge of 10m span in Australia.

The total span of log footbridges can be increased by providing intermediate pier supports with the log beams (stringers) overlapping at the cross-beam supports.

Further details of the design of timber log footbridges are given in Section 4.3 of Chapter 4.

Log truss footbridges provide a means for increasing the span of timber log bridges but design and construction is significantly more complex than the simple log stringer bridges described above. Truss structures are considerably more efficient in carrying loads than beams as the members are mainly in tension and compression rather than bending. Members can therefore be of smaller section, typically about 8cm to 15cm diameter logs. However, the members need to be relatively straight and uniform in section.

The main difficulty in constructing timber truss structures, particularly those made from logs, is in making effective joints where up to 6 to 8 members may need to be joined. Figure 3.5 shows a neat and effective design that has been developed by the American Institute of Sustainable Science and Technology Inc. The design uses log members that fit into joining sockets at their ends made from steel pipe sections. The whole structure is put into compression by tensioned wire cables to provide a good load-carrying capacity. The need for uniform size, straight logs and the cable-tensioning components put this design beyond the scope of most local bridge construction in rural areas.

3.2.2 Advantages and Disadvantages

The following comments refer only to log-beam bridges.

Advantages:

- They are simple to construct and can be built up on site.
- They are relatively low cost
3. SELECTING A FOOTBRIDGE DESIGN

Figure 3.3: 13m Span Log Bridge in Malawi
(Note the running boards on the deck for vehicles)

Figure 3.4: 10m Span Footbridge in Australia
(Details provided by Outdoor Structures, Australia)
A half-size prototype of a truss foot bridge constructed from timber logs with steel pipe connectors. Steel cables tensioned by screwed adjusters are used to pre-compress the truss structure so that the joints are able to better transfer tension forces. The bridge has been developed by the American Institute of Sustainable Science and Technology Inc (see Annex D).

**Figure 3.5: Timber Log Truss Bridge**

- Often they can be built from locally available materials, although in some countries or districts suitable timber is becoming increasingly difficult to obtain because of deforestation

**Disadvantages:**

- Fairly straight logs are needed and the logs for a specific bridge need to be reasonably well matched in size
- Single spans are usually limited to about 10 to 12m but longer spans are possible with the use of piers where conditions are suitable for installing piers
- The natural decay of timber exposed to the weather may limit life of logs to 5 to 10 years although 10 to 20 years should be achieved with appropriate timbers. Durability can be improved by the use of hardwoods, good detail design and use of preservatives. For long life, regular maintenance is needed to recoat with preservatives and repair decayed timber
- It is difficult to replace individual stringers if they show excessive deterioration
- Logs are heavy making them difficult to manually transport and manoeuvre.
3.2.3 Sources of Further Information


   Although this publication has only a short section on log bridges it has useful information on the preparation and preservation of logs.

2. United States Department of Agriculture National Wood in Transportation Centre, WV, USA

   The USDA provides technical briefs on the design of various types of timber bridges. That on log bridges has been consulted in the preparation of Section 4.3 of this manual.

3. Outdoor Structures Australia, Queensland, Australia

   Timber log bridges have been widely used on rural roads in Australia and much experience has been accumulated on their design. A 4-page technical brief is available from the above source and has been consulted in preparation of Section 4.3 of the manual.


   This manual contains much useful information on footbridges including design details for log footbridges.

5. Developing Technologies, Acton, London

   This is a charity that uses student project work to carry out engineering design work for the developing world. One of its projects is the design of improved timber log bridges.
3. SELECTING A FOOTBRIDGE DESIGN

3.3 SAWN TIMBER FOOTBRIDGES

3.3.1 Characteristics and Applications

When logs are sawn into planks the timber loses some of its strength due to the greater influence of the grain structure and also is more affected by defects such as knots and splits so strength reduction factors have to be applied to take into account the quality of the timber. However, the strength/weight ratio of rectangular sawn sections is better than for logs and since more beams can be fitted across the width of the bridge, individual members are lighter and easier to handle.

The regular shape and sizes of sawn timber beams allow bridge designs to be standardized. There are two basic types of designs;

1. **Beam structures** similar to the log-beams discussed above. Single spans are less than for logs, the general range being 5 to 8m with an upper limit of about 10m. Longer spans can be achieved with piers providing intermediate supports. Figure 3.6 shows a 10m span bridge with a central pier. Figure 3.7 shows an alternative option that avoids the use of piers where piers are not practical by providing cantilever supports at each end of the bridge built into the abutments. The span is 15m. It is reported that spans up to 20m can be achieved with this type of design.

2. **Truss structures** can be used for longer single spans usually where the use of intermediate supports is not practical. Various truss configurations are possible some with the truss above the deck (through truss) and some with the truss below the deck (deck truss). The latter tend to be used where a deep opening is to be crossed (plenty of clearance below the deck) and are generally the most economical for this purpose.

The **bowstring truss**, which forms the shape of an arc of a circle above the deck, is the most economic form but is limited to about 30m span. **Parallel-chord trusses** in which the truss is a constant height above or below the deck have been used for spans up to 80m in highway bridges, but because of the smaller width of footbridges, footbridges over 30m long need horizontal cable stays to stabilise the bridge against sideways sway. An example of a timber truss bridge (parallel-chord type) from Canada is shown in Figure 3.8. This is about 20m span and at the time of the photo was over 60 years old.

Although it is easier to construct trusses from rectangular sawn sections than round logs, there is still a problem of designing the joints to transmit high forces. Usually steel pins/bolts and steel shear connectors have to be used to obtain effective and reliable joints.

Many timber truss bridges were constructed in the past in countries such as Australia and USA but few are built today because of the high labour costs involved in their construction. However, they are an appropriate design for developing countries where labour costs are low. An advantage is that they can be constructed on site with limited tools. Constraints on their use are the lack of availability of ‘ready’ designs and of equipment for pressure treatment of the timber with preservatives to obtain long life. However, with use of appropriate timbers and regular hand application of preservatives a life of at least 20 to 30 years should be possible.
Figure 3.9 shows a modular timber truss bridge developed by UNIDO (United Nations Industrial Development Organisation, Vienna, Austria) and TRADA (Timber Research and Development Association, UK) for application in developing countries. It aims at centralised ‘factory’ production of the 3m long modules that can then be transported to site and pinned/bolted together to produce standard designs. This design could be appropriate for local applications if the modules were readily available for assembly from a central unit. However, the design is probably beyond the scope of local construction.

3. **Glued laminated timber (Glulam):** the major application of timber in bridge construction in developed countries is now in the form of glued-laminated sections. These are formed by gluing together sheets under pressure using a waterproof glue. The advantage is that long beams, both straight and curved, can be produced. The technology is not considered appropriate for the applications covered by this manual.

3.3.2 Advantages and Disadvantages

**Advantages:**

- Sawn timber is a common construction material and will usually be readily available in a number of sizes. It is less dependent on a local supply of timber than logs
- Sawn beams require little or no preparation, whereas log beams require removal of bark and trimming to even up variations in size
- Sawn timber beams are relatively light and easy to install, making footbridges simple to construct, particularly for short spans
- Truss bridges can be more readily constructed to extend the range of single span bridges where pier supports are not practical
- Sawn timber can be more effectively treated with preservatives than logs so that longer life can be achieved
- Timber bridges can be constructed on site with simple hand tools. The carpentry skills needed will probably be locally available

**Disadvantages:**

- The large sizes needed for longer bridges may not be readily available locally
- The cost of sawn timber bridges is likely to be considerably greater than for log bridges
- The cost of good quality timber is tending to increase as availability is reduced by deforestation.

3.3.3 Sources of Further Information


This large design manual (992 pages) contains a wealth of information on timber and all aspects of timber bridge design. The manual provides information on design procedures rather than examples of standard designs. It is produced for the US forest department and therefore concentrates on timbers commonly used in the US. However, it is a good reference source on the basics of design, treatment of timbers and timber bridge construction.
3. SELECTING A FOOTBRIDGE DESIGN


This includes standard plans for sawn timber beam (stringer) bridges made from Southern Pine. The designs are for single and dual carriage highway bridges but are useful in showing design details for timber beam bridges.


This manual (see 3.2.3 above) contains plans for 2 types of sawn timber beam footbridges with recommended beam sizes for a range of bridge spans.

4. A Design Manual for Small Bridges; Overseas Road Note 9, Transport Research Laboratory (TRL) International Division, Crowthorne, UK, 2nd Edition 2000

This manual covers the design of bridges up to 12m single span in developing countries. It covers the entire design process from site survey to detail design. It contains basic details of timber beam bridges, log and sawn timber, with recommended sizes for a range of bridge spans. The beam sizes can be reduced in proportion to the section modulus for the lower loading of footbridges. The data has been considered in the preparation of the design details in Chapter 4 of this manual.

5. Pre-Fabricated Modular Wooden Bridges; prepared by the Timber Research and Development Association (TRADA), UK for the United Nations Development Organization (UNIDO), Vienna, Austria, 1985

A series of reports describes the setting up of a plant to produce the modules for these timber truss bridges and the design of standard bridges. Although the designs are for road bridges, it is possible to adapt them for footbridges. The application of the design is limited to a certain extent by the truss structure being below the deck, requiring good clearance between the deck and water level.
10m span x 4.5m wide sawn-timber bridge for pedestrians, IMT and low-volume light motorized vehicles (about 10 pick-ups per day)

**Figure 3.6:** Sawn-Timber Beam Bridge in Laos
15m span x 1m wide sawn-timber footbridge for pedestrians and livestock. Note the cantilever supports used to extend the single span of the bridge.

Figure 3.7: Sawn-Timber Beam Bridge in Nepal
A ‘parallel chord’ truss bridge of about 20m span constructed in Canada. This bridge was 62 years old at the time of the photograph.

**Figure 3.8: Example of a Sawn-Timber Truss Bridge**

**Figure 3.9: A Modular Timber Truss Bridge Developed by UNIDO and TRADA.**
The 18m span bridge in Madagascar was erected in 4 days on prepared abutments
3.4 STEEL FOOTBRIDGES

3.4.1 Characteristics and Applications

For the same weight there is not a great deal of difference in the strength of steel and hardwoods. However, for the same section size steel is stronger so designs are more compact. Steel is therefore particularly suited to construction of truss type bridges where joining of the members is also easier than for timber. This type and steel cable bridges are likely to be the main application of steel for footbridges in developing countries.

Appropriate steel sections for footbridges are less likely to be available in rural areas than timber and construction of steel footbridges will probably need to be carried out in medium sized workshops in towns and urban centres. Components can be transported to site and assembled by bolting or riveting.

Providing it is adequately protected against corrosion, steel will have a considerably longer life than timber. Protection by simple hand methods of brushing or spraying is likely to be more effective than for timber and maintenance will be less. Hot-dip galvanising is likely to be the most effective method of protection but will probably be unavailable in many areas. Coating with 2 or 3 layers of anti-rust paint should also be effective. With regular, effective maintenance, steel bridges should last at least 30 years.

Steel bridges will usually have timber decks. These are best made up into integral panels to minimise problems in attaching them to the steel structure.

There are two types of steel footbridges, beam bridges and truss bridges. Suspension bridges using steel cables are described separately in Section 3.6 below.

**Steel Beam bridges** are usually constructed from 'I'-sections as these are the most efficient in bending. Standard lengths for these are 8, 12 and 15m so that single spans can be longer than for timber beams if suitable sizes are available. Beams can also be joined to give longer lengths using bolted, riveted or welded connectors but very careful consideration needs to be given to the design of the connectors to make sure they are strong enough, particularly welded joints.

Figure 3.10 shows a steel beam bridge in Indonesia designed for low-volume motorised traffic. The bridge has a span of 13m, total length of 14m and a width of 4.4m. It has 4 I-beams of section 400mm deep x 150mm wide x 8mm thickness. The deck is made of sawn timber planks. The cross-members are 200 x 50mm section and are bolted in position through holes drilled in the top flanges of the outer beams by 16mm diameter U-bolts. The longitudinal runners for vehicle wheels are 150 x 100mm in section. The replacement of worn and rotting deck timbers is usually the main maintenance requirement and cost for steel bridges. The handrails are made from steel angle section and are welded directly to the flanges of the outer beams. It should be pointed out that attachments to the beam flanges, either by welding or drilling is not good practice as these are areas of maximum stress. It is better to make attachments on the central part of the web where stresses are low.

The availability of steel I-section beams will probably be quite limited in many countries, especially in rural areas, and therefore this type of bridge is not considered a first-level option for footbridges.
A low cost alternative that has been suggested for footbridges is to use a scrap chassis from a large truck or bus for the beams. An example of this is included in Appendix C.

**Steel Truss bridges** use members in an arrangement where the load is carried mainly by direct forces, tension and compression, in the members rather than in bending as in beam bridges. This is a more efficient use of the material and allows a wider range of sections to be used. Steel truss bridges are often made from angle or channel sections. These sections are likely to be available in a reasonable range of sizes in most countries, particularly angle section, and therefore this type of bridge provides a good option for spans beyond the range of timber beam bridges i.e. greater than about 10m. The maximum span for this type of bridge is about 25m. Truss bridges may also be made from rectangular hollow tube but this section is less likely to be available in the sizes needed.

Most steel truss bridges are of the parallel chord type. Although joints are easier to make than in timber trusses they still need to be reinforced with gusset plates to increase the area for joining. Joints may be bolted, riveted or welded. The bridge will usually be made in a workshop and the choice of joint may well depend on the problem of transporting the bridge to site. If the site is remote and the bridge has to be carried a significant distance then individual components of the truss may be manufactured and drilled in the workshop, transported to site and bolted together on site. This requires considerable accurate manufacture in the workshop and careful assembly on site. A simpler procedure is to fabricate panels of the bridge in the workshop and bolt these together on site. If there is direct access for vehicles to the site then complete modules may be made in the workshop and transported to site to be bolted together. It is important to note that for this procedure of preconstruction of components and assembly on site it is essential to assemble and test the footbridge in the workshop to ensure everything is satisfactory before transporting it to site.

Figure 3.11 shows an example of the construction of a steel truss footbridge installed in Ethiopia. In this case the components were transported individually to site and bolted together. The footbridge is 12m long and 1.5m wide and is designed for pedestrians and livestock. It is constructed from 60 x 60 x 6 mm and 60 x 60 x 5mm angle section with 7mm thick gusset plates.

For a given installation the cost of materials for a beam and truss bridge is likely to be fairly similar but the labour cost for the truss bridge will be significantly higher. Applications for truss bridges will therefore be mainly for spans exceeding the limit for beam type bridges (timber or steel) of 8 to 12m or where suitable beams sections are not available.

### 3.4.2 Advantages and Disadvantages

**Advantages:**

- Steel can be more effectively protected using simple hand methods of brushing or spraying and therefore steel bridges are likely to have a longer life and lower maintenance costs than timber bridges
- Steel truss bridges are more straightforward to fabricate than timber truss bridges and are likely to be more appropriate for spans of intermediate length

**Disadvantages:**

- More complex tools and equipment are needed to construct steel bridges compared to timber bridges and in most cases construction will need to be in a workshop and components or sections transported to site for assembly
View of bridge showing the timber decking

View of the underside of the bridge showing the 4 I-section steel beams. Note the cross-bracing that is used to prevent twisting of the beams under load

Figure 3.10: Steel Beam Bridge for Low-Volume Traffic
3. SELECTING A FOOTBRIDGE DESIGN

Figure 3.11: Details of Construction of a Steel Truss Footbridge Installed in Ethiopia

This bridge was designed by Bridges to Prosperity Inc., an American charity that specialises in providing technical assistance and training for construction of footbridges in developing countries. It organises the supply of steel while the local communities (the beneficiaries of the bridge) provide all the sand, gravel and rock as well as all the labour. This labour is then guided and trained by Bridges to Prosperity technicians during the construction and installation of the bridge.

3.4.3 Sources of Further Information


   The manual contains details of 2 designs for steel beam footbridges for spans up to 16m, including notes on protection of the steel from corrosion

2. His Majesty’s Government of Nepal
   Ministry of Local Development
   Department of Local Infrastructure Development and Agricultural Roads (DOLIDAR)
   Trail Bridge Section

   A range of steel truss bridges in increments of span up to 30m have been developed in collaboration with HELVETAS ([www.helvatasnepal.org.np](http://www.helvatasnepal.org.np)) and the Swiss Association for International Co-operation. The designs involve the manufacture of individual members in a workshop and transport of these to site to be bolted together. Detailed Engineering drawings are available.
3. SELECTING A FOOTBRIDGE DESIGN

3.5 REINFORCED CONCRETE (RCC) BRIDGES

3.5.1 Characteristics and Applications

These bridges comprise a concrete slab reinforced with steel bar that spans the crossing. The slab may either be of a plain solid rectangular section or a thinner slab strengthened on its underside by integral beams that run along and across the bridge (see Chapter 6). The latter type of slab will use less material than a plain slab but will involve considerably greater difficulty and effort in preparation for pouring the concrete.

For footbridges the top surface of the concrete slab can be the walkway surface saving the need for a separate deck. The upper limit of span for a RCC bridge is about 12m. Piers are needed for longer spans. When large cranes are available slabs can be pre-cast and lifted into position. However, in situations covered by this manual, slabs will be cast in situ. This therefore requires the construction and support of wooden box-work (shuttering) in which the reinforcing steel is supported and the concrete poured. This will involve considerable time inputs from skilled carpenters and will prevent the use of RCC bridges where the river-bed does not allow the construction of timber scaffolding to support the shuttering.

Figure 3.12 shows a RCC footbridge constructed in Malawi. This has a span of 15m with a central masonry pier support. The bridge is provided with steel handrails bolted to the concrete side. The bridge was constructed by a local contractor in a reported time of 1 month and at a reported cost of USD $28,000.

3.5.2 Advantages and Disadvantages

Advantages:

- The main advantages of RCC bridges are their long life, at least 50 years, and their low maintenance costs. Therefore although their initial cost may be higher than other types, their “total life” cost may be lower as their maintenance costs will be lower and other types may need to be replaced one or more times during the life of the RCC bridge.

Disadvantages:

- The main disadvantages in regard to local construction are the effort and skills needed, particularly in erecting the shuttering for the concrete slab. The mixing and pouring of concrete will also require good organisation and experience. For example, the amount of water used to mix the cement affects the strength of the concrete. Some skilled and experienced labour will therefore be needed with possibly support from the local community in carrying out less skilled tasks.

3.5.3 Sources of Further Information

1. A Design Manual for Small Bridges; Overseas Road Note 9, Transport Research Laboratory (TRL) International Division, Crowthorne, UK, 2nd Edition 2000

The manual gives design details for plain slab RCC bridges for low-volume traffic. The designs cover use by trucks up to a gross loading of 20 tonne and are therefore considerably beyond the requirements for footbridges that might have to carry light vehicles such as pick-ups. An engineer competent in RCC design would be needed to adapt these designs for applications covered by this manual.
3. SELECTING A FOOTBRIDGE DESIGN

Figure 3.12: A 15m Span Reinforced Concrete Footbridge with Central Pier in Malawi

Note: Standard design used by Ministry of Works, Government of Malawi
3.6 SUSPENSION AND SUSPENDED FOOTBRIDGES

3.6.1 Characteristics and Applications

Where support piers are not possible the span of beam and truss type footbridges may be extended by partly supporting them with cables. This involves building towers at one or both ends of the bridge that are tall enough to achieve effective angles for the support cables. The other ends of the cables must be firmly anchored in the ground. A schematic arrangement of this type of suspension bridge is shown in Figure 3.13. This has 3 timber truss sections but other bridge types can also be used with careful design of the crossbeam supports at the joints between the sections.

The more conventional type of suspension bridge uses continuous cables supported by towers at each end of the bridge which hang in a catenary to support vertical hanging cables from which the bridge deck is suspended. A schematic outline of this type of bridge is shown in Figure 3.14. The bridge deck may be flexible or rigid but must be strong enough to support the traffic load between the support cables and also to resist wind loading. The end towers need to be tall enough to allow a sag of the cables of between 1:8 and 1:11.

Figure 3.15 shows an example of a suspension bridge in Nepal. This has a span of 30m and width of 1m and is used by pedestrians and livestock. The masonry towers are about 5m tall. The deck comprises timber planks supported on timber beams. These are a weakness of the design since the timber tends to rot and may need replacing after 10 years or so, whereas the steel cables and masonry towers may have a life of over 50 years. The reported cost of this bridge that was built 10 years ago was $7,600, comprising $1,000 for supports, $4,400 for materials and $2,200 for labour.

There has been a major programme of development of suspension bridges in Nepal, covering spans of up to 300m. The programme also encompasses suspended bridges that are less costly and require lower technical inputs than suspension bridges but also have some limitations on their applications. In suspended bridges the actual deck is attached to a sagging lower cable with an upper cable for the handrail. So unlike suspension bridges when the deck can be kept fairly level by using hanging suspender cables or rods of appropriate length, the deck of a suspended bridge has an inherent sag. The specified sag is span/20 for spans less than 80m and span/22 for spans over 80m. This gives quite a steep slope of about 1 in 5 at each end of the bridge. Figure 3.14 shows a schematic outline of this type of bridge. Because of the sag of the deck this type of bridge needs good clearance above the water level and is therefore suited to ravines or rivers with high banks. Suspended footbridges are limited to mainly pedestrian traffic, livestock and pack animals. In Nepal they tend to be used more in mountainous regions with suspension bridges being used more on the plains.

Figure 3.16 shows an example of a suspended footbridge. Note the steel deck. This provides a much longer life than timber decking.

3.6.2 Advantages and Disadvantages

Advantages:

- The main applications of cable type footbridges, suspension and suspended, are for spans over 20 to 25m where intermediate pier supports are impractical. In these situations they may be the only option, particularly where a ferry is not feasible. They are a cost-effective solution for light to moderate traffic of pedestrians, pack animals and livestock, for medium to long spans.
3. SELECTING A FOOTBRIDGE DESIGN

Disadvantages:

- **Suspended** footbridges are limited to use by pedestrians and livestock. Standard designs available for suspension footbridges also appear to be limited to this type of traffic although they could be developed for carts and light vehicles.

- Note that careful attention needs to be given to the stability of cable bridges, particularly for short spans. The centre of gravity of users of the bridge needs to be well below the anchor points of the cables.

- Cables and associated components, especially for suspension footbridges, are unlikely to be available locally and possibly not nationally. The introduction of cable bridges may need to be supported by a national development programme.

- Some skilled labour will be needed, particularly for the cable work, which will probably have to be brought in from outside the local area.

3.6.3 Sources of Further Information

1. **Short-Span Trail Bridge Standard**: Compiled by His Majesty’s Government of Nepal, Trail Bridge Section of the Department of Local Infrastructure Development and Agricultural Roads, Kathmandu, Nepal; With assistance from HELVATAS Nepal, and Swiss Association for International Cooperation; Published by SKAT, Swiss Centre for Development Cooperation in Technology and Management, Switzerland, 2002.

   Cable-type bridges are well suited to the terrain of Nepal and there has been a major programme of development and construction supported by the Swiss Association for International Cooperation. This manual deals with the design, construction and installation of suspended bridges. Information is also available from this source on suspension bridges.


   These guidelines are based on experience from the above programme in Nepal and more particularly on lessons learned from a pilot programme of construction of suspension bridges in Zimbabwe. The guidelines have limited technical detail but the Department of Roads in the Ministry of Transport and Communications, Government of Zimbabwe, has developed standard designs for spans of 20 to 160m in 20m increments.


   This gives details of a low technology suspension bridge for spans up to about 25m.
3. SELECTING A FOOTBRIDGE DESIGN

Figure 3.13: Schematic Design for a Simple Suspension Bridge
(Design suggested by Gatton Sawmilling Co., Queensland, Australia)
3. SELECTING A FOOTBRIDGE DESIGN

Suspension Cable sag 1 in 8 to 1 in 11

Deck suspended by hangers, rods or cables, from cable

(i) Schematic Layout of Suspension Bridge

Flood Level

Span

Sag

Handrail cable

Walkway cable

(ii) Schematic Layout of Suspended Bridge

Figure 3.14: Schematic Layouts of Cable Suspended Footbridges
3. SELECTING A FOOTBRIDGE DESIGN

Figure 3.15: 30m Span Suspension Footbridge in Nepal

Figure 3.16: Example of a Suspended Footbridge in Nepal
(Photograph provided by Bridges to Prosperity Inc.)
3.7 SELECTION OF TYPE OF FOOTBRIDGE

3.7.1 Selection Criteria

1. **Span**

The location of the abutments and the required span of the footbridge are found from the site survey (Appendix A). The typical range of unsupported span lengths for the various types of footbridges are summarised in Table 3.1 below. This provides an initial choice of possible options.

If the river bed allows the construction of pier supports then any of the options can be used. For example if a 20m span bridge is needed then the options are:

- Beam or RCC footbridge with 1 or 2 pier supports, the spacing of piers depending on the beam lengths available
- Steel or timber truss bridge with no pier supports
- Suspended or suspension bridges might also be considered although this is at the bottom end of their normal range

The selection will depend on other criteria discussed below.

2. **Traffic**

The manual covers mainly footbridges for pedestrians, livestock and IMTs but allows for the occasional light vehicle such as a pick-up with a gross loaded weight up to about 3.0 tonne. Most of the footbridge types can cope with this with the following limitations:

Bamboo bridges - pedestrians, bicycles, smaller livestock such as goats, sheep and possibly donkeys, and pushed motorcycles

Suspension bridges - pedestrians, pushed bicycles, livestock and pack animals

Suspension bridges - available standard designs appear to have capacity for pedestrians, bicycles and pushed motorcycles, livestock, wheelbarrows and small carts. They could be adapted for heavier traffic by a qualified engineer but with a proportionate increase in cost.

3. **Availability of materials**

An important criteria for construction at local level will be whether materials are locally available or readily available from larger resource centres that are readily accessible. It is unlikely that at this level it will be possible to organise importation of materials.

4. **Technical support and special skills needed**

Bamboo bridges can be constructed by the community with little or no technical assistance. For other types of footbridges, technical assistance and supervision will be needed. In some cases labour with special construction skills and experience not locally available may also have to be brought in. The manual prioritises selection of options where technical assistance can be provided at District level and where labour skills are locally available.
5. **Life of footbridge**

Most footbridge materials will deteriorate over a period of time and eventually the bridge will need to be replaced. The rate of deterioration and life of the bridge will depend on the initial choice of material, how well it is protected against deterioration and how well it is maintained to retain the protection. In some cases particular parts of the bridge may deteriorate and need to be replaced. For example, timber decks tend to deteriorate quite quickly due to wear from traffic and the difficulty of effectively protecting the timber.

Careful consideration must also be given to possible changes in future traffic. A significant improvement in prosperity of the area could cause a change in modes of transport used from walking to carts and motorised forms. A footbridge built for pedestrians and livestock only could therefore become obsolete and have to be replaced.

6. **Cost of footbridge**

Two factors need to be considered in comparing the costs of options for footbridges:

1. *Initial cost* - which is the cost of constructing and installing the footbridge including abutments and any piers

2. *Total life cost* - this the total cost of providing the footbridge over a period of time, which includes initial cost, maintenance costs and replacement costs if the time period is greater than the estimated life of the footbridge.

For example, if the estimated life of a RCC footbridge is 60 years, and that of a timber bridge 20 years with the timber deck of the latter replaced every 10 years, the comparison of the *Total Life* costs of the footbridges over 60 years is:

- **RCC footbridge** – Initial cost + 60 x (annual maintenance cost)

- **Timber footbridge** – Initial cost + 60 x (annual maintenance cost) + Replacement cost of bridge at 20 and 40 years + Replacement cost of deck at 10, 20, 30, 40 and 50 years.

(Note – to be theoretically correct the comparison of costs needs to take into account the time value of money and inflation. However, if it assumed that labour and material costs will continue to be roughly in the same proportion to the cost of living then a straightforward comparison of costs will be reasonably reliable)

Although the *Initial cost* of the RCC footbridge may be higher than that of the timber footbridge, the *Total life* cost will probably be substantially lower.

The lowest *Total life* cost gives the most cost-effective option for a footbridge and should be used in selection wherever possible. However, in many cases there will be budget constraints and the lowest *Initial cost* option may have to be selected.

The reported initial costs of various types of bridges obtained from case-studies are compared in Table 3.1. The data shows consistent unit costs for some types of low-volume traffic bridges but there is insufficient data to give reliable cost-estimates for footbridges.
It should be noted that the costs in Table 3.1 include abutments and piers (where used) and therefore it is not possible to compare the cost per m span for the different types of bridge structures.

Unit costs obtained from the case studies gave the following comparison of material costs for a 1.4m wide footbridge based on the designs presented in Chapters 4, 5 and 6. Note that these include only the deck structure and decking i.e. the features that differ for the three types.

<table>
<thead>
<tr>
<th>Type of Footbridge</th>
<th>Cost Component</th>
<th>Material Cost US$/m</th>
<th>Additional Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sawn-Timber Beam</td>
<td>Timber @ $250/m³</td>
<td>$85</td>
<td>Installation</td>
</tr>
<tr>
<td></td>
<td>Nails, preservative etc. @ 15%</td>
<td>$13</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>$98</strong></td>
<td></td>
</tr>
<tr>
<td>Steel Truss</td>
<td>Steel @ $0.6/kg</td>
<td>$52</td>
<td>Workshop and Installation</td>
</tr>
<tr>
<td></td>
<td>Timber deck @ $250/m3</td>
<td>$13</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bolts, paint etc @ 25%</td>
<td>$16</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>$81</strong></td>
<td></td>
</tr>
<tr>
<td>Reinforced Concrete</td>
<td>Cement @ $6/50kg (sand and stones not costed)</td>
<td>$28</td>
<td>Construction of shuttering and installation</td>
</tr>
<tr>
<td></td>
<td>Reinforcing steel @ $0.6/kg</td>
<td>$63</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>$91</strong></td>
<td></td>
</tr>
</tbody>
</table>

Adding labour costs, the overall cost of Sawn-Timber Beam and Steel Truss footbridges are likely to be similar for these unit costs, but timber footbridges will require intermediate piers for spans over 8 to 10m. Reinforced concrete footbridges will have a higher initial cost due to the higher input of experienced labour needed.

Comparative material costs (including average porterage costs) for footbridges in Nepal were reported as:
Steel truss $100/m, Reinforced Concrete $80/m, Cable Suspension $100/m

7. National policy on bridge design

A National roads department may decide to concentrate on particular bridge types that are generally suitable for the country in order to develop standard designs and make the materials needed readily available (for instance treated timbers, steel sections or steel cables and components). This would then dictate selection.

3.7.2 Comparison of Footbridge Types Against Selection Criteria

Table 3.1 compares the range of footbridge types in relation to the above selection criteria.
Table 3.1: Reported Costs of Footbridges and Low-Volume Traffic Bridges

<table>
<thead>
<tr>
<th>Country</th>
<th>Classification (1)</th>
<th>Span (m)</th>
<th>Width (m)</th>
<th>Abutments</th>
<th>Piers</th>
<th>Deck</th>
<th>Design Life (yrs)</th>
<th>Age (yrs)</th>
<th>Materials</th>
<th>Labour</th>
<th>Total</th>
<th>Cost/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malawi</td>
<td>Low volume</td>
<td>27</td>
<td>3.7</td>
<td>Masonry</td>
<td>3 x masonry</td>
<td>Sawn timber</td>
<td>10</td>
<td>4</td>
<td>22,640(2)</td>
<td>13,280(2)</td>
<td>36,000</td>
<td>360</td>
</tr>
<tr>
<td>Malawi</td>
<td>Low volume</td>
<td>13.5</td>
<td>3.7</td>
<td>Timber log</td>
<td>None</td>
<td>Sawn timber</td>
<td>10</td>
<td>7</td>
<td>10,000</td>
<td>Community 5,000 (Est.)</td>
<td>15,000 (Est.)</td>
<td>300</td>
</tr>
<tr>
<td>Malawi</td>
<td>Footbridge (iii)</td>
<td>50.5</td>
<td>2.5</td>
<td>Masonry</td>
<td>9 x masonry</td>
<td>Sawn timber</td>
<td>5</td>
<td>2</td>
<td>3,000</td>
<td>1,500</td>
<td>4,500</td>
<td>36</td>
</tr>
<tr>
<td>Nepal</td>
<td>Low volume</td>
<td>15</td>
<td>5</td>
<td>Sawn timber</td>
<td>3 x sawn timber</td>
<td>Sawn timber</td>
<td>30</td>
<td>24</td>
<td>20,800</td>
<td>5,200</td>
<td>26,000</td>
<td>347</td>
</tr>
<tr>
<td>Nepal</td>
<td>Footbridge (ii)</td>
<td>12</td>
<td>1.2</td>
<td>Masonry</td>
<td>None</td>
<td>Sawn timber</td>
<td>50</td>
<td>30</td>
<td>8,100</td>
<td>2250</td>
<td>10,350</td>
<td>719</td>
</tr>
<tr>
<td>Laos</td>
<td>Low volume</td>
<td>9.5</td>
<td>4.5</td>
<td>Sawn Timber</td>
<td>1 x sawn timber</td>
<td>Sawn timber</td>
<td>10 to 15</td>
<td>2</td>
<td>15,000</td>
<td>500</td>
<td>15,500</td>
<td>362</td>
</tr>
<tr>
<td>Ethiopia</td>
<td>Footbridge (ii)</td>
<td>12</td>
<td>1.5</td>
<td>Existing</td>
<td>None</td>
<td>Sawn timber</td>
<td>40</td>
<td>1.5</td>
<td>4,700</td>
<td>6,450</td>
<td>11,150</td>
<td>620</td>
</tr>
<tr>
<td></td>
<td>(3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Malawi</td>
<td>Footbridge (ii)</td>
<td>15</td>
<td>1.5</td>
<td>Masonry</td>
<td>1 x masonry</td>
<td>Concrete</td>
<td>50</td>
<td>1</td>
<td>18,500</td>
<td>7,500</td>
<td>26,000</td>
<td>1155</td>
</tr>
<tr>
<td>Nepal</td>
<td>Low volume</td>
<td>10</td>
<td>5</td>
<td>RCC</td>
<td>None</td>
<td>Concrete</td>
<td>100</td>
<td>2</td>
<td>8,200</td>
<td>3,500</td>
<td>11,700</td>
<td>234</td>
</tr>
<tr>
<td>Nepal</td>
<td>Low volume</td>
<td>9</td>
<td>3.6</td>
<td>Masonry</td>
<td>None</td>
<td>Concrete</td>
<td>100</td>
<td>2</td>
<td>9,300</td>
<td>3,000</td>
<td>12,300</td>
<td>380</td>
</tr>
<tr>
<td>Nepal</td>
<td>Footbridge (ii)</td>
<td>30</td>
<td>1</td>
<td>Masonry</td>
<td>Sawn timber</td>
<td>Sawn timber</td>
<td>50</td>
<td>10</td>
<td>5,400</td>
<td>2,200</td>
<td>7,600</td>
<td>253</td>
</tr>
</tbody>
</table>

Notes:  
(1) Classifications covered – (i) Low Volume, rural road bridge for low volumes of motorised traffic; (ii) Footbridge, mainly pedestrian and livestock.  
         (iii) Footbridge and NMT, pedestrian and non-motorised vehicles.  
(2) 5% was contributed by the community as a precondition of receiving funding.  
(3) This was a high quality bridge built by the NGO ‘Bridges to Prosperity’. All members were pre-drilled and transported individually to site for assembly. Fabrication costs were therefore high.
<table>
<thead>
<tr>
<th>Type of Bridge</th>
<th>Span Range (1)</th>
<th>Traffic</th>
<th>Availability of materials</th>
<th>Technical support needed</th>
<th>Life and maintenance</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bamboo</td>
<td>Up to 4m</td>
<td>Pedestrian, bicycles, small livestock</td>
<td>Often grown locally</td>
<td>None</td>
<td>Normally 2 to 3 years(2); regular replacement of bamboo</td>
<td>Generally constructed and replaced by community with little or no material cost</td>
</tr>
<tr>
<td>Timber log beams</td>
<td>8 to 10m; up to 12m</td>
<td>All types</td>
<td>May be available from local forests otherwise will be a problem</td>
<td>District technical supervision of local carpenters and community</td>
<td>Logs – 10 to 15 years; decking 5 to 10 years; Regular maintenance of deck</td>
<td>Initial – Logs low cost if locally available. Sawm timber deck raises cost. Long term – medium to high</td>
</tr>
<tr>
<td>Sawn timber beams</td>
<td>8 to 10m</td>
<td>All types</td>
<td>May need to be obtained from larger timber suppliers</td>
<td>District technical supervision of local carpenters and community</td>
<td>Beams – 10 to 25 years depending on quality of hardwood; decking 5 to 10 years; Regular maintenance of deck</td>
<td>Initial – cost of good timber beams will be high Long term – medium to high</td>
</tr>
<tr>
<td>Sawn timber truss</td>
<td>Up to 25m</td>
<td>All types</td>
<td>Smaller sections than for beams and more likely to be locally available but quality may not be adequate for construction of a truss</td>
<td>Standard designs need to be developed by qualified engineer. Workshop inputs needed for joint reinforcements</td>
<td>10 to 25 years or more depending on quality of hardwood; decking 5 to 10 years; Regular maintenance of truss and deck</td>
<td>Initial – cost of timber may be lower than for beams but construction costs will be higher Long term – medium to high</td>
</tr>
<tr>
<td>Steel beams</td>
<td>Up to 15m</td>
<td>All types</td>
<td>Availability likely to be a problem</td>
<td>Workshop inputs needed; District technical supervision of local carpenters and community</td>
<td>Steel – 30 to 40 years and longer if well maintained with repainting every 2 to 3 years decking 5 to 10 years; Regular maintenance of beams and deck</td>
<td>Initial – similar to good sawn timber beam bridge Long term – medium</td>
</tr>
<tr>
<td>Steel truss</td>
<td>Up to 25m</td>
<td>All types</td>
<td>Should be generally available</td>
<td>Workshop construction of standard design. District technical supervision of installation by carpenters and community</td>
<td>Steel – 30 to 40 years and longer if well maintained with repainting every 2 to 3 years decking 5 to 10 years; Regular maintenance of steel, joints and deck</td>
<td>Initial – similar to sawn timber and steel beam bridges Long term – medium</td>
</tr>
<tr>
<td>Reinforced concrete</td>
<td>Up to 12m</td>
<td>All types</td>
<td>Should be generally available</td>
<td>District technical supervision of construction of standard design. Labour needed with experience of RCC work</td>
<td>At least 50 years Low maintenance</td>
<td>Initial – may be higher than timber or steel bridges due to high labour cost Long term – low</td>
</tr>
<tr>
<td>Suspended</td>
<td>Up to 15m</td>
<td>Pedestrian, livestock</td>
<td>Cables and components may not be readily available</td>
<td>Experiences engineer and labour needed</td>
<td>Cables over 40 years; if timber deck used, 5 to 10 years. Regular maintenance of joints and deck</td>
<td>Initial – may be high for short lengths but unit cost will decrease with length Long term – medium</td>
</tr>
<tr>
<td>Suspension</td>
<td>Up to 150m</td>
<td>Pedestrian, bicycle, livestock</td>
<td>Cables and components may not be readily available</td>
<td>Experiences engineer and labour needed</td>
<td>Cables over 40 years; if timber deck used, 5 to 10 years. Regular maintenance of joints and deck</td>
<td>Initial – may be high for short lengths but unit cost will decrease with length Long term – medium</td>
</tr>
</tbody>
</table>

**Notes:**
1. Span Range is without piers. Span can be increased incrementally with addition of piers.
2. It is reported that some species of bamboo in Central and Southern America have a life up to 10 years.
3. SELECTING A FOOTBRIDGE DESIGN

### 3.7.3 Selection of Type of Footbridge

The factors considered in selecting footbridges for inclusion in the manual are summarised in Table 3.3 below.

<table>
<thead>
<tr>
<th>Type of Footbridge</th>
<th>Factors considered in selection</th>
<th>Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bamboo</td>
<td>Where bamboo is available these footbridges can be built by the community with no technical assistance and at little or no cost. They are suited to only light traffic and need to be rebuilt every 2 to 3 years.</td>
<td>Standard designs included in Section 4.2. of manual. For more developed designs see TRADA, Section 3.1.3.</td>
</tr>
<tr>
<td>Timber Log</td>
<td>These are an option if suitable logs are locally available. Reasonably straight and uniform logs are needed for a good bridge. Can be built by community with local technical assistance. Initial cost will be lowest for general traffic but life may be only 10 to 15 years.</td>
<td>Standard design included in Section 4.3. of manual.</td>
</tr>
<tr>
<td>Sawn Timber Beam</td>
<td>Beams may need to be obtained from larger timber suppliers. Good hardwood is needed for long life. Can be built by community with local technical assistance. Initial cost will be higher than for logs but life should be longer.</td>
<td>Standard design included in Section 4.4. of manual.</td>
</tr>
<tr>
<td>Sawn Timber Truss</td>
<td>Suited for spans of 10 to 25m where piers not possible but availability of the consistent shapes and sizes needed for construction may be a problem. Steel truss bridges are considered a better option for standard designs because of consistency of material.</td>
<td>Not included in manual. Possible option is the UNIDO bridge (Section 3.3.3) where local construction is established.</td>
</tr>
<tr>
<td>Steel Beam</td>
<td>Suitable beam sections probably not generally available.</td>
<td>Not included in manual. An alternative using a scrap truck chassis is described in Appendix C.</td>
</tr>
<tr>
<td>Steel Truss</td>
<td>Steel sections needed for truss bridge likely to be generally available. Size and shape reasonably consistent to allow construction of standard design in competent workshop.</td>
<td>Included in manual, Chapter 5, for spans of 10 to 20m.</td>
</tr>
<tr>
<td>Reinforced concrete</td>
<td>May have higher initial cost but likely to be most cost-effective in long term due to low maintenance and long life. Applications may be constrained by need to erect box-work for in-situ casting supported by piers. Labour with experience in RCC work needed.</td>
<td>Should be considered. Most Roads Departments at provincial level will have standard designs for RCC bridges that can be adapted by a qualified engineer. Designs for plain slab RCC footbridges for spans of 4 to 10m are included in Chapter 6.</td>
</tr>
<tr>
<td>Suspended and Suspension bridges</td>
<td>The ready availability of cables and components may depend on there being a national programme to introduce these bridges. Qualified engineer needed together with workers who have experience in cable installation.</td>
<td>Good manuals already available – see section 3.6.3. Therefore not included in manual.</td>
</tr>
</tbody>
</table>
3.7.4 Recommended Selection Options

1. **Spans up to 10 to 12m**
   - *Bamboo footbridge (Section 4.2)* that can be built by community for little or no cost for light traffic and where community is prepared to regularly replace the deteriorated bamboo
   - *Timber log footbridge (Section 4.3)* for general traffic where suitable logs are locally available
   - *Sawn-timber beam footbridge (Section 4.4)* where logs not available or better quality bridge wanted
   - *Reinforced concrete footbridge (Chapter 6)* where budget allows consideration of long-term cost and necessary technical assistance is available

2. **Spans 10 to 20 or 25m – No piers possible**
   - *Steel truss footbridge (Chapter 5)* constructed in competent workshop and transported to site

3. **Spans over 20 to 25m – No piers possible**
   - *Suspended or suspension bridge* where these are feasible

4. **Spans over 10m – Piers possible**
   - Consider all types to assess which is most feasible and cost-effective

A selection procedure is outlined in Table 3.4
### 3. SELECTING A FOOTBRIDGE DESIGN

#### Table 3.4: Procedure for Selection of Footbridge Type

<table>
<thead>
<tr>
<th>SELECTION CRITERION</th>
<th>BAMBOO</th>
<th>TIMBER LOG</th>
<th>SAWN TIMBER BEAMS</th>
<th>STEEL TRUSS</th>
<th>REINFORCED CONCRETE</th>
<th>CABLE SUSPENSION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. USERS</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Category 1: pedestrians, bicycles, livestock, donkeys, handcarts</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Category 2: Above + animal drawn carts and light motorised vehicles</td>
<td>✗</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✗</td>
</tr>
<tr>
<td>2. SPAN RANGE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.1 Piers NOT possible</td>
<td>4m max</td>
<td>10 to 12m</td>
<td>8 to 10m</td>
<td>25m</td>
<td>10 to 12m</td>
<td>50 to 150m</td>
</tr>
<tr>
<td>2.2 Piers possible, number needed</td>
<td>Piers at 3 to 4m</td>
<td>Piers at 10 to 12m</td>
<td>Piers at 8 to 10m</td>
<td>Piers at 20 to 25m</td>
<td>Piers at 10 to 12m</td>
<td>Piers not needed</td>
</tr>
<tr>
<td>3. MAIN MATERIALS NEEDED</td>
<td>Bamboo</td>
<td>Hardwood Logs</td>
<td>Hardwood Beams</td>
<td>Steel Angle</td>
<td>Cement; sand; Stone aggregate; Steel reinforcing bar up to 25mm</td>
<td>Steel cable; Cable attachments</td>
</tr>
<tr>
<td></td>
<td>100 to 150mm size</td>
<td>200mm for 5m span; 400mm for 12m span</td>
<td>150x75mm for 5m span; 300x150mm for 10m span</td>
<td>40x40x6mm; 50x50x6mm; 60x60x6mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Are these available?</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Mark ✔ or ✗</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. SKILLS AND INPUTS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.1 Community only</td>
<td>✔</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>4.2 Technical Supervision and Community</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>4.3 Outside inputs needed</td>
<td>Workshop</td>
<td>Experienced RCC workers</td>
<td>Technical and construction experience</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>5. TRANSFER OF MATERIALS TO SITE</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>5.1 Flat/undulating terrain</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
</tbody>
</table>
### 3. SELECTING A FOOTBRIDGE DESIGN

#### TYPE OF FOOTBRIDGE

<table>
<thead>
<tr>
<th>SELECTION CRITERION</th>
<th>BAMBOO</th>
<th>TIMBER LOG</th>
<th>SAWN TIMBER BEAMS</th>
<th>STEEL TRUSS</th>
<th>REINFORCED CONCRETE</th>
<th>CABLE SUSPENSION</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.2 Hilly paths/tracks</td>
<td>✔️</td>
<td>✗</td>
<td>Difficult</td>
<td>Individual parts</td>
<td>✔️</td>
<td>✔️</td>
</tr>
</tbody>
</table>

#### SUMMARY OF OPTIONS POSSIBLE FROM ABOVE

<table>
<thead>
<tr>
<th>MARK ✔️ OR ✗</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.2 Hilly paths/tracks</td>
</tr>
</tbody>
</table>

#### COMPARISON OF OPTIONS – the more stars the better

<table>
<thead>
<tr>
<th>Feature</th>
<th>Bamboo</th>
<th>Timber Log</th>
<th>Sawn Timber Beams</th>
<th>Steel Truss</th>
<th>Reinforced Concrete</th>
<th>Cable Suspension</th>
</tr>
</thead>
<tbody>
<tr>
<td>7. Ease of Installation</td>
<td>****</td>
<td>**</td>
<td>*****</td>
<td>****</td>
<td>**</td>
<td>*</td>
</tr>
<tr>
<td>8. Maintenance Needed</td>
<td>*</td>
<td>**</td>
<td>**</td>
<td>***</td>
<td>*****</td>
<td>***</td>
</tr>
<tr>
<td>9. Life</td>
<td>*</td>
<td>**</td>
<td>**</td>
<td>***</td>
<td>*****</td>
<td>***</td>
</tr>
<tr>
<td>10. Initial Cost</td>
<td>*****</td>
<td>****</td>
<td>***</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>11. Long-Term Total Life Cost</td>
<td>****</td>
<td>***</td>
<td>**</td>
<td>***</td>
<td>*****</td>
<td>***</td>
</tr>
</tbody>
</table>

### PROCEDURE:

- Steps 1 to 5 identify the options that are possible. Summarise these in Step 6.
- Steps 7 to 11 compare the features of the possible options.
- Choose the **possible** option with the best combination of features, particular **Life** and **Total Life** cost, that fits in with the community or district resources.
4 DESIGN OF TIMBER FOOTBRIDGES

4.1 INTRODUCTION

This Chapter presents details of three types of timber footbridges that are selected in Section 3.7.4 as being appropriate for local construction and installation. These are:

1. **Bamboo footbridges** – these can be constructed by communities in areas where suitable size bamboo is readily available at little or no cost. Details of construction are described in Section 4.2.

2. **Timber log footbridges** – these are appropriate where suitable logs are readily available from local forests. Logs need to be reasonably straight and uniform to construct a good quality bridge. They have a higher load capacity than bamboo footbridges and are likely to have the lowest initial cost after bamboo. However, life may only be 10 to 15 years, possibly only about half of that of sawn timber footbridges. Details are presented in Section 4.3.

3. **Sawn-timber beam footbridges** – these may be selected when suitable timber logs are not available or when funds available allow the construction of a higher quality, longer life footbridge. Details are presented in Section 4.4.

The other type of timber bridge considered in Section 3.7 is a timber-truss bridge. These are suitable for longer spans than the above beam (stringer) footbridges but it is considered that the quality of timber sections readily available at local level might not be good enough for construction of truss type footbridges. It is considered that steel is a better option for truss type footbridges because of the greater uniformity of section, ready availability in many areas and simpler construction of joints. The design of a steel truss bridge is presented in Chapter 5.
4.2 BAMBOO FOOTBRIDGES

4.2.1 General Design Notes

Bamboo grows locally in many rural areas, particularly in Asia. It can also be readily cultivated. It is a hollow circular log with a hard, shiny outer skin. Diaphragms, closed sections, occur at regular nodes along the length of the log. Logs used in construction should be cut just outside a node to reduce the risk of the log splitting.

Bamboo is very susceptible to attack by moisture and insects such as termites. It therefore has a short life, possibly 2 to 3 years in reasonably dry conditions and only 1 to 2 years under water or in moist soil. It is difficult to treat with preservatives because of the hard skin. A number of traditional and chemical treatments are available (see Jules J.A. Jansen, 1988) but the only one that seems appropriate for situations covered by this manual is to submerge the logs for 2 to 3 months immediately after cutting and then allow them to dry away from sunlight. This is said to reduce the risk of attack by insects. However, it is not recorded what increase in life can be obtained.

Where bamboo is available it is likely that there will be good local knowledge on its use and this should be used in selecting, cutting and treating bamboo logs for footbridges.

The strength of bamboo depends on its density which can vary from about 550kg/m$^3$ for dry bamboo up to about 800kg/m$^3$ for green bamboo. Dry bamboo has a higher strength per unit weight than green bamboo.

Bamboo bridges comprise longitudinal beams, stringers, supported on cross-beams. Quite large size beams are needed to support the loads of bridge users and because bamboo logs reduce in size along their length the maximum unsupported span that is possible is quite short.

The maximum unsupported span for bamboo footbridges is about 4m. For longer spans pier supports will be needed under the deck or support from a structure above the bridge if piers are not possible. Examples of each of these types are given in this section of the manual.

Table 4.1 shows allowable loads for single bamboo stringers for a span of 4m. Allowable loads for other spans can be found from proportion. For example, loads for a 3m span can be 4/3 x those in the table.

<table>
<thead>
<tr>
<th>Outside Diameter of Stringer mm (1)</th>
<th>80</th>
<th>80</th>
<th>100</th>
<th>100</th>
<th>120</th>
<th>120</th>
<th>140</th>
<th>140</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall thickness mm</td>
<td>6</td>
<td>8</td>
<td>8</td>
<td>10</td>
<td>8</td>
<td>10</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>Allowable central concentrated load kg</td>
<td>29</td>
<td>36</td>
<td>59</td>
<td>70</td>
<td>89</td>
<td>105</td>
<td>149</td>
<td>171</td>
</tr>
<tr>
<td>Allowable distributed load kg/m</td>
<td>14</td>
<td>18</td>
<td>30</td>
<td>35</td>
<td>44</td>
<td>53</td>
<td>74</td>
<td>75</td>
</tr>
</tbody>
</table>

Note: (1) This is the diameter at the centre of the span, approximately the average along the length of the stringer.
An average diameter of 100mm gives an allowable point load of 59kg and using 8 stringers across a 1m width, a distributed loading of 30x8 =240kg/m². This may be just about adequate for situations in which bamboo footbridges are used if there is good transfer of load between stringers. However, it is advisable to reduce the span for this average size of stringer to 3m.

Recommendations for the design of bamboo bridges are given in Table 4.2.

### Table 4.2: Design of Bamboo Footbridges

<table>
<thead>
<tr>
<th>Width of Footbridge</th>
<th>Type of users</th>
<th>Average Diameter of Stringers (mm)</th>
<th>Maximum Span between Supports</th>
<th>Number of Stringers per m width</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2 to 1.4m</td>
<td>Pedestrians; bicycles; goats; sheep; small carts</td>
<td>100 (1)</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>120</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>2.1m</td>
<td>Above plus other livestock, donkeys and ADVs</td>
<td>120</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>140</td>
<td>4</td>
<td>6</td>
</tr>
</tbody>
</table>

**Notes:**

1. This is the diameter mid-way between the supports
2. Cross-members should be used at mid-span to distribute the loading across the footbridge between the stringers. Since bamboo is flexible these should be quite effective.

### 4.2.2 Basic Construction of Bamboo Footbridge

Figure 4.1 shows the basic construction of a bamboo footbridge. The footbridge is intended for use by pedestrians and cyclists. The main construction features are further illustrated by the photographs in Figure 4.2 and outlined below.

**Stringers** – 9 stringers of 120 to 150mm diameter are used for a 1.2 to 1.3 m wide deck. They are supported at intervals of 4m by piers.

**Abutments** - the ends of the stringers rest on 2 lengths of bamboo held in position by bamboo stakes along their length and at their ends. To increase their life the abutment logs should rest on a bed of stones. To hold the footbridge in position the stringers should be bound to the stakes.

**Piers** – each comprises 2 props of 120 to 150mm bamboo supporting a cross-beam of 80 to 100mm bamboo. Slots are cut in the tops of the props just above nodes, the cross-beam fitted in and bound to the props. In the example shown in the figures, the props are fixed by wedging them with rocks contained in baskets made with bamboo strips. They are not sunk into the ground. This method is satisfactory when the height of the deck above the river-bed is relatively small, say up to 2m, but for greater heights the props need to be cross-braced as shown in Figure 4.3. Larger baskets should also be used or props sunk into the ground.
4. DESIGN OF TIMBER FOOTBRIDGES

Details of joint of longitudinal stringers. The small end of one length fits inside the large end of the previous length. Joints must be well supported by the cross-member.

Bamboo strip deck
See Figure 4.2

Spacer strips every 1 or 2m bind deck to stringers

Cross-members distribute load between stringers

About 4m spacing

Longitudinal stringers, 120 to 150mm diameter

Abutments - 2 bamboo poles 100 to 150mm in size, held in position by bamboo stakes hammered into ground

Cut slot in top of prop for cross-beam

Prop for cross-beam

Cross-beams, 80 to 100mm diameter

0.75m

0.9 to 1m

1.2 to 1.3m

0.75m

1 to 1.2m

1.2 to 1.4m

1 to 1.2m

Props are tightly wedged in bamboo baskets by rocks 80 to 250mm in size

Figure 4.1: Design of a Simple Bamboo Footbridge
The bamboo stringers are supported at about 4m intervals by piers comprising 2 vertical props held in position in bamboo baskets by rocks 80 to 250mm in size.

Details of the support of the longitudinal stringers by the props and cross-beam. The stringers are bound to the cross-beam with strong vines from the forest. Note also the cross-members (top of photograph) that help to distribute the load across the width.

Details of the deck formed from woven bamboo strips. The arrows indicate spacer strips located at 1 or 2m intervals to clamp the deck to the stringers. The spacer strips are bound to the longitudinals with vines.

Figure 4.2: Details of a Simple Bamboo Footbridge from Laos
Deck – this is made of weaved strips of bamboo. It is held in position by spacer strips that have slots cut to locate longitudinal strips of the matting. Stronger matting is needed for the 2.1m wide bridge to accommodate the heavier users.

Binding – traditionally, strong natural vines are used. Galvanised wire gives a stronger, longer life option with lower maintenance but introduces costs to the construction. Synthetic fibre rope is often locally available and may also be used.

4.2.3 Improved Bamboo Footbridge

The footbridge type shown in Figures 4.1 and 4.2 is a basic but effective design. With regular replacement of bamboo members it has been in place for 30 years even though, because the deck is too low, it is regularly submerged during the monsoon season.

There will be many cases in which the deck has to be at a higher level above the river-bed than that shown in Figure 4.2. This will require improved design of the piers and also a safety rail for footbridges over about 3m span.

Figure 4.3 shows improved designs for 1.4m and 2.1m wide footbridges. The main features are:

- The pier props (posts) are sunk into the river bed to increase stability. A depth of 0.5m may be adequate if rock supports are also used and 1.2 to 1.5m without the rocks. Posts can be hammered into the ground with a sledgehammer or long-handled mallet or using a dropping weight as described in Chapter 7. A piece of hardwood should be held over the top end of the post to distribute the impact blows and limit damage to the bamboo

  \[\text{Note}\] – if the river-bed does not allow sinking of posts then increased support with rocks can be used with baskets wider and deeper than those shown in Figure 4.1

- The pier posts are cross-braced to increase stability

- The maximum height of piers is about 3m. For piers over about 2m tall, stability in the axial direction (along the bridge) may be increased by adding props each side of the pier.

- The footbridge is fitted with a safety rail for pedestrians and the 2.1m wide bridge with a kerb for wheeled vehicles.

Other basic features of the design are the same as in Figure 4.1. The Details of spans and numbers and sizes of longitudinal stringers are obtained from Table 4.2.

The design in Figure 4.3 relies quite heavily on joints bound with vines, rope or wire. The following methods may be used to increase the rigidity of bound joints:

- Tighten the binding as much as possible. Tying a short stick of bamboo in the binding at the joint and twisting to tighten the binding is effective. The stick can be forced under the loops of binding to prevent the joint untwisting

- Anchoring the binding around the nodes of the bamboo to prevent it slipping

- Cutting a hole through the bamboo member at the joint, preferably at a node, and hammering in a bamboo peg to be used as an anchor for the binding.
4. DESIGN OF TIMBER FOOTBRIDGES

Safety Rail and Support Posts
60 to 80mm diameter

Deck, stringers (see Table 4.2), cross-beams and pier posts same as in Figure 4.1

Kerb, 80 to 100mm diameter

Cut slots in top of pier posts to support cross-beam

Cut slot in end of brace to fit over rail post

Braces 80 to 100mm diameter

1.4m Wide Footbridge

2.1m Wide Footbridge

Figure 4.3: Improved Design of Bamboo Footbridge
4. DESIGN OF TIMBER FOOTBRIDGES

**Abutments:**

For the 1.4m wide footbridge the abutment can be the same as that shown in Figure 4.1. For a 2.1m wide footbridge 2 pairs of bearing poles should be used as shown in Figure 4.3.

4.2.4 Longer Span Bamboo Footbridge

If it is not practical to use pier supports, the span of bamboo footbridges can be increased by using support from a structure constructed above the bridge. A fairly crude example of this is shown in Figure 3.1 (Chapter 3) where the deck of the bridge is supported by bamboo poles attached to branches of trees growing on the banks of the river.

Figure 4.4 shows a neater construction based on a design from Indonesia. This is suitable for spans up to about 12m but should only be used for widths of 1.2 to 1.3m because of the lack of central support for the cross-beams that support the stringers. In this case the deck is supported from an ‘A’ frame, the bottom ends of which rest on the banks of the stream/river.

It is important that the feet of the ‘A’ frame do not sink into the bank as this will upset the seating of the stringers and deck. The feet should be seated on flat rocks set in holes about 0.5m deep in the bank.

The design uses the method of cutting holes through bamboo members and inserting pegs to provide positive support for cross-beams instead of relying only on joints bound with vines or wire. The joints should still be securely bound.

4.2.5 Maintenance of Bamboo Footbridges

The main maintenance requirements are:

1. To check joints about every 6 months and retighten or replace any that are not secure

2. To regularly check and replace any deck matting and bamboo members that have deteriorated. It is particularly important to carry out a thorough inspection after the rainy season.
Note:
3 sets of cross-beams support 4 sections of stringers of 2.5 to 3m length, giving span of up to 12m

Figure 4.4: Design of Bamboo Footbridge for Spans up to 12m
4.3 TIMBER LOG FOOTBRIDGES

4.3.1 General Design Notes

If suitable logs are locally available this type of footbridge will probably have the least *initial* cost after bamboo bridges. The main cost will be from sawn timber planks for the deck. However, due to difficulties of treating the logs with preservatives the life may be only 10 to 15 years depending on the quality of the timber used. The *total life cost* will therefore be medium to high.

These footbridges can readily be constructed by communities with some technical assistance in choosing logs and attaching decking and handrails. Spans are usually 8 to 10m but can be up to 12m if suitable logs are available. Longer spans are possible where intermediate piers can be constructed.

*Selection of logs*: hardwood logs are preferred. Desirable properties are – durable, resilient (resistant to shock loading) and resistant to splitting. Figure 4.5 shows factors to be taken into account in selection in regard to size and shape.

Logs should be as straight as possible and have a low number of branches. Running a string from one end to the other, the maximum deviation from straightness should not be greater than about 100mm.

The 2 or 3 logs used for a footbridge should be matched in size as closely as possible, say within about 15% between the smallest and largest logs.

*Log sizes*: the log sizes needed for 1.4m and 2.1m wide bridges of various spans are listed in Table 4.3.

**Table 4.3: Timber Log Sizes for Footbridges**

<table>
<thead>
<tr>
<th>Span (m)</th>
<th>1.0m Wide</th>
<th>1.4m Wide</th>
<th>2.1m Wide</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Up to 1.0m Wide</td>
<td>Up to 1.4m Wide</td>
<td>2.1m Wide</td>
</tr>
<tr>
<td>2 Logs at 600mm</td>
<td>3 Logs at 600mm</td>
<td>3 Logs at 800mm</td>
<td>4 logs at 600mm</td>
</tr>
<tr>
<td>Size (mm)</td>
<td>Size (mm)</td>
<td>Size (mm)</td>
<td>Size (mm)</td>
</tr>
<tr>
<td>4</td>
<td>225</td>
<td>200</td>
<td>250</td>
</tr>
<tr>
<td>6</td>
<td>275</td>
<td>250</td>
<td>300</td>
</tr>
<tr>
<td>8</td>
<td>325</td>
<td>300</td>
<td>350</td>
</tr>
<tr>
<td>10</td>
<td>375</td>
<td>350</td>
<td>400</td>
</tr>
<tr>
<td>12</td>
<td>425</td>
<td>400</td>
<td>450</td>
</tr>
</tbody>
</table>

**Notes:**

1. The size is the diameter of the heartwood after the bark is removed and not including the sapwood.
2. The size should be the minimum diameter over at least the middle 33% (one third) of the log stringer.
3. Based on live load of 400kg/m² + dead load and maximum fibre stress in bending of 10MPa.
4. DESIGN OF TIMBER FOOTBRIDGES

String

Maximum deviation from straight should be about 100mm

Remove all bark

Layer of sapwood
Unless treated, the sapwood will quickly decay. Therefore, it should be trimmed off on all bearing surfaces at supports and where deck planks are seated.

The effective diameter is that of the heartwood i.e. not including the sapwood

The straightest face should be at the top where the deck is sealed

Large end diameter

The log diameter is the minimum diameter over this length

Small end diameter

If 'flare-out' is too large it should be removed

Note:
1. Total length of log, \( L = \text{span} + \text{bearing lengths} \)
2. Difference between large end and small end diameters should not exceed about 100mm

Figure 4.5: Selection of Timber Logs
**Preparation of logs:** all branches should be cut off just above the joint to the trunk. The bark should be completely stripped from the log.

**Treatment of logs:** to extend the life of the logs the procedures outlined in Section 4.3.4 should be followed as far as is possible.

**Decking:** a very crude deck can be constructed by nailing smaller logs, at least 75mm in size, across the log stringers. This is only suitable for low levels of pedestrian traffic. For more general traffic a deck of sawn timber planks will be needed. The minimum sizes of plank needed are:

- **Up to 1.4m wide deck** – 175 wide x 50mm thick
- **2.1m wide deck** – for 3 logs, 150 x 75mm *; for 4 logs, 150 x 50mm

(* An alternative is to use 150 x 75mm cross-members at 500mm spacing supporting longitudinal runners of minimum size 150 x 50mm. This will probably reduce cost.)

Deck planks should be nailed to the log stringers with 125 or 150mm long galvanised nails through pre-drilled holes if this is possible. Since nails tend to work loose, those with ribs to counter this should be used if available. Nails may be dipped in sump oil before inserting them to limit the effects of moisture penetration along the nails.

Soaking the deck planks in sump oil or brushing it on may help to preserve their life. Surfaces should be recoated at regular intervals.

### 4.3.2 Basic Design of Timber Log Footbridge

**Figure 4.6** shows the design and construction of a basic timber log footbridge. The steps in construction are outlined below:

1. Locate the positions of abutments and, if the span is greater than 8 to 10m, piers, as outlined in Appendix A.

2. Construct the abutments and piers as described in Chapter 7. These may be existing rocks, or constructed from timber poles or masonry depending on the local situation and materials available. Guidelines on the choice are discussed in Chapter 7.

3. Logs should be prepared and cut to length before being transported to site. A 400mm diameter log 10m long may weigh up to about 1.2 tonne so handling and moving the logs will be difficult. They will probably have to be dragged into position on rollers. A tractor or team of oxen would be helpful.

4. **Bearing seats:** depending on the choice of abutments and piers the log stringers may be seated on timber, concrete or masonry sills. The seats need to be constructed so that the tops of the logs are as near level as possible

   - For timber log sills, grooves are cut to seat the stringer, the depth of groove being used to level the tops of the stringers. The maximum depth of groove should not exceed a quarter of the diameter of the sill. A layer of bitumen should be put in the groove to prevent trapping of moisture on the seat of the stringer.
Use level to check the top surfaces of the log stringers but also check along the stringers to balance the differences in height to minimise work in leveling the deck planks.

Cut grooves in sill so that tops of stringers are fairly flat. Seal seat with bitumen.

Secure stringers to sill with galvanised wire bound to 10mm anchor pins hammered into sides of sill.

Cut flats up to about 80mm wide on smaller logs and 160mm on larger logs for bearing seats and to level tops of logs.

For small logs packing pieces may be needed.

Seat logs on 10mm rubber pads 5mm smaller all round than bearing seat of log.

Figure 4.6: Bearing Supports for Log Stringers
- For concrete and masonry sills a flat at least 40mm wide should be cut on the log stringer to seat it on the sill surface. The width of flat can be adjusted to level the tops of the stringers but should not exceed about 80mm for a 200mm log and 160mm for a 400mm log. If the end of a log is particularly small a packing piece can be inserted to level up the top of the log. If available, a hard rubber pad should be inserted on the seat of the stringer. This should be about 5mm smaller all round than the flat cut on the stringer log to avoid trapping water.

**Note:** In both cases it is important to remove any sapwood from the bearing surface.

5. Prepare the ends of the log stringers before installation, making sure that the straightest surface of the log will be on top. Also if log sills are to be used, prepare these before installation using the end measurements of the logs to size the grooves needed.

6. Use one of the methods shown in 7.4.1 or other means to install the stringer logs in position on the support sills.

7. Adjust the bearing supports by trimming and packing to achieve the best balance in differences in height of the top surfaces of the stringers over their length i.e. to minimise the trimming and packing needed to bed the decking planks.

8. The stringer logs need to be securely fixed on the sills of both abutments and piers. There are various options for this. The methods shown avoid drilling of the timber.

9. **Seating of deck planks** – it is important that the deck planks are level and rest as evenly as possible on the stringers. Preparation of the stringers and fixing of the decking is shown in Figure 4.7. The top surfaces should be trimmed to produce flats for the deck planks to sit on. It is important to remove any sapwood from the logs where the deck planks are seated.

**Typical examples:** Figure 4.8 shows examples of basic log bridges in Malawi, one with timber sills and the other with masonry sills. These are both bridges for low-traffic rural roads and therefore have larger and more log stringers to support vehicle loads. Figure 4.9 shows a well-constructed timber log footbridge in Nepal. In this example the abutments are constructed from rocks that are obviously readily available in the environment shown.
**Limits for trimming:**

Maximum width of flat on heartwood over central 1/3 of span:
80mm on 250mm log
140mm on 400mm log
Can be greater towards the ends

Use levels to check the flatness of the deck along and across the footbridge.

If gap is too large, fit spacers. These should be at least 300mm long and securely nailed to the stringer.

Trim the tops along the lengths of the stringers so that the deck planks are flat and evenly supported. Remember that reducing the diameter by 5% reduces the strength by about 15%. Therefore trim off sapwood but limit trimming of heartwood as indicated above.

Nails 125 to 150mm long. Angle them slightly to the centre so that they are less likely to work loose.

Stagger nails about 15mm each side of centre of contact area to avoid splitting of logs.

*Figure 4.7: Fitting the Decking on the Log Stringers*
4. DESIGN OF TIMBER FOOTBRIDGES

Timber log bridge supported on timber crib abutments and with timber log wing walls

Figure 4.8: Timber Log Bridges in Malawi
(Note that these are both bridges for low-volume rural roads and therefore are wider with more stringer logs than footbridges)
Figure 4.9: Basic Timber Log Footbridge in Nepal

Note the use of readily available rocks for construction of the abutments
(Photo supplied by Bridges to Prosperity)
4.3.3 More Developed Timber Log Footbridge

For spans over about 3m footbridges should be fitted with safety rails, especially if mixed traffic will use the bridge. If wheeled vehicles will use the bridge (other than bicycles) then kerbs should also be fitted.

A low cost safety rail can be made from smaller logs, about 100mm diameter, if good straight logs are available. The logs should be stripped of bark and painted with creosote or other preservative, especially where the logs are cut to make joints. A neater construction of handrail can be obtained with sawn timber but this will increase cost.

Figure 4.10 shows suggestions for construction of both types of handrails.

4.3.4 Treatment of Timber

Timber is susceptible to decay by rotting from contact with moisture and attack by insects. Some hardwoods are very resistant to this but in general the life of timber can be significantly extended by effective treatment with preservatives. Unfortunately these treatments are unlikely to be available for the footbridges covered in this manual and hand treatments are not very effective because of lack of penetration of preservatives. It is therefore recommended that the following procedures are adopted. These are applicable to both timber logs and sawn timber.

- Choose timbers that are resistant to rotting and insect attack
- Avoid direct contact between the timber and soil, particularly the ends of the timber
- Provide barriers to access of insects to the timber
- Avoid details that could trap moisture – make sure surfaces are well drained and ventilated
- Protect the sawn ends of timber and contacting surfaces where moisture could be trapped – bearing surfaces for beams and decking – with bitumen/tar
- The best alternative to pressure treatment is to soak the timber in a preservative. For example, timber poles to be sunk into the ground can be treated by soaking in a 50/50 mixture of diesel and creosote for 2 weeks.
- If hand brushing is the only option, this should be repeated regularly as soon as there are signs that the surface treatment is weathering. All surfaces that are cut, trimmed or drilled should in particular be treated in this way. Creosote, a tar derivative, may be used, or a low-cost alternative is sump oil.
4. DESIGN OF TIMBER FOOTBRIDGES

For details of abutments see Section 7.2

Timber Log Handrail and Kerb

Protection: Stringers - coat cut surfaces (flats) with 2/3 coats of creosote. Protect ends with bitumen
Handrails and Kerb - 2/3 coats of creosote
Deck Planks - soak in or brush with engine sump oil
Nails: use galvanised nails and dip in sump oil to protect holes against moisture

Sawn Timber Handrail and Kerb

Figure 4.10: Construction of Timber Log Footbridge
4.4 SAWN TIMBER BEAM FOOTBRIDGE

4.4.1 General Design Notes

If timber logs are not available the next choice for a simple-to-construct footbridge would be sawn timber beams or stringers, although the cost will be significantly higher than for logs. Prices reported for hardwood beams in the case-studies ranged from USD250 to 650/m³. Therefore a typical size of 150 x 250mm would cost from USD9.50 to 24.40/m length.

Sawn timber beams have advantages over logs – lighter and easier to handle; little preparation is needed; they are more regular in shape and therefore produce neater designs; and they can be more effectively treated with preservatives.

However, their strength is more affected by defects such as splits and knots. Beams should be carefully inspected and those with excessive defects that could cause local weaknesses, especially near the top and bottom surfaces and over the middle 50% of the length of the beam, should not be used.

Sizes and Number of Beams (Stringers) Needed

The stringers carry the footbridge loading in bending. For cost-effective use of the timber the depth of the stringer should be at least 2 x its width. However, the depth should not be more than 3 x width to avoid the risk of the stringer twisting under load.

Table 4.4 shows recommended stringer sizes and number needed for spans up to 10m. These are based on standard sawn timber sizes with depth/width ratios of about 2 to 2.5.

Table 4.4: Sizes and Numbers of Stringers Needed for Various Footbridge Spans

<table>
<thead>
<tr>
<th>Footbridge Span</th>
<th>1.4m Wide Footbridge</th>
<th>2.1m Wide Footbridge</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Beam Size (mm)</td>
<td>Number needed</td>
</tr>
<tr>
<td>4m</td>
<td>75 x 150</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>75 x 200</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>100 x 200</td>
<td>4</td>
</tr>
<tr>
<td>6m</td>
<td>100 x 200</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>100 x 250</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>150 x 250</td>
<td>4</td>
</tr>
<tr>
<td>8m</td>
<td>100 x 250</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>150 x 300</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>150 x 350</td>
<td>4</td>
</tr>
<tr>
<td>10m</td>
<td>150 x 300</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>150 x 350</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>150 x 400</td>
<td>4</td>
</tr>
</tbody>
</table>

Note: (1) In order to adequately support deck planks, the minimum number of stringers are – 4 for 1.4m wide footbridge: 6 for 2.1m wide footbridge
(2) The Total Area of cross-section gives a comparison of the costs of the options
(3) Based on live loading of 400kg/m² + dead load and maximum fibre stress in bending of 8MPa.
4.4.2 Design and Construction of a Sawn Timber Beam Footbridge

The steps involved in the construction and installation of sawn-timber bridges are basically the same as for timber log bridges (see 4.3.2).

Abutments and piers are most likely to be constructed from sawn timber or masonry. Masonry is preferred since it gives a long life with low maintenance and provides better protection for the sawn timber stringers.

For the same span the weight of sawn-timber stringers will be considerably less than for log stringers so movement and installation of the stringers will not be as difficult. The weight of a 150 x 300mm section stringer of 10m length will be about 350 to 400kg. They may be installed using similar methods to those used for logs.

Figure 4.11 shows construction details for a sawn timber beam footbridge with timber abutments and Figure 4.12 shows construction details with masonry abutments. The details of the construction of the footbridge itself are the same in both cases. The main features are outlined below.

**Stringers:** Recommended sizes and numbers are listed in Table 4.4. Stringers should be protected with 2 or 3 coats of a preservative such as creosote. Engine sump oil may be used if preservatives are not available. The ends of stringers should be coated with bitumen. The top surfaces where the deck planks are attached should also be sealed with bitumen or tar.

**Decking:** provided that at least 4 stringers are used for the 1.4m wide footbridge and 6 for the 2.1m bridge the minimum plank size needed for the deck is 150 x 50mm.

The planks are nailed to the stringers with 100 to 125mm long galvanised nails. Nails with ribs to prevent them working loose should be used if available, and should be dipped in sump oil before being inserted. Pre-drilled holes should be used if possible. Nails should be staggered to avoid splitting the wood and inserted at an angle to reduce the risk of them working loose.

Deck planks should be soaked in or brushed with engine sump oil.

**Abutments:** If timber abutments are used a bearing seat length of at least 150mm is required and the seat should be sealed with a layer of bitumen. On masonry and concrete a hard rubber pad at least 10mm thick should be used on the bearing seat if possible. This should be about 5mm smaller all-round than the seat to avoid trapping of water on the seat.

It is important to prevent contact of the ends of the stringers with the surrounding soil as the risk of rotting of the timber is greatest at the ends. On masonry abutments this is easily achieved by a raised lip or step around the sill. On timber abutments a barrier is needed. This may be formed from timber boards, steel sheet (for example, flattened oil drums) or a masonry wall.

Stringers should be firmly fixed on the abutment.

**Piers:** Similar arrangements should be used for supporting the stringers as for the abutments. Joints between stringers should be centrally located on the pier with each stringer having a bearing length of at least 150mm. This means that for butt joints (end to end) the pier will need to be at least 300mm wide OR joints will need to be overlapped. If butt joints are used, the joints should be covered by deck planks and sealed with bitumen.
4. DESIGN OF TIMBER FOOTBRIDGES

Cross members 100 x 50mm

Stringers - for size and number see Table 4.4

Gaps between deck planks 12 to 15mm

Rail 100 x 50

Posts 100 x 75

Brace 100 x 50

Nail on piece of deck plank to support brace

Extend deck plank by 600mm each side to brace posts

Hammer in 10mm spikes and tie stringers to timber sill with 3mm galvanised wire

Seal bearing seats and end faces of stringers with bitumen

Figure 4.11: Construction of Sawn Timber Footbridge with Timber Abutments
1.5m

1 to 1.2m

1.5m

1 to 1.2m

10mm thick rubber pads 5mm smaller than bearing area to avoid trapping water

Embed plastic pipe
To drain seat

Shape of bearing seat

Raised lips or steps to protect ends of stringers

Figure 4.12: Construction of Sawn Timber Footbridge with Masonry Sills
**Handrails**: Sturdy handrails are needed that will safely support users leaning on them. They should be painted with creosote and joints should be sealed with bitumen.

Figure 4.13 shows details of typical examples of abutments, pier supports and attachment of handrails.

### 4.4.3 Increasing the Span of Timber Stringer Footbridges

Where intermediate piers cannot be used the span of timber stringer footbridges can be increased by using cable supports as in Figure 3.13 or using cantilever abutment supports as shown in Figure 4.14. In the cantilever arrangement there needs to be enough area of logs/beams buried within the abutment together with enough weight of rocks and fill covering it to balance the cantilever load from the footbridge deck. It is reported that spans up to 20m are possible.
Detail of sawn timber abutment with sill supported by 3 posts. Note the timber behind the abutment and the wing wall to protect against erosion of the bank.

Detail of pier support of timber stringers. Note the butt joint of stringers with 2 cross-beams supporting the ends of the stringers.

Figure 4.13: Examples of Details of Sawn Timber Bridges

(Photographs from Laos Case Study)
Details of cantilever support. The moment from the weight of the rocks acting on the cantilever beams must balance that from the cantilever load at the support of the footbridge.

**Figure 4.14: Use of Cantilever Supports to Increase the Span of a Sawn Timber Footbridge**

(Photographs supplied by Bridges to Prosperity)
4.5 MAINTENANCE OF TIMBER FOOTBRIDGES

The main causes of deterioration of timber structure are attack by insects and rotting due to contact with moisture. The first should be overcome by use of local knowledge in choosing hardwoods that are resistant to attack by insects.

Attention to detail in the design and construction of the footbridge can do much to increase resistance against rotting and prolong the life of the bridge. Some of the main factors are:

- Avoid construction features, especially at joints, that could trap water. Grooves and holes can be used to drain away water and good ventilation can reduce surface moisture. Where water might run into joints a sealant such as bitumen can be used in the joint. Engine sump oil can be used to provide some protection against moisture on nails and in pre-drilled holes.

- Avoid direct contact with soil. For example in the designs shown above a barrier of timber, steel sheet or masonry is recommended at the ends of the stringers to prevent contact with the soil. Where timber posts are sunk into the ground their life may be increased by soaking them in a 50/50 mixture of creosote and diesel fuel or in engine sump oil for about 2 weeks.

- Protect the vulnerable ends of timber beams, particularly of stringers, with a sealant such as bitumen.

To be effective, hand application of preservatives such as creosote needs to be carried out regularly over a period of at least one to two years. This is unlikely to be practical on footbridges, especially for the stringers. Therefore, if timber bridges are being widely used in a district or region it may be a good idea to keep a store of prepared and treated timber components, so that those used in a particular application have been treated over a sufficiently long period to develop reasonable protection.

Regular inspection and maintenance of footbridges can also extend their life. Factors to look for in particular are:

- Areas of timber where there is excessive deterioration, try to identify and rectify the causes. For example dirt and debris that could trap moisture should be cleaned out.

- Deck planks where defects or worn areas are trapping water should be turned over or replaced.

- Nails that have worked loose should be hammered in. If they are badly corroded replace them.

- Inspect regularly for any signs of insect attack, for instance termites. Since termites have to gain access to the timber structure via the abutments or piers, it is good practice to place metal caps on the top of timber abutments or piers to clearly show if termites are crossing the metal cap to reach the timber stringers and deck.

- Timber that has rotted, especially any that could cause a safety hazard, should be replaced as soon as possible.

Periodic maintenance to be carried out every 1 or 2 years should include the re-treatment of surfaces that were originally treated with preservatives.