7. Materials

Introduction

This chapter aims to provide sufficient information to enable road designers and builders

- to identify potentially suitable materials
- to know what materials' properties will be required for various uses
- to know how testing for these properties can simply be conducted
- to know something about the range of uses appropriate for each material

The chapter will also discuss potential causes of deterioration and damage and how these might be avoided by good design.

A particular aim of this chapter is to enable road builders to make more extensive use of local materials and existing craft skills in the construction of road structures. These are particularly suitable for use by small local enterprises and community implementation. Where manufactured materials such as steel and cement are used, initial costs tend to be high; special training in the correct procedures for construction are required. This guideline focuses particularly on materials such as brick, stone masonry and timber, which have until now been comparatively neglected both in guidelines for road construction and in the training of the designers and builders of roads. These materials usually allow lower cost durable solutions to structure requirements by making better use of locally available materials, skills and labour resources.

The guideline is not intended to be used either as a Standard, prescribing minimum requirements and specific procedures for particular situations, or as a Specification, prescribing the requirements for a particular piece of work. Both of these types of document have to be produced locally. But reference will be made, in discussing the particular materials, to examples of standards and other more detailed sources of information which have been consulted in the preparation of this guideline, and which may be helpful in producing local Standards and Specifications.

The remainder of this chapter on materials is organised into four sections:

- Stone masonry
- Brick and block masonry
- Timber and organic materials
- Concrete and reinforced concrete

It is recommended that consideration be given to all locally available construction materials. For all materials meeting the specification requirements a costing of the various options and consideration of training, maintenance and other factors will enable a rational decision to be made regarding the final choice of materials. National standards, which have often been 'imported' from developed country conditions or are aimed at structures on main roads, often ignore the possibility of using some of the materials covered by this guideline. This may deny the benefits of lower costs, use of local resources, labour, skills and enterprises, and reduce the likelihood of maintenance being carried out in a timely manner.

Stone and stone masonry

The density and durability of natural stone make it an ideal material for road structures, where it is available. Fortunately, in hilly territory where road-building entails frequent retaining walls and river crossings, stone of building quality can often be found relatively close by, or may even be generated in forming the roadway. Even in lowland terrain, “field” stone of suitable quality may often be found. And because of the inherent durability of most types of stone, relatively simple field tests are appropriate to assess its suitability for building, and it may be excavated, prepared and incorporated in the works using hand tools and manual methods, or by mechanised means.

For these reasons, where good quality stone is available, it should be the first choice for retaining walls, piers and wingwalls for river crossings, the formation of masonry culverts, and for low-level drifts. Stone can also be used for masonry arches and other simple bridges.

Stone sources and extraction

The well-known classification of types of stone by their geological origin is valuable, because each class has recognisable characteristics.

Figure 7.1 Dry jointed, multiple opening, cantilevered laterite stone culvert approximately 1,000 years old and still in service.

Figure 7.2 Dry jointed, laterite, stone viaduct, approximately 1,000 years old, still in service on a national main road.

Classes of rocks used for building

Igneous rocks

Granite, Basalt, Pumice or Tuff

These are of volcanic origin and form as a result of cooling of molten material either within the earth's crust or at its surface. Granites and basalts are hard, dense, strong and impermeable, and can form excellent rubble building stone, but they require a lot of work to quarry and form to precise dimensions. Pumice and tuff are relatively soft and porous materials formed by depositions of ash materials on the surface or under water. Strength is very variable, but they can often be easily cut and worked, and may be suitable for building road structures where they are protected from water.

Sedimentary rocks

Sandstones, Limestones

These are formed by deposition (usually under water) of particles from older rocks and organic materials, and chemical precipitation. They show natural stratification with separate layers having different properties, and natural bedding planes. The stratification makes quarrying and working to precise dimensions easier. Limestones and sandstones often have colour and texture varieties which make them attractive as well as durable building stones.

Metamorphic rocks

Slates, Quartzite, Marble

These are rocks which can be either igneous or sedimentary in origin, but which have been subsequently altered due to movements in the earth's crust causing them to experience enormous heat and pressure. As a result they are often hard and durable, and they tend to have a foliated structure with layers of stratification. Slates are metamorphasised clay and shale which quarry easily and are frequently suitable for walling and roofing stones. Marbles are metamorphasised limestones which have been crystallised by heat and pressure. They are hard and durable, and suitable for sawing and carving and can often take a high polish.

Laterite

This is strictly a form of soil rather than a rock. It is the end product of the intense tropical weathering of primary rocks, and it consists largely of the oxides of iron and aluminium, but it has the useful property of hardening on exposure to air. When soft it can easily be cut with a hoe, but on hardening it becomes weather resistant, and has a durability comparable with some building stones. It is widely used as a building material in humid tropical areas. However the quality can be very variable and care needs to be taken in selecting suitable material.

Field stone

Stone which is found away from quarries or other formal deposits, usually transported by water or landslides, and may be of any of the geological types described. It is usually of a durable type. Field stone can be a useful source of stone for small road projects, but should be subjected to tests as described below to determine its suitability.

Although the classification of a stone is not essential for its successful use, knowing the origin and type of stone does help to know what properties to expect. Stone from an existing quarry will probably already be classified. Unless it is obvious, help in classifying stone from an unknown source should be sought from professional geologists in the national Geological Survey Department or the Earth Science Department of a local university - samples sent to laboratories can usually be very quickly identified.

Methods of quarrying stone vary greatly from one quarry to another, and are developed to suit the character of the particular stone being worked and resources available. There are basically two different approaches. Where the stone is evenly bedded and valuable, a stone-by-stone approach may be used. The stone is cut straight from the bed to the size required, largely with hand tools, and hand drills, 'plugs and feathers', chisels, crowbars or explosives may be used to assist the cutting. The operation is labour-intensive, but little waste is produced; in some quarries, the stone is even mined from underground.

Alternatively, large-scale blasting may be used, bringing down many tonnes at a time, including large blocks of various shapes and sizes which can be further split down or removed by cranes for cutting. There will be a large amount of waste which can be crushed for use as concrete aggregate; this may even be the main product of the quarry. This method uses less labour and more mechanical equipment, and in certain circumstances may be more economical.

Cutting and finishing methods also range from very labour-intensive techniques using only hand tools to highly mechanised operations.

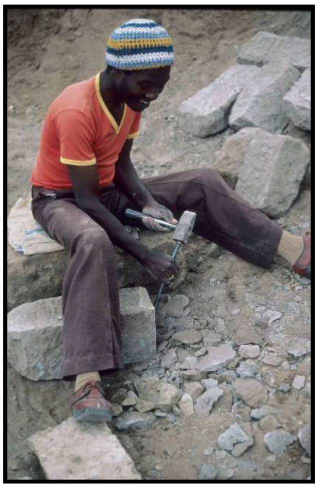


Figure 7.4 Hand dressed stone

Figure 7.3 Hand quarrying of stone

Figure 7.5 Hand quarried granite stone blocks

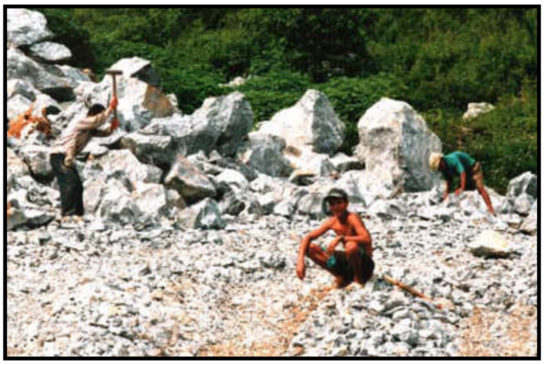


Figure 7.6 Manual quarry operations can create local employment, however good management is required to ensure a safe working environment

Properties of stone

- Size

The most important prerequisite of a good building stone is that the stone is available in pieces of a size and shape suitable for the type of wall or structure to be built. Stones should also be small enough to be lifted and placed by hand. For use in rubble walling, a range of sizes is needed. The individual stone height may be up to 300 mm, the length should not exceed three times the height and the breadth on base should not be less than 150 mm, or more than three-quarters of the wall thickness. A range of sizes should be used, with larger stones being used for corners (quoins) and for through (bonding) stones.

- Durability

Durability is the resistance of the stone to weathering or deterioration from other causes. The structure of the stone is the most important aspect of its resistance to decay. Stone used for building should be uniform in colour and texture, without soft seams or veins or other visible blemishes. The surface of a freshly broken stone should be bright, clean and sharp without loose grains and be free from an earthy appearance. Visual tests are sufficient to assess its suitability as described below.

Frost Action

Some types of stone are seriously affected by frost, and in cold climates must not be used in positions where they can become saturated. The remedy is to detail the wall to protect the stone from becoming saturated, by means of a coping, and providing protection for the base from upward percolating water by means of a damp-proof course.

Soluble salts

Soluble salts can disfigure and ultimately cause deterioration of some sedimentary stones. Soluble salts may occur in the sands used for mortar, in the water behind retaining walls, or in road salts. The remedy is not to use a stone which is liable to react poorly to soluble salts in circumstances where it will be exposed to them.

Thermal and moisture movement

Some small variations in the dimensions of stones always occur as a result of changes in temperature and moisture. These are rarely sufficient to cause any cracking problems, but it is a good precaution to insert movement joints in mortared masonry walls at intervals of approximately 15 metres.

- Compressive strength

The compressive strength of dense stone is generally greatly in excess of that required in any small road structures. A few porous stones, like pumice or tuff, or soft stones like laterite, may require some testing to establish that they have a suitable compressive strength: in other cases, the compressive strength can be assumed to be adequate for the small road structures described in this guideline.

- Seasoning

Certain stones, notably soft limestones, sandstones and laterites, increase significantly in strength and durability after quarrying. The appropriate time for seasoning depends on the quarry, and local knowledge is needed to decide on the correct seasoning time. It is a potential problem mostly where there are frosts.

- Porosity

Porosity is not in itself a disadvantage in most cases, but some stones are capable of absorbing substantial amounts of water; this can reduce the strength and also, in cold climates, freezing can cause disintegration of the stone. A good building stone should not absorb more than 5% of its weight in water.

Field Testing

In many cases the best test of the suitability of a stone from a local quarry or other source is its previously successful use in structures in the area which have been subjected to the local climate for a long period of time. Enquiries to local builders and contractors may result in knowledge gained regarding the best sources of building stone, and any local characteristics. This information can be supplemented by additional tests as required.

- Structure test

The structure of a stone from sedimentary rock sources can be tested by immersing small pieces in clear water in a glass jar for about an hour and then shaking them vigorously. If the water discolours, the stone is not well cemented and should not be used.

- Water absorption

The water absorption of a stone is a measure of its porosity and of its liability to frost damage. The water absorption of a stone can be assessed by:

1. Weighing it when dry (stored in a dry environment for at least 5 days)
2. Immersing it in water for 24 hours at ambient temperature
3. Weighing it again after removing excess surface moisture.

The difference in weight should not exceed 5% of the initial weight.

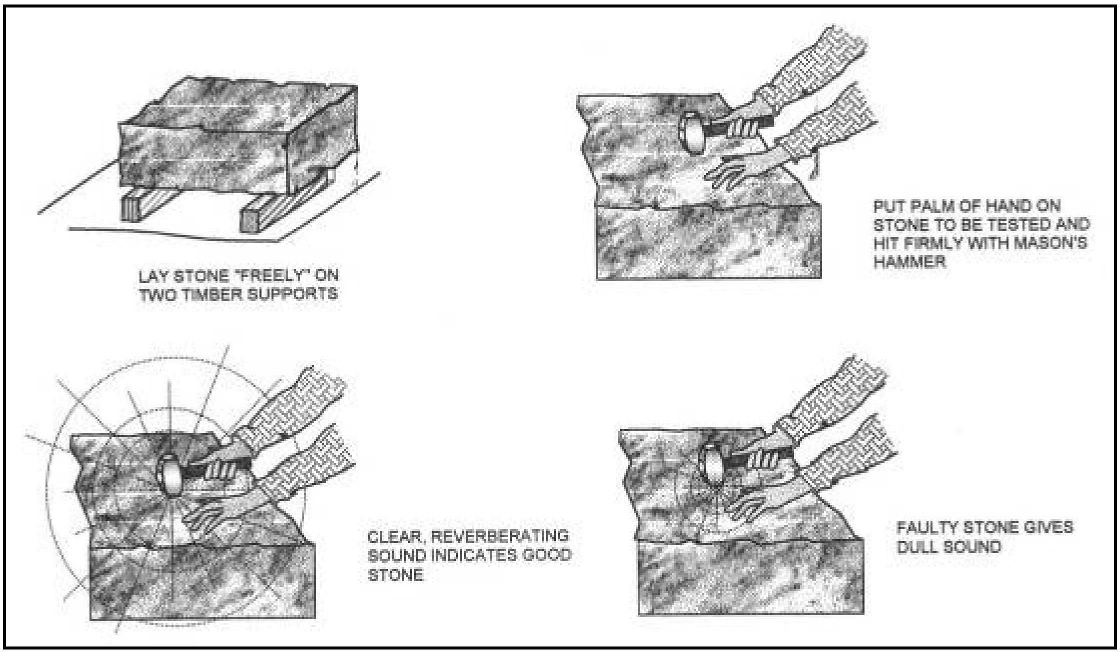


Figure 7.7 Hammer test for stone

- Soundness test

The soundness (freedom from cracks or weaknesses) of a stone can be tested by means of the hammer test (see above).

- Acid test for weathering potential

A small sample is immersed into a 1% solution of hydrochloric acid for seven days, during which time it is frequently agitated. If the sample has retained the sharpness of its edges and corners, it will weather well.

- Compressive strength

There is no adequate field test for compressive strength. This is not normally an important consideration except with blocks made from rather weak stones such as tuff. Where needed, testing should be entrusted to a competent laboratory.

- Hardness

The surface hardness can be tested by scratching with a penknife. All types of stone will be marked by a knife blade under firm pressure; but stone in which a penknife blade can make a groove exceeding 2 mm is likely to be moderately weak in compression, and compression testing may be needed.

Mortars

Unless dry stone walling skills are available or can be introduced, stone masonry usually involves mortar jointing. The principal function of mortar in masonry is to provide an even bed to distribute the load over the whole bearing area of the units, and to bond the masonry units together.

Good mortars should:

1. be cohesive, spread easily and retain water so that they remain plastic while the masonry units are positioned and adjusted
2. set and develop strength rapidly after the units are in place
3. have a final strength adequate to carry the load without cracking the masonry
4. be impermeable to moisture movement, and resistant to weathering

Mortars are composed of clean sand and a binding agent (usually Portland cement) and often some additive (either lime or plasticizer) to improve plasticity and workability. Sand should be soft building sand free of organic particles and clay. Lime should be bagged dry hydrated lime or lime putty. A plasticizer is an admixture to the mortar used in small quantities to improve the workability of the mix or to achieve the same workability with less water, thus improving both strength and durability. Plasticizers are proprietary materials and should be used according to manufacturers' instructions.

It is important that the strength should not be greater than that of the units being joined so that movement cracking will be dispersed through the mortar joints and not lead to a few wide cracks which could affect strength and weather resistance.

The table below shows typical mortar mixes using cement-sand or cement-lime-sand.

	Type of mortar	
	Cement:lime:sand	Cement:sand
Higher strength for structural use or contact with water	1 : 0.5 : 4	1 : 4
Lower strength for general use	1 : 1 : 6	1 : 6

Mortar – proportions by volume

Commonly used mixes are 1:4 cement:sand for structural use, or where there is contact with water, and 1:6 in other cases. For a good quality mortar, water content should be low (typically 0.4 water/cement ratio). The quantity mixed in any one batch should not be more than can be used in about one hour; during that time unused mix should be covered to protect it from excessive evaporation.

Stone walls

Random stone masonry is constructed from stones as they came from the quarry with minimal dressing. The laying skill is selecting individual stones so that they create a reasonable joint with the adjacent stone without the excessive use of jointing mortar. Stone should be bonded both longitudinally (along the wall) and transversely (across the thickness of the wall). Longitudinal bond is achieved by placing each joint more than one-quarter of a stone's length away from the joint below. Transverse bond is obtained by the use of bonders - at least one per m^2 of wall, extending about two thirds to three quarters across the width of the wall or right through the wall if water penetration is not a problem.

Random stone walls may be constructed without any courses, or brought to level courses for example every 600 or 900mm.

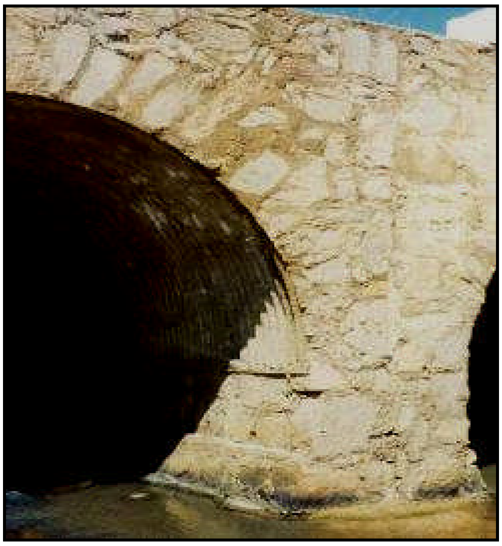


Figure 7.8 Rubble stone large bore culvert

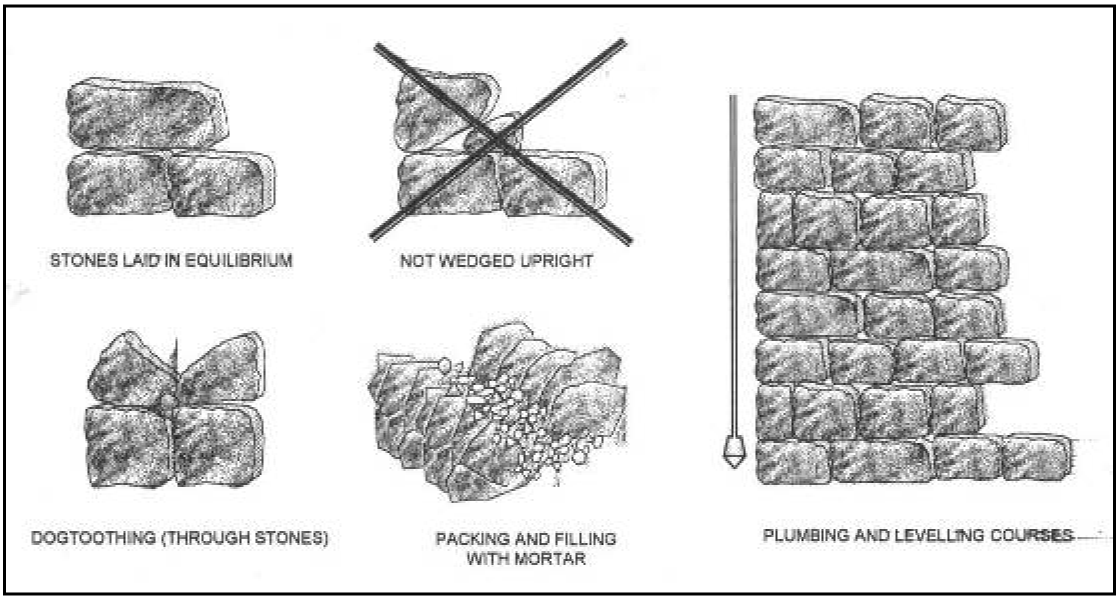


Figure 7.9 Rubble masonry wall

Dressed stone masonry is built with stones which are dressed to approximately rectangular shape usually before leaving the quarry. It is built in courses which may vary in height from 100mm to 300mm, often with thicker courses lower in the wall. All stones in any course are squared to roughly the same height. Bond stones are laid in each course at about 1.5m spacing.

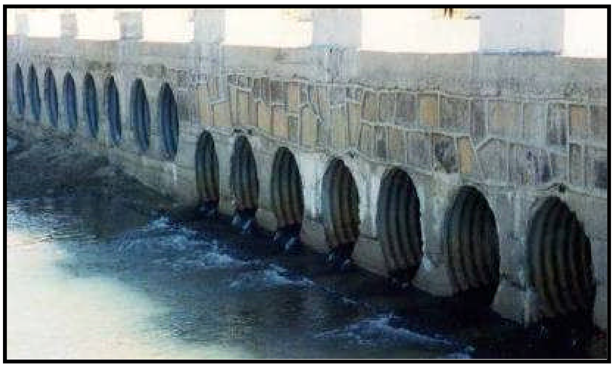


Figure 7.10 Masonry walling

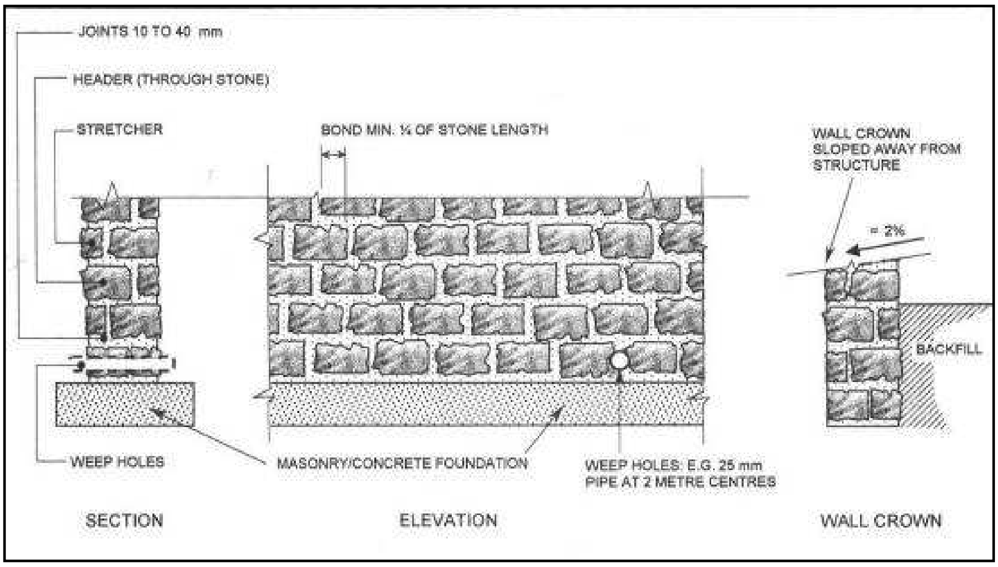


Figure 7.11 Squared masonry walling

Some general requirements for stone walls are:

1. The minimum thickness of a stone masonry wall should be 400mm.
2. The height of a free-standing wall should not be more than six times its width at the base, and may be tapered over its height.
3. Mortar joints should be between 10 and 40mm thick, and have a minimum overlap of one quarter of the length of the smaller stone.
4. Mortar joints should be pointed on the face of the masonry.
5. No stone should touch another, but should be laid into mortar.
6. Mortar should be made of cement and sand using volumetric proportions shown in the table above. A common mortar is 1:4 cement:sand.

Some additional requirements for retaining walls are:

1. The thickness of a gravity retaining wall at any point should be at least one third of the retained height above that point.
2. Retaining walls should be provided with regular weep holes just above ground level on the outer face. Weep holes should be of 75mm diameter and spaced at 1.5 m centres. A filter of loose stone or lean concrete should be placed at the back of the weep holes to permit free drainage of water, but not allow material to be washed through.

Dry stone walling

Dry stone walling is a form of stone walling built without mortar. A dry stone wall costs substantially less than a mortared wall, but calls for considerable skill in choosing and laying stones if instability and rapid deterioration is to be avoided. The face stones are usually roughly dressed and laid on a firm natural soil bed; the core is formed from earth or smaller stones. Typical arrangements are shown in the following diagram. Undressed stone may be suitable for retaining walls where stone is available locally and the ground beneath is firm. Walls should not exceed 5m in height.

Figure 7.12 Dry stone wall supporting road embankment

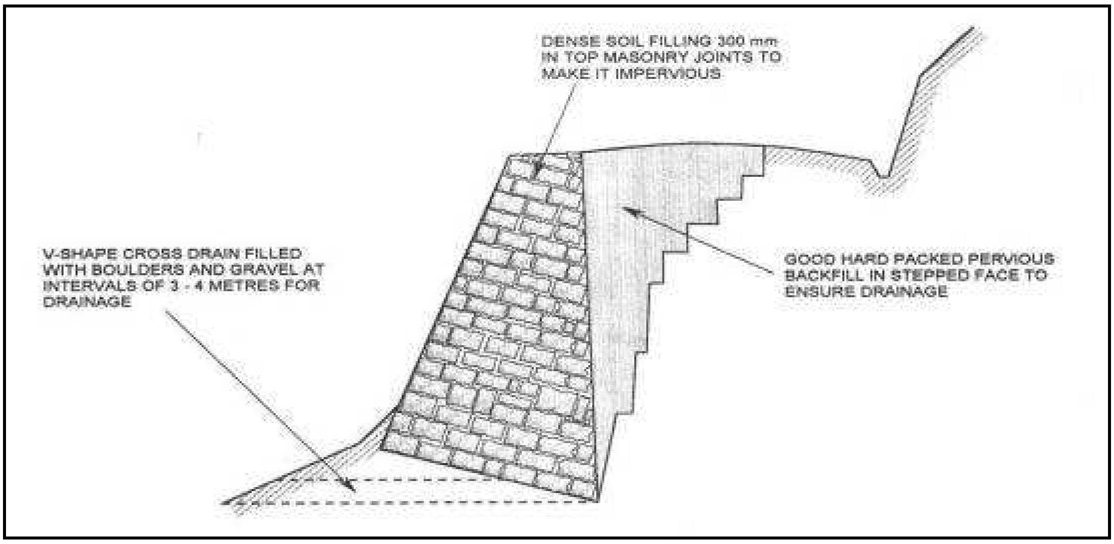


Figure 7.13 Dry stone retaining wall

Figure 7.14 Dressed dry stone wall

Some guidelines for the construction of dry masonry walls are as follows:

1. All front-side inclinations should be in the range of 3:1 to 4:1 (vertical:horizontal).
2. All back-side inclinations should be 1:10.
3. The top width of the wall should be 1m.
4. The tilt of the bottom of the foundation should be at right angle to the front inclination of the wall and hence fixed in the range of 1:3 to 1:4.
5. The stones used should be generally of a large size and care must be taken in dressing and placing them.

6. The joints between the stones must be arranged in a staggered fashion as in brick masonry (see diagram above).
7. All other construction details can be considered analogous to the rules applicable to gabion wall construction.

Hybrid walls

Hybrid walls are walls made of bands of mortared stone masonry reinforcing areas of dry stone masonry. The construction of a hybrid wall is recommended when the height of a dry stone wall is greater than 5m. The construction technique is the same as that of a dry wall, except for providing 0.6m bands of mortared cement masonry at intervals of 2m–3m both horizontally and vertically. This type of wall is recommended for heights between 5m and 12m both in valleys and on hillsides.

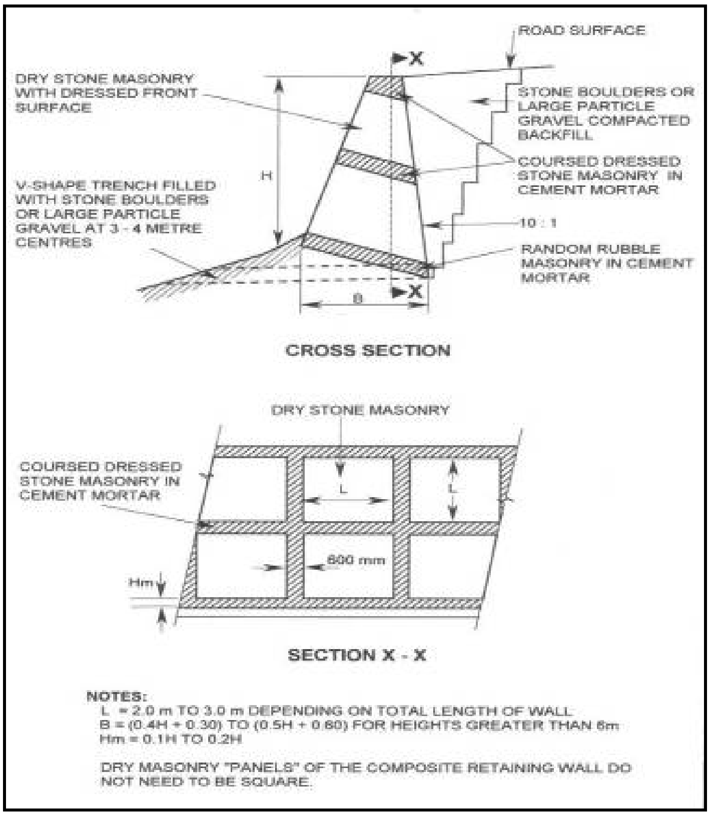


Figure 7.15 Hybrid wall

Figure 7.16 Hybrid retaining wall

Masonry culverts

Masonry arch culverts may be more economical than pipe culverts where stone is locally available. Some general requirements are:

1. Culverts are usually up to 2 metres in span.
2. Strip foundations of concrete or stone masonry should be laid on firm ground: the foundation walls are brought up to the level of the arch springing.
3. Arch formwork may be made from corrugated steel roof sheets (left insitu), timber or reusable steel formwork. Simple compacted earth fill can also be used and excavated after the masonry has been constructed.
4. The arch should have a minimum thickness of 400-500mm with all stones having the same dimensions as the arch thickness.
5. The ground seepage cut-off, invert (base) slab, headwalls, wingwalls, drop inlets and aprons may also be constructed of masonry as required.

Figure 7.17 Masonry culvert with steel former to be left insitu after construction

The masonry is normally mortar jointed using skills commonly available with local building contractors. Dressed stone skills are required for dry stone masonry culverts.

Figures 7.18 Dry stone masonry culvert extension works – Dry stone Conservancy, USA

Gabion works

- ♦ Use of gabions

Gabions are wire mesh boxes filled with stones and tied together to form basic structures. Their principal uses are for retaining walls, drifts and erosion protection. Gabion boxes may be made from purpose made gabion cages, welded steel mesh sheets or galvanised chain link fencing.

Gabions are used as a substitute for concrete or masonry, and gabion structures should be built with the same principles of good foundation, stability and quality control. The advantages of gabions are their simplicity of construction (requiring low levels of skill), use of local materials (stones), ability to let moisture pass through, avoiding the build up of water pressure, and flexibility (should minor settlement occur). Flat gabions are also referred to as gabion mattresses.

Figure 7.19 Gabions supporting a road on a steep slope

- ♦ Gabion construction

1. The process of gabion construction is as follows: Foundations should be excavated level and cleaned as for a conventional structure, with any unsuitable material removed and replaced with good soil, stone or gravel, and compacted.

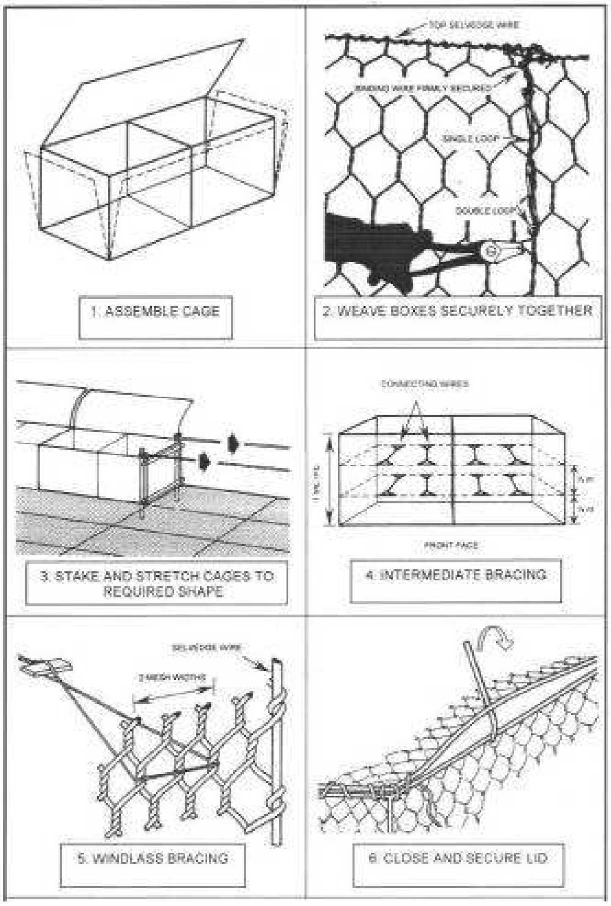


Figure 7.20 Gabion details

2. The baskets should be erected in their final position.
3. Cages should be woven together using 3mm binding wire securing all edges every 150mm with a double loop. The binding wire should be drawn tight with a pair of heavy duty pliers and secured with multiple twists.
4. The connected baskets should be stretched and staked with wires and pegs to achieve the required shape.
5. Filling should only be carried out by hand using hard durable stones not larger than 250mm and not smaller than the size of the mesh. The best size range is 125 - 200mm. The stones should be tightly packed from the edges inwards with a minimum of voids.
6. Boxes of 1 metre height should be filled to one-third height. Horizontal bracing wires should then be fitted and tensioned with a windlass to keep the vertical faces even and free of bulges.
7. Further bracing should be fixed after filling to two-thirds height. 500mm height boxes should be braced at mid height only. 250 - 330mm gabions do not require internal bracing.
8. Where water falls directly onto the

top of the gabion, vertical bracing wire should also be fitted to secure the gabion lid when closed.

9. The stones should be carefully packed to about 3 - 5cms above the top of the box walls to allow for settlement. Smaller material can be used to fill the voids on the top face, but excessive use of small stones should be avoided. Fibre matting can be placed over the stones on the top of the gabion to promoted vegetation growth.
10. The lids are then closed and stretched tightly over the stones, (carefully) using crowbars if necessary. The corners should be temporarily secured to ensure that the mesh covers the whole area of the box, the lid should then be securely woven to the tops of the walls, removing stones if necessary to prevent the lid from being overstretched.

Figure 7.21 Filling gabion baskets

Figure 7.22 Gabion retaining wall used as river bank protection

Figure 7.23 Natural fibre matting inserted in gabion protection works to encourage rapid growth of vegetation cover

Figure 7.24 Steel mesh gabions

Figure 7.25 Gabion river crossing

Brick and block masonry

Brick and block masonry materials are made in almost every part of the world, and are frequently the standard materials used for walling in building construction.

Fired clay bricks have been used for centuries for bridges and are one the most flexible general building materials; their small and regular size make them suitable for incorporation in any shape of structure. They are ideal for utilising local building labour and contractor skills. Good quality fired brick is suitable for most types of road structure. The following requirements should be met for its application:

- Material selection and firing methods should ensure a consistent quality of brick
- Bricks should be laid with a suitable durable mortar (as stone masonry), that is however not as strong as the bricks themselves
- Bricks should be laid bonded, to similar principles as stone masonry
- Bricks should be protected from the possible incidence of soaking in frost susceptible climates
- Abrasion situations such as drift surfaces should be avoided

This makes fired clay bricks suitable for use in foundations, bridge piers, abutments, wing walls, arches, culverts and retaining walls. Bricks are particularly important construction materials in regions with shortages of hard stone resources, such as Bangladesh and the Mekong Delta in South East Asia.

Local brick making skills are established in many areas, and could be developed in new ones as a small scale rural industry where there could be complementary demand in the road, building and infrastructure sectors. In some locations only low grade bricks are produced to meet a relatively undemanding requirement for general building bricks. In these cases some improvements in production such as kiln/clamp design, firing temperature and period may be required to achieve bricks of suitable quality for the more demanding structures applications. Bricks produced in ‘one burn clamps’ can have variable quality; the bricks near the outside usually being less well burnt. Permanent kilns and industrial production usually ensure more consistent quality products.

Fired clay bricks may be produced using agricultural wastes (such as rice husk) as the kiln fuel as described in the gTKP report on practices established in Vietnam (Reference: Dzung).

Figure 7.26
Fired clay brick is a very versatile material. This elliptical brick arch bridge over the River Thames at Maidenhead, UK was constructed in 1838 and has two main spans of 38 metres. It is still in use today (designer: Isambard Kingdom Brunel) photograph by Jon Combe

Figure 7.27
Fired clay brick structures exist in many countries and still provide service for today's traffic after centuries of use.

Figure 7.28
High quality burnt clay bricks produced in small 'beehive' kilns fired by rice husk. Bricks can be fired using coal, wood or other agricultural waste products.

The range of masonry materials which are manufactured is wide. Burnt clay bricks are still in many places the most widely available manufactured masonry materials. However, concrete blocks are increasingly widely available and can often be cheaper for the same applications as burnt clay bricks. Other masonry materials such as stabilised soil blocks and trass (a naturally occurring binder) - lime blocks are found in different places, and may be suitable for less demanding applications such as culvert headwalls and low retaining walls. Where natural stone is locally available, this may be better to use than any manufactured material on environmental and transport costs grounds. The requirements, properties and testing recommendations described for bricks and blocks need to be adapted for other masonry materials.

Figure 7.29 Simple burnt clay brick clamp

A wide range of soils is suitable for brick and block making. To make bricks, a suitable soil (called clay or brick-earth) is mixed with water, formed into the desired shape in a mould, dried, and then set in a kiln and fired at a sufficient temperature (usually 850-1000°C) to create permanent ceramic bonds between the soil particles.

Bricks are classified in various ways according to their intended use. A common classification recognises three classes according to their durability: internal quality bricks or blocks (suitable only for protected situations inside buildings); ordinary quality (suitable for external use in normal conditions of exposure (walls protected by damp-proof courses and a coping); and special quality (suitable for unprotected external uses such as parapets, earth retaining structures etc). Bricks and blocks may also be classified according to strength characteristics or shape.

Concrete blocks are made from aggregates and cement, and mainly manufactured in large fixed or mobile plants using heavy compaction or vibration, and sometimes steam curing. They can also be made on site using individual moulds; a labour intensive process which can result in quality variability without adequate control processes. Solid blocks have no holes, cellular blocks have cavities which do not pass right through the block, and hollow blocks have cavities passing right through. Manufactured blocks are made to satisfy standards requiring a minimum crushing strength.

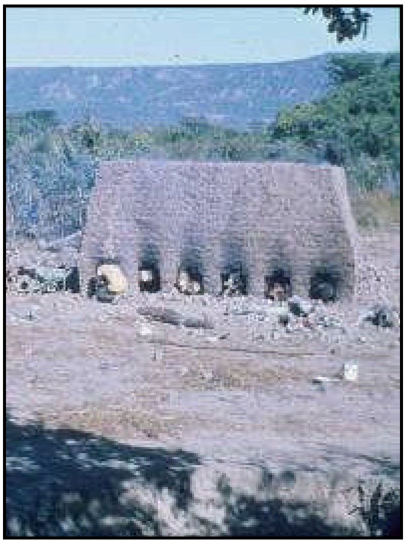


Figure 7.30 Bricks baked in a kiln

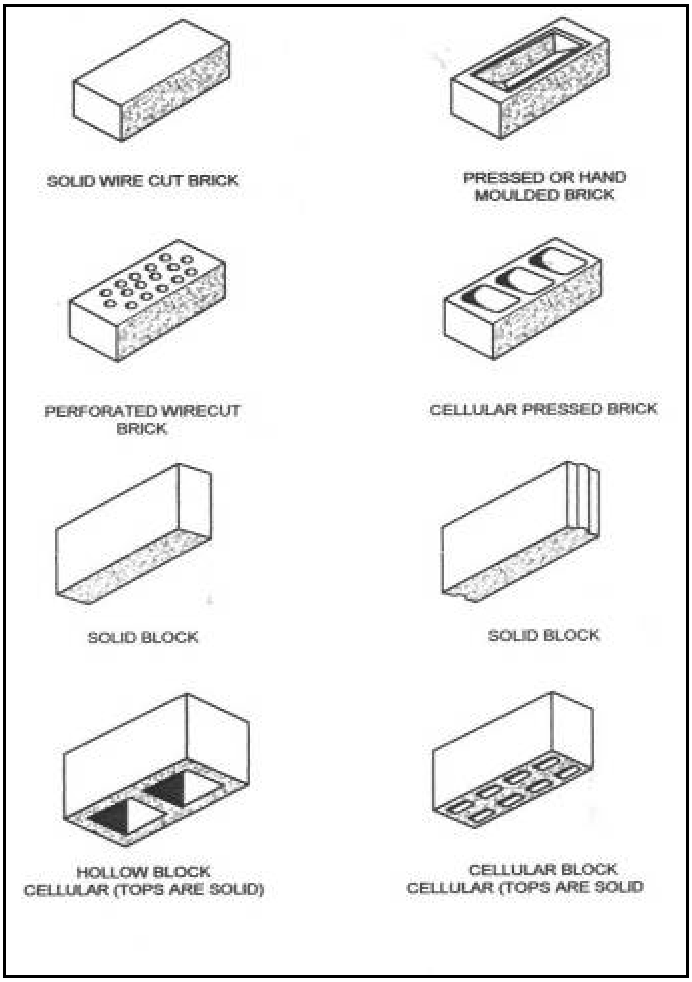


Figure 7.31 Brick types

Properties of bricks and blocks

For all brick and block materials the principal requirements are:

1. acceptable and handle-able size and small variation in dimensions
2. dimensional stability over time
3. strength
4. durability

Chemical composition and limited water absorption are also important for clay bricks.

- ♦ Size

The standard size of clay bricks differs to some extent from country to country. In many parts of the world the standard brick format (the average size of a brick plus mortar) is 225 x 112.5 x 75mm, though a plan size of 200 x 100mm is sometimes used; the average size of the actual brick is typically 10mm less than this to allow for the mortar joint. For individual bricks some variation is acceptable and must be allowed because of the differences of firing and moulding of individual bricks, but the average over a large number of bricks should stay within about 3 to 4% of the standard size. For walls whose appearance is important, the distortion of individual bricks should be limited, but normal distortions, even of hand-made bricks, can usually be absorbed in the mortar joints.

Blocks are produced to a variety of standard dimensions, but to fit with coursing, lengths of 390 and 440mm, heights of 140 and 190mm and thicknesses of 100, 150 and 200mm are commonly produced. Dimensional variability limits and mortar jointing thickness are similar to those for clay bricks.

- Dimensional stability

Burnt clay bricks change in dimension to a small extent over time as a result of moisture movements, and temperature. There is an initial expansion of about 1mm per metre length, most of which occurs within the first week after the bricks leave the kiln. Subsequent moisture movements are small, and thermal expansion (about 0.15 to 0.25mm per metre for a 30 °C temperature rise) is small compared with other building materials. Expansion joints are normally allowed every 12m in facing brickwork in order to accommodate these movements without causing cracking.

Blocks shrink after manufacture by about 0.5 to 1mm per m length of wall, which can be sufficient to cause cracking if expansion joints are not used; expansion joints are normally required to be spaced at 8 m centres in blockwork to allow for the initial drying shrinkage, and subsequent moisture and thermal movements.

- Strength

The compressive strength of individual bricks and blocks is usually much higher than is needed, but the strength of panels is affected by their shape, how they are supported, and by the mortar used. The compressive strength requirement depends on the loading on the wall. A minimum unit compressive strength of 3.5N/mm^2 may be adequate for walls which are not carrying large loads, and this is easily achievable in masonry materials made by simple processes; but masonry units of strengths up to 50N/mm^2 or even more can be manufactured for use in special conditions. The stronger masonry units also tend to be less permeable, more resistant to frost and water erosion and thus more durable.

- Water absorption

Water absorption is a concern for burnt clay bricks. It is a measure of the porosity of a brick, and should be limited, especially if the bricks are to be used in exposed positions - parapets, piers and abutment walls. A water absorption not greater than 15% by weight of the dry brick weight is required for acceptable performance.

- Chemical composition

For clay bricks, limitations on the content of certain salts are sometimes specified to reduce the problems of efflorescence and sulphate attack. Limiting sulphate content to 0.5% can eliminate the problem of sulphate attack (see below); alternatively sulphate resisting cement may be needed. Efflorescence is unsightly but does not seriously affect the strength or durability of the masonry. Elimination of nodules of lime (kankar) in the brick earth is essential; their expansion after the bricks have fired can damage the brickwork.

- Durability

The durability of a brick or block masonry wall depends as much on the climatic conditions, the extent to which protection of the faces and edges is ensured by copings and damp-proof courses, and the quality of the mortar as it does on the masonry units themselves. A key consideration is whether the site may be exposed to frosts. No specific requirements for durability can be stated, but units satisfying the requirements for strength and water absorption can usually be expected to perform satisfactorily if properly protected, by design, from extreme exposure. Specific actions to limit susceptibility to frost and chemical action for clay bricks are discussed below.

- Frost resistance

Water expands on freezing; where walls can become saturated with water which subsequently freezes, the expansion can be very damaging to masonry work. Well-made bricks or blocks of low porosity are generally able to withstand regular freeze-thaw cycles: but more porous and lower strength masonry units may be damaged. Where frosts may occur, bricks or blocks which are not of the highest quality should be protected from conditions in which they may become saturated. The use of damp-proof courses to protect the base of the wall from rising damp, copings to protect the top, and weathering details to prevent water from running down the face of the wall form the best protection from frost damage. All mortar joints should also be well pointed to ensure that the finished face of the joints is dense.

- Resistance to chemical action

Soluble salts in bricks, which may derive from the original clay used or from the kiln reactions, can cause staining and efflorescence or deterioration of the mortar. Efflorescence is the crystallisation of soluble salts at the surface of the brickwork, when bricks dry after a prolonged period of wetting. It is usually not damaging and can be tolerated. If the bricks contain soluble sulphates, these may cause an expansive reaction with Portland cement in the brickwork mortars, which will damage the integrity of the wall. Sulphate attack may also occur as a result of sulphates in groundwater in contact with earth retaining walls.

- Abrasion and impact

Bridge structures, piers and abutments may be subject to abrasion (due to driving rain, wind-borne sand or dust, or flood water). The possibility of vehicle impact from road or water should be considered. Well-made masonry units will have adequate resistance to these actions, but they should be considered in deciding the quality of bricks or blocks and mortar to use; and impact loads should be considered in the design of the wall resistance. In some instances the design of the structure needs to be detailed to minimise the risk of, or physically protect vulnerable components from, the impact from road or water born traffic or debris.

- Thermal and moisture movement

Thermal and moisture movements can cause expansion and contraction in brickwork, which can result in cracking unless it is allowed for. Mortars should normally be designed to be weaker than the bricks or blocks laid up in them, to enable high stress concentrations to be relieved - the recommended mortars for various classes of bricks allow for this. Expansion joints should be provided through brickwork (and any supported structure) every 12m; they should be 10mm wide, and filled with compressible material so that they do not become inactive.

Field testing

- Manufacturer’s testing

Where possible, obtain information from the brick or block manufacturer regarding the Standard to which the units conform, and details of the results of recent tests on strength, dimensional stability, water absorption and chemical composition as appropriate. Failing such information, field testing will help ensure that the bricks are of generally sound quality.

- Quality of the raw materials used

The brick earth used for making burnt clay bricks should not contain iron pyrites, pebbles, or nodules of lime or tree roots. The content of clay should be around 15% to 30%. A small quantity of lime is acceptable as long as it is in a finely divided state. Soils from areas which are or have been saturated in salt or sea-water should be avoided. Similarly aggregates for concrete blocks should satisfy the requirements for good concrete, as set out later in this chapter.

- General characteristics of clay bricks

A good clay brick should be sound, hard and well-burnt with uniform size, shape and colour, homogeneous in texture, and free from flaws and cracks. A broken surface should show a uniform structure free from holes or embedded lumps. Corners should be square, straight and well-defined. When struck against another brick or with a small hammer, bricks should give a metallic ring, not a dull thud. When soaked in water for 24 hours there should be no sign of softening or distortion. Before or after immersion, the surface should not be able to be scratched with the finger nail.

- Strength: drop test

If no specific compressive strength requirement is required for load-bearing purposes, the strength of a masonry unit may be crudely assessed by dropping it flat from a height of about 1.2 to 1.5m to the ground, or striking one brick against another. In neither case should it break.

- Strength: impact test

For a more controlled impact strength assessment, place a brick with its largest face downwards, resting on timber battens 180mm apart. Drop a mason’s 2kg hammer from a height of 0.5m so that it strikes the upper face midway between the battens. The brick should not break. If more than 2 in a sample of 20 bricks break in this test, the bricks should not be used. For bricks and blocks of different shapes a similar test may be used, but the height of drop and span will vary.

- Dimensions

No dimension should differ by more than 5mm from the standard size. The overall dimensions of a set of 20 or more bricks or blocks, randomly selected, should not deviate by more than +/-4% (length and width) or +/-3% (height) from the standard size.

- Water absorption test for clay bricks

Take a sample of 5 bricks at random. Dry and weigh each brick (W1); then submerge in clean water at ambient temperature for 24 hours. Wipe surface and weigh again (W2).

The water absorption (%) is the ratio:

100 x (W2-W1) / W1

For bricks to be used in normal conditions of exposure, water absorption should not exceed 15%. More severe limitations would be required for bricks to be used in conditions exposed to permanent wetting and drying; e.g. at the base of piers or abutments.

- Durability

One way to test durability is through the construction of a test panel to be exposed to conditions similar to the proposed work; but a period of some months’ exposure in severe weather would normally be needed to assess performance adequately. Alternatively observing the performance of the same masonry units in other building situations of comparable exposure (reference sites) can be a good indication of durability. Some kind of exposure test should be used if the units are to be used in conditions where they will be exposed to heavy frosts.

Mortars for brick and block masonry

The requirements for mortars are the same as those for stone masonry.

Uses of masonry in road structures

Brick and block masonry may be used for bridge piers, abutments and wing walls, arch culverts and wing walls, and small bridges.

Figure 7.32 Bricks in a bridge pier

Timber and organic materials

Timber, in the form of sawn sections or poles, is in many areas a highly cost-effective material to use for load-bearing structures, even where there are concerns about the over-exploitation of tropical forests. The quantities of timber required are relatively small and a good management regime will ensure or arrange for planting of replacement trees for construction and maintenance needs. With proper selection of species, stress-grading to ensure efficient utilisation, and attention to seasoning, preservation and subsequent maintenance, structures made from either softwoods or hardwoods can have a design life comparable to that of steel or concrete structures; the appearance of timber structures fits the natural surroundings; and its use can provide local employment without the need for highly sophisticated technology in manufacture or preparation, and reduce transport costs. Sustainably produced timber can have attractive carbon footprint attributes.

The principal use of timber in low-cost road structures is for bridge decks, where its structural advantages can be utilised most fully, and where it is more easily protected from moisture penetration. Use of timber for running surfaces may make sense even when the supporting structure is of steel or concrete. Trussed or girder bridge decks can be made from cut sections of timber or from timber poles. Timber has also been used for both bridge abutments and for retaining structures, though in these uses a relatively shorter lifetime must be expected; and in Tanzania, a successful programme to use timber for culvert linings has been in progress for some years.

Figure 7.33
Steel beams being moved into position using labour methods without the use of cranes ready for completion with a timber deck

Figure 7.34
Timber deck on recycled steel beams

Figure 7.35
Completed timber deck

Figure 7.36
Timber bridge deck, pier and abutments

Characteristics and utilisation of timber

- Hardwoods and softwoods and their availability

Softwoods are derived from coniferous evergreen trees grown mainly in temperate forests. They are relatively rapid-growing and the wood is of a generally relatively low density (typically less than 500 kg/m3) and moderate strength and easy to work. However, the wood is not normally very durable, unless protected by preservatives. Globally, coniferous forests are very extensive, and are managed to produce a sustained yield of timber. In areas of temperate climate, softwoods are therefore relatively cheap, making timber structures highly cost-efficient.

Hardwoods are derived from broad-leaved (deciduous) trees which lose their leaves in winter; they are found in both temperate and humid tropical climates. Compared with softwoods, they are relatively slow-growing, and this results in wood which is denser (typically > 650 kg/m3), and of higher strength, though sometimes difficult to work with normal hand-tools. Often hardwoods are highly durable even without the use of preservatives. However, some hardwoods, such as balsa, are extremely light and have a low strength - hardwood is a botanical rather than a mechanical classification of timber. Hardwoods of a number of species from the tropical forests have been seriously over-exploited, and are or will soon become scarce. Nevertheless in most tropical regions there is a sufficient supply of less well-known species which are available locally at reasonable prices, and these may prove to be ideal for use in road structures in these regions. Efforts are being made to introduce sustainable hardwood management practices.

The principal species suitable for road structures are shown in the tables below (with their scientific and common name), which divide them into heavier and lighter hardwoods and softwoods.

Heavy hardwoods

Density >650kg/m^3 when dried to 18% moisture content

Afrormosia	(Pericopsis elata)
Ekki	(Lophira elata)
Greenheart	(Ocotea rodiaei)
Iroko	(Chlorophora excelsa, regia)
Jarrah	(Eucalyptus marginata)
Karri	(Eucalyptus diversicolor)
Keruing (gurjun)	(Dipterocarpus spp)
Opepe	(Nauclea diderrichii)
Sapele	(Entandrophragima cylindricum)
Teak	(Tectona grandis)

Lighter hardwoods

Density <650kg/m^3 when dried to 18% moisture content

African Mahogany	(Khaya ivorensis, anthotheca)
Afzelia	(Afzelia spp.)
Dahoma	(Piptadeniastrum africanum)
Gum	(Eucalyptus saligna)
Jacareuba	(Calophyllum brasiliense)
Meranti	(Shorea spp.)
Muminga	(Pterocarpus anyolensis)

Softwoods

Softwoods for bridge construction should generally have density >420kg/m^3 when dried to 18% moisture content

Cedar	(Cedrus spp.)
Cypress	(Cuppressus spp.)
Douglas fir	(Psewdotsuga taxifora)
Kauri, East African	(Agathis alba)
Parana Pine	(Araucaria angustifolia)
Pine, Caribbean Pitch	(Pinus Caribaea)
Pine, Scots or Redwood	(Pinus sylvestries)

- Forms of timber and timber products

Timber is most commonly utilised structurally in the form of sawn sections. Timber is generally sawn at sawmills, in or close to the forests from which the trees are extracted, and then supplied to timber wholesalers or importers, who sort, grade and treat the timber for supply to the users. But there are many local variations, and hand-sawing is still practised in some parts of the world. Whether machine or hand-sawn, logs are usually sawn by means of a series of parallel cuts through the log, which is referred to as flat-sawn. The resulting sections have a tendency to some distortion because of different shrinkage rates on the upper and lower surfaces. The alternative quarter-sawn logs will have less distortion, but waste more of the log. In sawing timber into rectangular sections some of the log is inevitably wasted, and a more economical way to use timber, which eliminates sawing and also preserves more of its natural strength, is in the form of round poles.

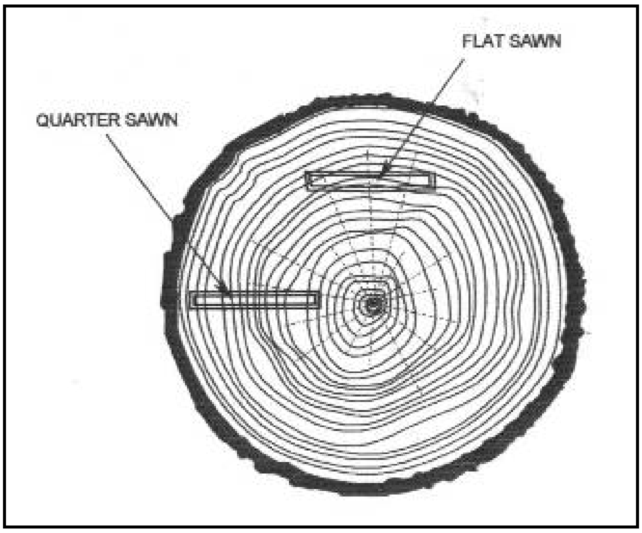


Figure 7.37 Saw cuts

Figure 7.38 Timber poles for piles (not covered by this guideline) for a concrete box culvert in very soft ground

Figure 7.39 Timber poles as deck beams of a twin span bridge

The poles can be used for piling or as part of a timber lattice structure. Larger logs can be used as abutment, pier or deck members. Use of pole structures enables younger trees or thinnings from immature forests to be used, and thus the timber is cheaper.

Bamboo, though botanically closer to grass than timber, can often be of very high strength and strong enough to be used structurally. Bamboo bridges have been built for road traffic, but it is very difficult to achieve good durability in bamboo structures and its use is not recommended in this guideline.

- Seasoning

Freshly cut timber contains a substantial proportion of water, up to 100% of its dry weight, and if used in the green state it is subject to substantial shrinkage movement, as well as being prone to fungal attack. Thus, for effective structural use timber must be dried so that its moisture content is close to the equilibrium moisture content (between 10% and 20%, depending both on the type of timber and the climatic conditions). This process, which has to be carried out with care to avoid distortion, is referred to as seasoning. Seasoning also increases the strength and stiffness of the timber.

- Timber preservation

Preservative treatment is needed to protect timber from fungal attack, insects and marine borers. There are a number of chemical treatments available, and the success of the treatment depends on effective choice of both the chemical substance used and the treatment process.

Chemical preservatives include:

Oil-based preservatives such as creosote
Water-based preservatives such as copper/chrome/arsenite
Organic solvent preservatives such as pentachlorophenol.

- Stress grading

Because of the natural variability of timber, even of pieces from the same source, careful grading, piece by piece, is essential to ensure safe and efficient use. Stress grading can be done either visually or mechanically. Visual grading involves making a visual assessment of the extent of the principal factors affecting strength - knots, fissures, grain slope, wane, distortion, and perhaps worm holes and fungal decay, and classifying the timber according to predetermined measures of each which are acceptable in the various grades. Some aspects of visual stress grading are described below. In machine grading, each piece is subjected to a bending test under load in an automated process, and is graded according to its deformation; a visual assessment is carried out at the same time.

Properties of timber

- Natural defects

Natural defects are features which develop in the living tree, which may affect its structural usefulness. Some can be accommodated within limits.

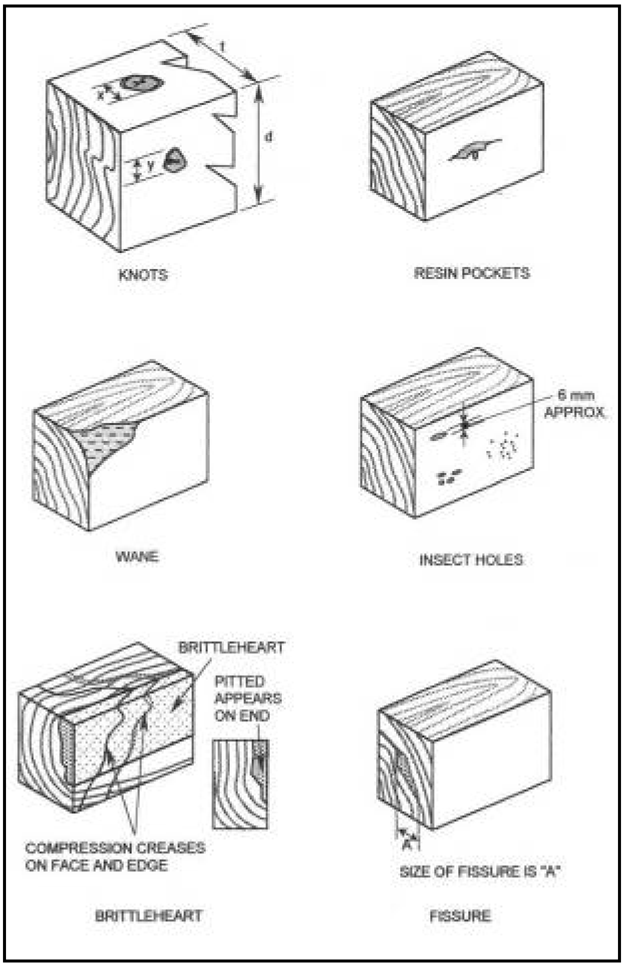


Figure 7.40 Natural defects in timber

The most important are:
Knots - parts of branches which have become enclosed in the main tree; can reduce strength in tension, can be difficult to work.
Fissures - splitting separation of the fibres due to a variety of causes including: stresses in the standing tree (shakes), slits from rapid drying, resin pockets (in resin-bearing softwoods).
Wane - inclusion in the sawn timber of part of the original round surface of the log.
Insect holes.
Grain slope - the small angle between the direction of the grain and the length of the cut timber.

Several other types of natural defect are unacceptable and should be eliminated from any timber used structurally:
Brittleheart - this material is found in the centre of some tropical trees, and should be avoided because it is of low strength and breaks with a brittle fracture.
Compression failures.
Fungal decay - this is discussed below.

- Shape

The processes of sawing and seasoning timber create distortions which must be limited for satisfactory use. The four principal types of distortion encountered are bow, spring, twist and cup. Some suggested limits are given in the table below.

- Moisture content

Moisture content needs to be limited to achieve the best structural properties and reduce shrinkage as well as reduce susceptibility to fungal attack. Seasoning should reduce the moisture content to within 5% of the equilibrium moisture content, which is in the range 10-12% for hot-dry regions, but may be 14-18% for tropical rainforest regions.

- Density

The density of timber depends on its type. Softwoods typically have densities in the range 350-480 kg/m^3, but for bridge construction those suitable have densities above 420 kg/m^3 at 18% moisture content are required. Tropical hardwoods typically have densities in the range 500 to 800 kg/m^3 or even higher, but there are many hardwoods with much lower densities. The tables above divide the common species of hardwoods into two classes: heavy hardwoods with densities above 650 kg/m^3 when dried to a moisture content of 18%; and lighter hardwoods with densities less than 650 kg/m^3.

- Strength and elasticity

Strength and stiffness are the most important properties from the point of view of structural utilisation, and they are closely related; timbers with higher strengths generally also have higher modulus of elasticity. For structural design maximum allowable stresses in bending, tension, compression (both parallel to and perpendicular to the grain) and in shear must not be exceeded. These are normally derived from guidelines or codes of practice in which timbers are grouped into strength groups; values of the strength and stiffness parameters are given for each group depending on the moisture content and extent of defects in the timber.

Design stresses for the three principal timber groups

	Heavy Hardwoods (N/mm^2)	Lighter Hardwoods (N/mm^2)	Softwoods (N/mm^2)
Bending	15.1	8.6	5.4
Tension	9.0	5.0	3.2
Compression parallel to the grain	11.3	6.8	5.0
Compression perpendicular to the grain	2.2	1.8	1.5
Shear	2.2	1.1	0.9

- Durability

The durability of timber relates primarily to its resistance to fungal attack and attack by insects or marine borers, which are discussed below. Durability is enhanced by good timber selection, effective seasoning and preservative treatment, and maintenance after construction. It is also enhanced by good design, particularly measures to ensure that timber is protected from water; the end grain and joints are particularly susceptible.

Fungal attack can cause both staining and decay. Some fungi attack cell contents only, rather than the cell wall substance, and as a result, no structural degradation of the timber occurs. Decay is not an inherent property of the material itself but depends on the availability of food (the wood itself), moisture, air and favourable temperature conditions. Some species have more durable heartwood than others and this is related to the toxic chemicals present in the cells and cell walls of the more durable species.

The natural resistance of wood to decay can be increased by ensuring that its moisture content is below 18% (based on the oven-dry weight of the wood). In addition to using seasoned timber, the wood should be protected from dampness by moisture barriers or flashing. If timber is in contact with the ground, only the more durable heartwood or preservative-treated timber should be used.

In tropical climates, great damage is done to wood by subterranean termites. Termites must have access to the soil or to some other constant source of moisture. They can severely damage timbers in contact with the ground and may extend attack to the roof timbers of high buildings.

Damage above ground may be prevented by ensuring that all means of access are eliminated. Metal shields or stump caps, or poisoned soil barriers, are effective in preventing the passage of termites from the foundations to other parts of the structure. Where shields are used, adequate clearance below deck level should be provided to allow easy, and regular, inspection. In areas of severe infestation, the only practical methods of control are, however, the use of termite-resistant or preservative-treated timbers.

Apart from termites, there are a number of other insects which attack timber. Moisture is an essential element for some insects' development and hence drying is an obvious protective treatment. However, preservation is generally regarded as being a broad and more positive measure particularly where the timber is to be used in structural applications.

Protection of timber submerged in sea water against attack by marine organisms is usually based on the use of mechanical sheathing with resistant timbers, concrete or non-ferrous metal, or the use of preservatives which are resistant to leaching, such as creosote. Some tropical woods possess a natural resistance to marine attack.

- Shrinkage and thermal movement

Some shrinkage and expansion as a result in changes in the moisture content of the timber must be allowed for in design. The important shrinkage movements are tangential and radial, that is across the width of the timber; in these directions the movement can exceed 3% as a result of a change in relative humidity from 90% to 60%. In the longitudinal direction the shrinkage movement is very small, less than 0.1%. The coefficient of thermal expansion is 30-60 x 10^{-6} per °C across the fibres, but less than one tenth of this parallel to the fibres. Thermal expansion even of large structures is therefore not a problem.

- Fire resistance

Timber is a combustible material and will ignite at temperatures of around 220 to 300°C; it also produces toxic carbon monoxide and large quantities of smoke when ignited. When used in external conditions on road structures the risks are from fire caused by fuel spillage in overturned vehicles and wildfires. However, timber chars as it burns, at about 0.5-0.7 mm per minute, which helps to insulate the interior; there is no instant loss of strength in fire, nor a rapid expansion, and timber structures can safely carry their loads for some time in a fire, enabling people to escape and the fire to be extinguished. Fire retardant and fire-protection chemical treatments are available either as paints or for pressure impregnation, but they are expensive, and the paints require maintenance. Fire protection is therefore not usually applied to external structures for low volume roads..

Field testing

- Condition

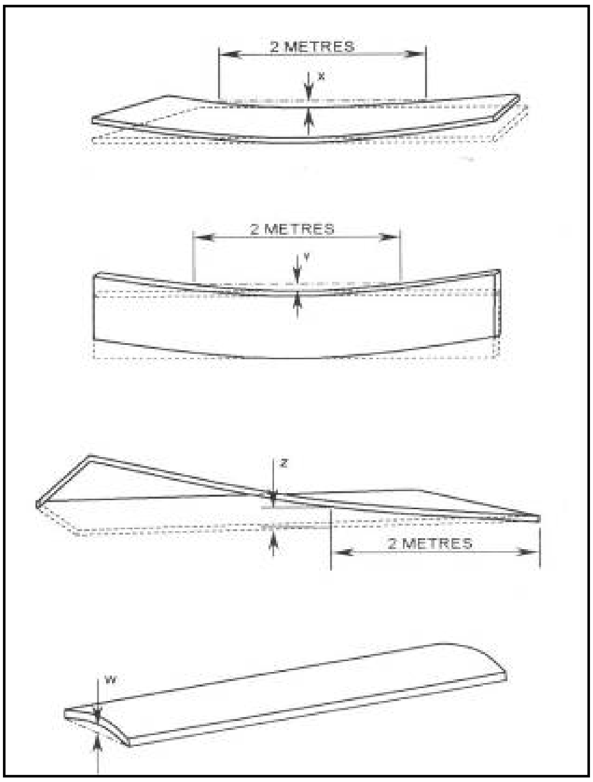
Some visual indicators for a good quality timber are:

1. The cellular tissue should be hard and compact
2. The fibrous tissues should adhere firmly together and should not clog the teeth of the saw
3. Depth of colour indicates strength and durability
4. A freshly cut surface should be firm, shining and somewhat translucent, whereas a dull chalky appearance is a sign of bad timber
5. In resinous timbers those with least resin in the pores are the strongest and most durable; in non-resinous timbers those with least sap are best.
6. A good timber is uniform in colour, with straight grains, free from dead knots, cracks and shakes, and has regular annual growth rings

- Shape

The bow, spring, cup and twist of a piece of timber can be measured directly if the timber is placed on a flat surface. An average of at least 10 measurements should be taken. Some limits to distortion appropriate for tropical hardwoods and softwoods to be used structurally are shown in Figure 7.41.

Figure 7.41 Timber shape criteria



Bow: X should not exceed 15mm per 2m length (in a piece of 75mm and greater in thickness)

Spring: Y should not exceed 7mm per 2m length (in a piece of 250mm or more in width)

Twist: Z should not exceed 10mm per 2m length

Cup: W should not exceed 1mm per 25mm of width

- Visual stress grading

Visual stress grading involves making measurements or inspections of natural defects: slope of grain, knots, fissures and resin pockets, wane and insect holes.

Minimum acceptable limits for all these characteristics are shown in the table below. Other visible defects including bark pockets, compression failures, fungal decay, and brittleheart should not be permitted in any structural timber.

Limits of visible defects for structural timber from tropical hardwoods

Property	**Acceptable limit for structural timber**
Slope of the grain	1 in 11
Knots: size	25% of the thickness, up to 75mm
Knots: frequency	One sizeable knot per metre of length
Fissures and resin pockets	Moderate fissures (of greater than 1/3 the thickness but less than the thickness): not to exceed in length 20% of the length or 1.5 times the width. Large fissures (equal to the width): not permitted
Wane	Not to exceed 25% the sum of the width and thickness
Insect holes	In a square of 100mm sides not more than 32 pinholes (<1mm), nor more than 4 shot holes (<3 mm) nor more than 2 holes of 6mm diameter

.

- Determination of moisture content

The moisture content of wood can be measured by the oven test method. Small samples are cut from the wood to be tested, the samples are weighed and then dried in the oven at 100 ^{0}C until their weight becomes constant. They are then weighed again.

The moisture content, m, is calculated, as a percentage.

$$m\ \% = 100 \times \frac{\text{weight of water}}{\text{dry weight}} = 100 \times \frac{\text{initial weight - final weight}}{\text{final weight}}$$

Typical equilibrium moisture contents for different regions are shown in above. The equilibrium moisture content of the timber to be used should be determined by a laboratory; the oven test can then be used as a check on the effectiveness of seasoning of timber delivered to site. Moisture content should be kept within 5% of the equilibrium moisture content.

- Strength and elasticity: load testing

The suitability of the structural properties of a timber are normally determined by the use of standard tables of properties for the species to be used, coupled with stress grading to determine the classification of the sections available. However, in certain circumstances, the structural properties of timber can be checked by a direct load test. This is easiest to carry out when the timber is to be used in bending.


Figure 7.42 Timber decked bridge

A pair of joists is set up between solid supports using the span length which will be used in the actual structure. The joists are connected to each other by cross-bracing, and a deck is placed over them. The deck is loaded uniformly, using heavy materials such as bricks or stone, until it reaches the design load. The deformation at mid-span is then measured. Under the design load it should not exceed about 1/300 of the span. The load should then be increased to 50% above the design load, under which load the timber should show no sign of failure.


Figure 7.43 Log abutments & deck


Figure 7.44 Treated timber culvert

Uses of timber

The principal use of timber in low-cost road structures is for bridge decks, where its structural advantages can be utilised most fully, and where it is more easily protected from moisture penetration. Timber can also be used for bridge abutments and retaining structures (though in these uses a relatively shorter lifetime must be expected), and for culverts.

Plain and Reinforced Concrete

Plain and reinforced concrete are the widely used choices of material for a range of uses in road construction. Concrete technology is now established almost everywhere in the world, even if it is not always well understood. Suitable raw materials to use as aggregates, forming the bulk of the material, are found almost everywhere. Cement and reinforcing bars are widely manufactured to standards that are internationally recognised. Thus concrete is often the cheapest option, even when other entirely locally produced materials are available. When it is well-made, concrete is also a strong and durable material, leading to a low maintenance requirement, important for rural structures. Concrete also has the particularly important property of being able to resist the action of water.

Reinforced concrete is suitable for bridge decks, piers and abutments, as well as for box culverts and culvert rings; plain concrete may be used for drifts and causeways, culvert rings up to 900mm diameter and for the foundations of walls, piers and abutments made of masonry and timber.

Because concrete, unlike other structural materials, is generally made on site from its raw materials, an important requirement for the use of concrete in structures is that both designers and builders, as well as those responsible for long-term maintenance, understand its essential properties and characteristics.

Materials for concrete

There are three essential constituents of concrete:

1. Cement is the active ingredient. It constitutes about 10%-15% of the concrete by weight. The cement, in combination with water, forms a strong matrix which surrounds and binds the aggregate together. As the concrete mix sets and hardens it gains strength and durability.

2. Water constitutes about 5% of the concrete by weight. Initially, it gives the concrete workability, allowing it to flow and take up the shape in which it is moulded. Over time, the water combines chemically with the cement in a process called hydration, which causes the concrete to set and develop strength.

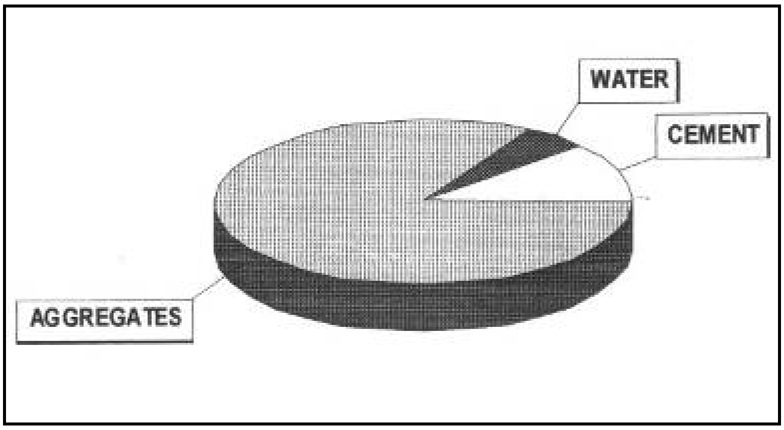


Figure 7.45 The constituents of concrete

3. Aggregates are inert materials, usually of mineral origin, which constitute the bulk of the concrete (about 75%-85%). They are usually chosen from local sources for low cost, but their size range, shape, density, hardness and surface properties have important effects on the resulting concrete.

In making concrete, these three constituents are mixed together in appropriate proportions to make a fluid mass, which is then placed in formwork, compacted to remove air, and finally allowed to set and harden.

Plain concrete is relatively weak in tension, therefore steel reinforcement is used where tensile stresses are expected. When reinforced concrete is being made, the reinforcement is formed into a cage, which is placed in the formwork before the concrete is placed. The following sections describe the materials requirements.

- Aggregates

The aggregate is divided into two parts: coarse aggregate and fine aggregate. The fine aggregate is normally a naturally occurring sand, with particles up to about 2mm in size. The coarse aggregate is normally stone with a range of sizes from about 5mm to 20mm (or sometimes larger); it may be a naturally occurring gravel, or more commonly crushed or hand-broken quarry stone. In areas without hard stone resources and with an establish fired clay brick industry, bricks are sometimes machine or hand crushed to be used in concrete.

Aggregates must be entirely free from soil or organic materials such as grass and leaves, as well as fine particles such as silt and clay, otherwise the resulting concrete will be of poor quality. Some aggregates, particularly those from the seashore, may need to be washed to make them suitable for use. Tests for aggregate quality are described below.

Both the coarse and fine aggregates need to contain a range of particle sizes, and are mixed together in such a way that the fine aggregates fill the space between the coarse aggregate particles. A ratio by volume of one part fine aggregate to two parts coarse aggregate is generally used.

Aggregates should be stored in such a way that they do not become contaminated by soil, and that rainwater can drain easily.

- Cement

The cement most commonly used for concrete is Ordinary Portland Cement (OPC). This is made in factories in which a mixture of limestone (or other calcium-rich minerals) together with clay or shale is fired at a high temperature, and the resulting cement clinker is ground to a fine powder. The operation is highly controlled and the resulting cement is produced to a specification which defines the essential properties including strength, setting rate and chemical composition.

Cement is normally delivered to site in 25 - 50kg paper bags. The cement must be kept totally dry until it is to be used, otherwise it will begin to react with the water and be rendered useless. Cement should therefore be stored off the ground in a shaded, dry and well-ventilated place. If any lumps of hardened cement are found in a bag, the cement in that bag should not be used for structural work. Cement should typically be used within 6 months and therefore stored in a 'first in – first out' system.

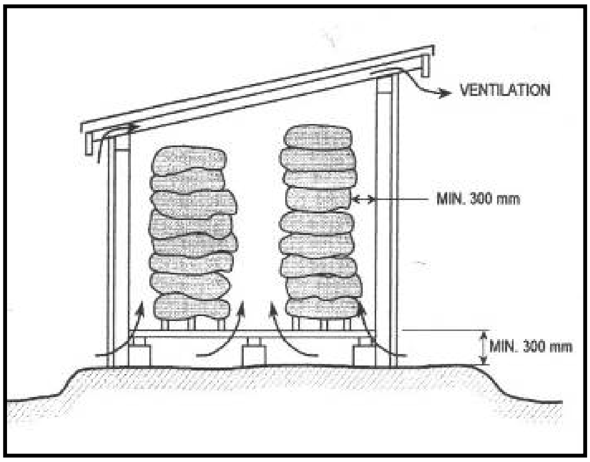


Figure 7.45 Cement stored in dry conditions

- Water

The mixing water used should be clean and free from salts. It can be taken from rivers, lakes or wells or from a treated water supply. Sea water may be used for plain concrete, though it will affect the rate of setting, but should not be used for reinforced concrete. River water containing sediments can be used if the sediments are first allowed to settle out in a tank or drum until the water is clear.

Figure 7.46 Aggregate can be crushed and screened by hand or machine

- Reinforcement

Reinforcement is normally in the form of steel bars. Three characteristics are of primary importance: enough strength that a small amount of reinforcement can be used to carry the tensile and shear forces; enough ductility that the rods can be bent without breaking, and, if a member is overloaded, that the structure will deform without failing; and sufficient bond between the reinforcing and the concrete that forces can be transferred between them.

Two types of steel reinforcement are in common use: mild steel and hot rolled high-yield steel. Mild steel bars are round, while high yield bars have a deformed surface to improve the bond with the concrete. Typical reinforcement sizes range from 6mm to 30mm in diameter. Reinforcing steel is usually available both in rod and mesh forms. Reinforcement bars are cut to the required length and bent to the required shape; they are then tied together in the arrangements shown on the drawings using binding wire and spacer blocks.

On site reinforcement should be kept straight until needed, and should be stored clear of the ground to prevent contamination with soil.

Figure 7.47 Steel reinforcement cage being assembled for the cut-off wall in a drift

- Concrete mixes

The proportions of the constituents may be varied to obtain the required properties. As a rule, the larger the amount of water added to the mix, the more fluid and easy to cast in place it will be, but the lower will be the final strength and durability. The ratio of water to cement should therefore be as low as possible for the necessary workability of the concrete. Given this requirement, mixes with a larger proportion of cement to aggregates will tend to be stronger and more durable. A test for workability is given below.

Three principal types of concrete are required for use in rural roads.

Structural concrete

Grades 20 and 25

This is concrete intended for use in reinforced structures and load-bearing applications such as bridge decks and culvert rings. The grade indicates the target crushing strength (N/mm^2) at 28 days after casting. Maximum aggregate size is normally 20 mm to allow the concrete to pass round the reinforcement and give good compaction. Typical mix proportions for Grades 20 and 25 are given in the table below.

Mass concrete

This is appropriate for gravity structures where reinforcing steel is not used. A large sized stone (up to 50mm) is permitted. For the construction of drifts and causeways, larger pieces of stone (referred to as plums) may be set in place before the concrete is poured, to act as fill. These should be of the same quality as the aggregate and have a maximum size not greater than three-quarters of the depth of the concrete. The cement content for mass concrete is higher than for lean concrete but lower than for structural concrete. Mix proportions are 1:3:6.

Lean concrete

This is a meagre mix with a low cement content. It is used for blinding the foundation excavations for structures, where it acts as a clean working surface prior to placing structural concrete. It is also used as a porous backing to structures and behind weep holes to allow water to migrate through without washing soil particles through the structure. The mix proportions are 1:4:8 by volume.

The nominal mixes shown in the table below should achieve the strengths indicated, with good quality graded aggregates, and water content just sufficient to give adequate workability. It is crucial that the mix does not contain excess water as this will result in increased porosity in the final concrete, and considerably reduced strength and durability.

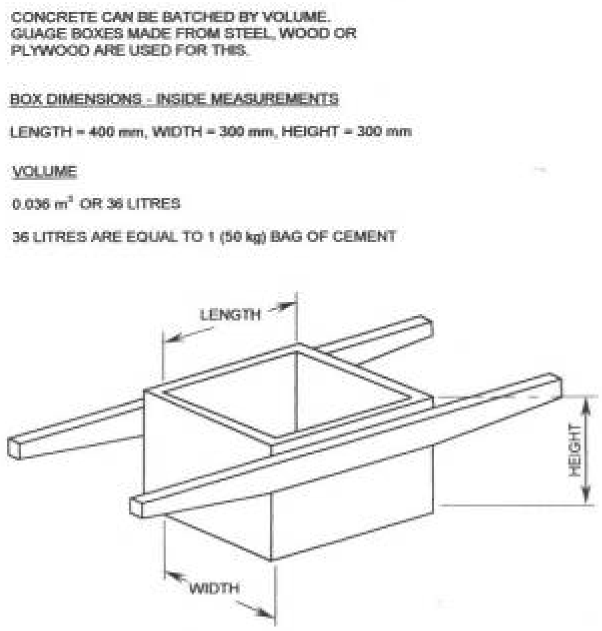
Concrete grades, strengths and batching strengths

Class of concrete	Expected 28 day strength N/mm^2	Mix cement/ fine agg./ coarse agg.	Material required for $1m^3$ finished concrete		
			50kg Cement bags (kg)	Fine (m^3)	Coarse (m^3)
Lean	-	1:4:8	3.3 (166)	0.47	0.94
Mass	15	1:3:6	4.3 (215)	0.46	0.92
Grade 20	20	1:2:4	6.0 (300)	0.42	0.84
Grade 25	25	1:1.5:3	7.3 (365)	0.38	0.76

Making concrete

- Mixing

Concrete may be mixed by hand or by a mechanical mixer. When batching by volume is to be used, the mix proportions should be measured using a gauge box with dimensions as shown below. This gauge box has a volume of 0.036 m3, equivalent to one 50kg bag of cement.



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

BOX DIMENSIONS - INSIDE MEASUREMENTS

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

VOLUME

0.036 m^3 OR 36 LITRES

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

Class of Concrete	Batch with 1 bag cement		
	Number of boxes of aggregates		Yield per batch (m^3)
	Fine	Coarse	
Lean	4	4	0.30
Mass	3	6	0.24
Grade 20	2	4	0.16
Grade 25	1.5	3	0.14

Aggregates and cement are thoroughly mixed together in the dry state, and then the water added gradually while mixing until a uniform mass of the right workability is achieved. Concrete should be mixed on a clean, hard, level and impermeable platform.

- Transporting

Concrete should be mixed as near as possible to the site of placement and may be transported using trucks, wheelbarrows, or even using headpans for sites with difficult access. The wet mix should be transported within 30 minutes to allow placing before setting commences.

- Placing

The formwork or shuttering for the concrete must be clean, smooth faced, and secure from movement or leakage when the concrete is poured. Formwork is normally constructed from timber and plywood, especially where shapes are complex. Where the same shape is repeated (e.g. for culvert barrels or headwalls) then steel formwork can be economical and efficient to use). The dimensions and widths of the space to be filled must be carefully checked. Formwork construction should be planned to enable later removal. Formwork must be strong and well secured so that it does not6 move or distort under the pressures exerted by the wet concrete or the vibration operation. It must be complete without gaps for the wet concrete to escape through. Any reinforcement must be well secured and positioned away from the formwork with set mortar or plastic spacers to ensure that the correct cover is achieved.

The wet concrete should be placed in layers and rammed or vibrated immediately to form a dense well graded mass with no air pockets. The layers should be built up and compacted into each other without allowing joints of set concrete to form (except at predetermined construction joints). The concrete should be placed in layers of thickness less than 300mm when hand ramming. This may be increased to 600mm when a vibrating poker is used. Care must be taken not to disturb the formwork or any reinforcement during placing and compaction. Over-vibration must be avoided as it can lead to segregation of the concrete paste from the aggregates.

The top of the placed concrete should be finished smooth with a mason's trowel or float. However, any day work joints e.g. in a wall lift, should be left rough to ensure a good bond for the next layer of concrete. Concrete should not be mixed or placed in ambient temperatures of less than 3 degrees centigrade or above 38 degrees centigrade.

- Curing

Concrete hardens as a result of hydration of the cement with water. Fresh concrete contains more than enough water to hydrate the cement completely but if the concrete is not protected against drying out, the water content, especially near the surface, will be insufficient for complete hydration. This causes cracking. Direct sunlight will speed up evaporation so temporary shading should be provided where needed. Curing should start as soon as the concrete begins to harden (3-4 hours after placing). Suitable methods include: sprinkling or flooding; covering with empty cement bags, hessian bags or other fabric, sand, sawdust (50mm thick), grass or leaves, all of which should be kept wet. For faces cast against formwork, the formwork may be loosened after one day and left in place, dampening from time to time. All concrete should be cured for at least 7 days. During this time it should be protected from frost if necessary.

Detailed local specifications for concreting procedures should be followed, as these can take account of local raw materials, site practices and climate. Protection of the workforce from injury is a vital element of good concreting practice.

Recommendations for good quality concrete

Placing concrete
- Forms and the shutters should be cleaned before placing the concrete
- Concrete should be placed in layers of 300mm depth
- Concrete should not be placed in heaps, as this causes separation of the stones from sand and cement
- Concrete should not be dropped from a height of more than 1.5m, as this also causes separation of the stone from the sand and cement
- Reinforcement bars are to be placed inside the shuttering before placing the concrete

Compacting concrete
- Compacting is undertaken by tamping with an iron or wooden rod. It is important to remove all the air in the concrete as entrained air reduces the strength of the concrete.

Curing concrete
- Curing means keeping the outside of the concrete moist (wet) during the setting (hardening) of the concrete by:
    - Wetting the concrete surface frequently
    - Covering the surface with wet material (cloth, paper bags, sand etc)
- Hardening of concrete requires at least seven days. Curing prevents cracks in the surface layer of the concrete.
- As cement is normally one of the most expensive items in the construction process, it should not be wasted.

Too much cement = costly   Too little cement = low strength

Properties of concrete

- Workability of fresh concrete

In its freshly mixed state concrete needs sufficient workability to enable it to be placed into the formwork and compacted. The workability needed depends on the shape of the formwork to be filled, the amount of reinforcement in it, and sometimes on the method of transportation. Workability is measured on site by the slump test, which is described below. The table below indicates the maximum workability suitable for different situations.

Maximum slump values for particular uses

Concrete use	Maximum slump
Lean concrete	100mm
Reinforced foundations	80mm
Other reinforced areas	50mm

- Strength and stiffness

The strength of a concrete develops slowly as the cement hydration reaction continues. After 28 days, the concrete will have attained most of its final strength, and this is the age at which the strength is specified for use in design. Concrete mixes are designed to achieve a given 28 day strength in compression, as measured by crushing tests on cubes or cylinders. Typical structural concretes have strengths in the range 25 to 40N/mm^2. For high quality control concrete crushing test samples are made regularly on site, and sent to a testing laboratory for testing at 28 days.

Tensile strength and stiffness also develop as the compressive strength develops. The tensile strength of concrete is normally about one-tenth of its compressive strength. A quality control test which could be used to assess the strength based on the tensile strength is suggested in field testing below.

- Moisture movement

Wet cured concrete exposed to air will shrink over time. It will also expand and contract subsequently as a result of changes in ambient humidity or exposure to rain or moisture. The extent of shrinkage depends on the properties of the concrete and ambient conditions, but typically about 0.8 to 1.0mm per m of drying shrinkage can be expected (in all dimensions) with subsequent variations of about one-third of these values. This can cause unsightly cracking in concrete structures unless joints are provided at intervals to allow it to occur. Additional (creep) moisture movements occur as a result of the load. Creep continues over a long period of time (some months). Both creep and shrinkage can be restrained (though not prevented) by the presence of reinforcement.

- Durability

The durability of concrete depends on its resistance to the major causes of deterioration: corrosion of the reinforcement, frost attack, sulphate attack, chemical attack, and deterioration of the aggregate-cement bond. There are four principal agents of deterioration shown in the table below. Protection of the concrete from these agencies of deterioration can be achieved by:

1. Good compaction - permeability of concrete is increased if compaction is poor or cracking occurs as a result of poor curing.
2. Adequate cover to reinforcement - minimum cover is specified according to the environmental conditions; greater for external surfaces, and surfaces which are to be tooled etc.
3. Use of low permeability concrete - by using well-compacted concrete with low water cement ratio, which reduces the ability of water to move through the concrete.

<table>
<tr><th colspan="2">Agents of concrete deterioration</th></tr>
<tr><td>Corrosion (rusting) of the reinforcement
Corrosion is caused by an electro-chemical reaction occurring in the presence of water and air. It occurs when water gains access to the reinforcement either through inadequate concrete cover to the reinforcement, or because of poorly mixed or poorly compacted concrete, or as a result of cracking.</td><td>Frost attack
Frost attack is caused by expansion of water in the cement paste pores resulting in reduction of the strength of the cement paste - concrete is particularly vulnerable at early ages (up to 3 days) when its strength has not developed.</td></tr>
<tr><td>Sulphate attack
Sulphates in soil, sea water and some aggregates will react with the hydrated cement resulting in expansion and damage of the concrete.</td><td>Alkali-silica reaction
So-called "concrete cancer" is a deterioration of the concrete as a result of a reaction between alkaline fluids and reactive minerals in certain types of aggregates.</td></tr>
</table>

4. Providing a minimum cement content - to create a sufficiently alkaline environment to inhibit reinforcement corrosion, a minimum quantity of cement is needed. Nominal mixes provide an adequate amount.
5. Minimise the risk of alkali silica reaction - by limiting the alkali content of the concrete or by using non-reactive aggregates.

- Thermal movements

The coefficient of thermal expansion of concrete is about 10 to 14 x 10^{-6} mm/mm, i.e. about 3mm per m for a 30°C temperature rise, about the same as for structural steels (12 x 10^{-6}). Thus, for long concrete structures such as multi-span bridges, expansion joints are needed to allow for seasonal temperature changes.

Field testing

- Presence of silt and clay in sand and coarse aggregates: visual test

Rub a sample of the sand between damp hands, and note the discolouration caused. Clean materials will leave the hands only slightly stained. If the hands remain dirty after the sand has been thrown away, it indicated the presence of too much silt and clay.

Presence of silt and clay in sand and coarse aggregates: bottle test. Half fill a clear bottle or tumbler with aggregates; add water until it almost reaches the top, shake vigorously and then allow the aggregates to settle. After about 30 minutes there should be no fine material deposited on top of the aggregates and the water should be clear.

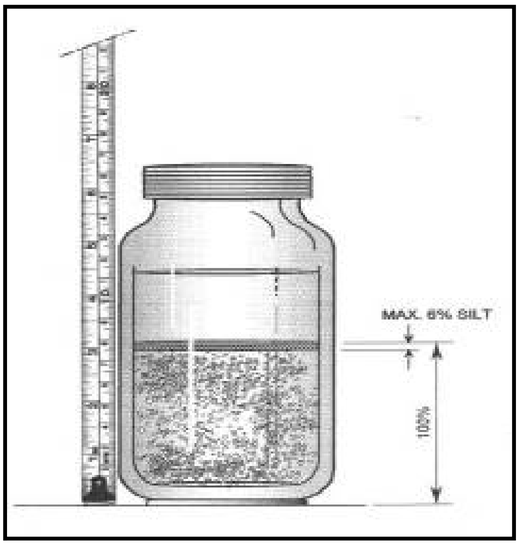


Figure 7.48 Field fines test

Salt may be added to the water (one teaspoon per 0.5 litre) to speed the settlement. If the height of the silt layer is more than 6%, the sand should be washed.

- Quality of reinforcement

Reinforcement to be used should be supplied to an agreed national standard. Before use it should be checked to ensure that all bars are straight and free from loose scale, loose rust, oil, grease and dirt.

- Quality of cement

Cement to be used should be supplied to an agreed standard. To check that it has not deteriorated in storage, it should be tested by hand for hardened lumps. A small proportion of lumpy cement may be removed by sieving.

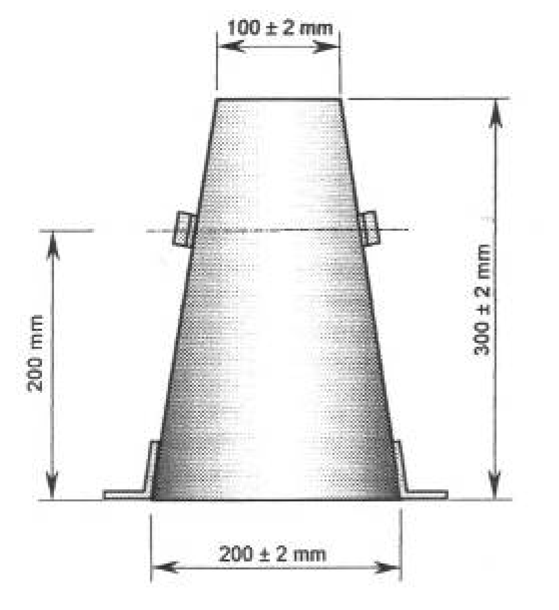
- Test for workability of fresh concrete: the slump test

The slump test is the standard way of making sure that concrete does not vary in consistency due to variations in the water - cement ratio. To make the test you will need the standard cone-shaped mould, and a steel rod described in the box below.

Mould shall be made of a metal not readily attacked by cement paste and not thinner than 1.5mm (e.g. galvanised steel). The interior of the mould shall be smooth and free from projections such as protruding rivets and shall be free from dents.

The mould shall be in the form of a hollow part of a cone having the following internal dimensions:
diameter of base: 200 ± 2mm
diameter of top: 100 ±2mm
height 300 ± 2mm.

Tamping rod: Made out of straight steel bar of circular cross section, 16mm diameter, 600mm long with both ends hemispherical.



The procedure for the test is as follows. The cone has to be clean and dry inside and is put on a smooth, hard surface. The cone is filled one-quarter full. Holding it in place with the feet, rod the concrete thoroughly 25 times. Then add more concrete to about half-way and rod it another 25 times, taking care to take the rod just through into the first layer. Next add the third layer filling the cone three-quarters full, and rod again 25 times, going through into the layer below. Finally fill the cone up, rod 25 times again, going well down into the third layer and smooth off the top. The top is smoothed off level with the cone.

Wipe the metal plate it stands on clean and dry and wipe round the base of the cone. Then, carefully and keeping it quite straight, lift the cone off and put it down beside the concrete. The concrete will collapse to some extent - very dry concrete hardly at all, very wet concrete completely. Test it by measuring how far it has collapsed.

To measure the slump, rest the rod across the top of the empty cone, so that it reaches over the concrete. With a rule measure down from the underside of the rod to the top of the concrete always measuring from the highest point on the concrete.

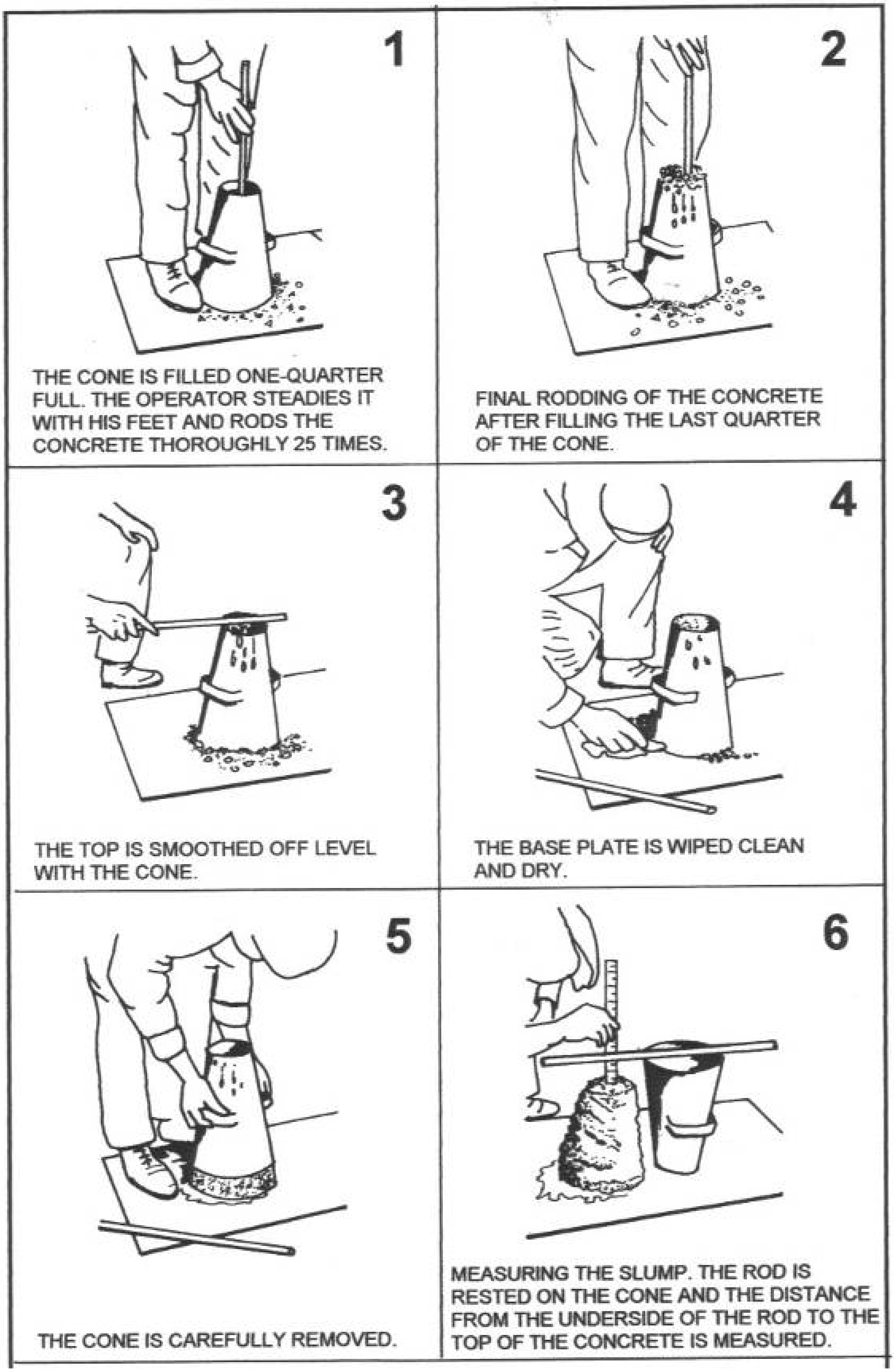


Figure 7.49 Slump test

- Concrete strength: cube tests

Test cubes may be made on the site to check whether the concrete used on a job has the required strength. The cubes are used to find the crushing strength of the concrete. It is essential that the cubes are made with great care. They are generally sent away to a laboratory for testing. This test is only recommended for structural concrete with a design strength of 20 N/mm^2 or above. Cast cubes should be cured as the constructed concrete by immersion in a tank of clean water for the initial period after casting and tested 28 days after casting. In some cases additional cubes are cast and crushed after 7 days to indicate whether the concrete is on track to achieve the required specification strength.

- Strength: impact test

For a rough strength assessment for concrete of mass concrete grade, make a set of 10 briquettes from plain concrete of dimensions 100 x 200 x 50 mm. Place each brick in turn with its largest face downwards, resting on timber battens 150 mm apart. Drop a mason's 2 kg hammer from a height of exactly 0.5 m so that it strikes the upper face midway between the battens. The briquette should not break. If more than 1 in a sample of 10 bricks break in this test, the concrete is not of adequate strength and should not be used.

Uses of concrete

Reinforced concrete is used for bridge decks, piers and abutments, as well as for box culverts and culvert rings; and plain concrete may be used for drifts and causeways, and for the foundations of masonry and timber walls, piers and abutments.

Figure 7.50 Concrete culvert rings

Figure 7.51 Concrete drift in construction

Figure 7.52 Reinforced concrete slab

Figure 7.53
Flow spreader structure at the outlet of a mitre drain on a steep fragile slope. Bio-engineering planting should be established downhill of such structures.

Figure 7.54
A simple reinforced concrete walled box culvert ready to receive pre-cast top slab units (timber or reinforced concrete).

(Chapters 8, 9 and 10 continue in Volume 2)

References

The references below may be used to supplement the information contained in this manual. In order to assist readers in the selection of relevant additional information the following information has been provided with each reference;

- list of the topics covered
- a brief review of the issues discussed in each reference
- contact details of selected publishers

Many of the documents and further information on specific topics may be accessed on the global Transport Knowledge Partnership website: www.gtkp.com

Berger L, Greenstein J, Arrieta J, 1987, *Guidelines for the Design of Low Cost Water Crossings,* TRR 1106, Transportation Research Board, Washington
(Finance, Bridges, Design, Materials) pp10
This paper reviews the different designs and materials used for the construction of bridges on low volume roads in Central America. The article indicates that the standards used on these roads need only be suitable for vehicles up to 10 tonnes, resulting in major cost savings when compared with full specifications. The use of gravelled fords, split deck concrete bridges and timber bridges are discussed. The paper outlines a design for timber bridge decks.

Brandon T, 1989, *River Engineering – Part 2, Structures and Coastal Defence Works,* Institute of Water and Environmental Management, London
(Design, Hydraulics, Maintenance) pp332
This book is the second of two volumes and covers the design, construction and maintenance of water structures. It is primarily concerned with the design of river control structures such as locks, weirs and sluices, but also includes limited discussion on river protection, culverts and bridges. There are two useful chapters on maintenance issues and construction planning and management.

Clark J, Hellin J, 1996, *Bio-Engineering for Effective Road Maintenance in the Caribbean,* Natural Resources Institute, Chatham, UK
(Environmental, Materials, Erosion Protection, Slope Stability) pp122
This book discusses the use of vegetation for the control of erosion and stabilising slopes, indicating the functions different types of vegetation can perform. Six simple techniques are described, along with the vegetation species that may be used, which are useful in the road sector for drainage control. The book also contains a large section which gives background details of eleven species which are suitable for bio-engineering. These species are normally found in the Caribbean, however the description of the species and specification of different planting material should allow practitioners in other areas to make use of the information.

Dzung Bach The, Petts Robert, 2009, *Report on Rice Husk Fired Clay Brick Road Paving, Vietnam*, global Transport Knowledge Partnership
This report documents the experiences in Vietnam of the established practice of burning high quality clay bricks for building and road works use. The flexibility of the process suggests that other agricultural wastes could be used to produce high quality clay bricks for structures and other road works uses.

Farraday R, Charlton F, 1983, *Hydraulic Factors in Bridge Design,* Hydraulics Research, Wallingford
(Bridges, Design, Hydraulics, Erosion Protection) pp102

This book explains in fairly simple terms the different hydraulic issues which need to be addressed when designing bridges over rivers. It describes the data which needs to be collected and a step by step design process which must be undertaken to ensure that bridges will be able to withstand the loads exerted by the water and changing flow patterns due to scour of the river bed. Each chapter is extensively referenced.

Flavell D. (ed), 1994, *Waterway Design,* Austroads, Sydney
(Bridges, Culverts, Design, Hydraulics) pp138
This book provides guidance on the selection of design floods required for the various aspects of the design of waterway structures and the hydraulic design of bridges, culverts and floodways. It also provides information for the design of works required to protect these structures from the effects of scour.

Gupta D P, 1997, *Manual on Route Location, Design, Construction and Maintenance of Rural Roads,* Special Publication 20, Indian Roads Congress, New Delhi
(Design) pp108
This book primarily covers the design and construction of roads, however it has two chapters covering drainage and cross drainage structures. Other sections of the book highlight design issues which are affected by highway structures. This book would be a useful reference if structures were to be designed on a new road.

Heyman J, 1980, *The Estimation of the Strength of Masonry Arches,* Proc. Institution of Civil Engineers Part 2 Dec 1980
(Design) pp921-937
This paper discusses the development of the simplified method for estimating the strength of masonry arches by the military load classification. It discusses the mathematical proof of the assumptions made and explains that the strength of an arch is closely related to its span and crown thickness. The paper suggests that nomographs could be used to predict strength with correction factors used to account for span/rise ratio, mortar condition and quality of material used.

Hindson J, 1983, *Earth Roads: Their Construction and Maintenance,* IT Publications, London
(Culverts, Design, Drifts, Erosion Protection, Site Construction) pp124
This book covers the design and construction of earth roads for traffic up to about 50 vehicles per day. It concentrates on the control of water through drainage control measures. The first half of the book deals with the theory of road design which includes splashes, drifts and culverts. The second half of the book deals with the techniques of construction offering different solutions for different topological conditions. The second half of the book also includes a section on maintenance.

ILO, 1991, *Stone Masonry,* (Training Element and Technical Guide for SPWP Workers Booklet 2), UNDP/ILO, Geneva
(Materials, Site Construction) pp84
This booklet covers the design, construction and maintenance of small masonry structures which include culverts and small headwalls. It may be used as a technical manual for site personnel or as the basis for a training course for site supervisors in the use of masonry for construction.

ILO, 1986, *Gabions,* (Training Element and Technical Guide for SPWP Workers Booklet 3), UNDP/ILO, Geneva
(Materials, Site Construction) pp84
This booklet is similar to its predecessor covering stone masonry. It does not specifically deal with highway structures but highlights the uses of gabions and how they should be constructed.

Jayanetti, L. 1990, *Timber Pole Construction,* IT Publications, UK

(Materials) pp64
Although not focused on road structures this book provides information to designers of timber pole bridges.

Jones T, Parry J, 1993, *Design of Irish Bridges, Fords and Causeways in Developing Countries,* Highways and Transportation (Jan 1993), Institution of Highways and Transportation, London
(Drifts) pp28-33
This article explains the differences between the different types of low level water crossing. It discusses site selection and the materials which may be used for different crossings. The article also describes with a series of photographs and diagrams the key design points of the different structures.

Kadam S.P, 1993, *Vented Paved Dips for Rural Roads,* Indian Highways
(Design, Hydraulics, Drifts) pp14
This paper discusses the use of vented fords on rural roads to allow for monsoon rains. It concentrates on the issues of scour downstream of the structure but also discusses the hydraulics of a vented ford when it is being overtopped. The optimum dimensions for a structure are provided which include a standard construction drawing.

Khanna, P.N. , 1996, *Indian Civil Engineer's Practical Handbook*, 15th Edition, Engineer's Publications, New Delhi.
(Design, Site Construction)
This book provides a wide range of practical information for engineers involved in the design, planning and construction of civil engineering projects. The handbook contains a chapter specifically covering the engineering aspects of roads and road structures, in addition to chapters covering surveying, setting out, material properties and basic design principles.

Lal G, 1995, *Guidelines for the Design of Small Bridges and Culverts,* Special Publication 13, Indian Roads Congress, New Delhi
(Bridges, Culverts, Design, Hydraulics, Drifts, Erosion Protection) pp176
This book covers the complete design of small bridges and culverts from the collection of the initial design data to the preparation of construction drawings. It concentrates on the mathematics of the estimation of maximum water flows and scour around structural supports. However, other empirical results and solutions are also described throughout the book to simplify the design process where applicable.

Morris, J, 1995, *Earth Roads,* Avebury
(Bridges, Culverts, Drifts, Materials, Maintenance, Erosion Protection, Site Construction) pp304
This book is a practical guide for managers and engineers of agricultural estates to provide guidelines and advice on how roads can meet the needs of their commercial operation. It concentrates on earth and other unsealed roads in developing countries, but has extensive sections covering bridges and culverts. The majority of the solutions discussed make use of timber which is likely to be available as a by-product from the agricultural operations.

PIARC, 1994, *International Road Maintenance Handbook,* Transport Research Laboratory (for the World Road Association (PIARC)), UK
Vol. 1 Maintenance of Roadside Areas and Drainage,
Vol. 2 Maintenance of Unpaved Roads,
Vol. 3 Maintenance of Paved Roads,
Vol. 4 Maintenance of Structures and Traffic Control Devices (Maintenance)
These four handbooks are aimed at the supervisors of road maintenance contracts. They explain the causes and the measures required to prevent road deterioration. Each

maintenance task is addressed in turn with simple text and illustrations to show the labour and tools required to carry out the task.

Shadmon, A, 1989, *Stone; An Introduction*, IT Publications, London
(Materials), pp184
This book provides a good introduction to the extraction and use of both field and cut stone. It describes the different types of stone and outlines tests that can be carried out to determine the tensile and compressive strength of stone samples.

Spence, R, and Cook D, 1983, *Building Materials in Developing Countries*, John Wiley and Sons.
(Materials) 356pp
This book provides practical information about various building materials commonly available in developing countries. The majority of the information is focused on housing construction. However, a significant proportion of the information available will be useful to designers of road structures.

Stern, P. et al, 1983, *Field Engineering*, IT Publications, London
(Bridges, Culverts, Design, Maintenance, Site Construction) pp272
This book is aimed at individuals working on engineering projects in rural areas. It has a detailed section dealing with site survey and setting out techniques. In addition to sections on roads, simple river crossings and bridges, it also covers water supply, sanitation and small dams.

Stulz, R and Mukerji, K, 1993, *Appropriate Building Materials*, SKAT, St Gallen, Switzerland.
(Materials) 456pp
This book provides technical data and practical information about various building materials for low cost construction. The majority of the information is focused on non road structures. However, a significant proportion of the information available will be useful to designers of road structures.

Thagesen B (ed), 1996, *Highway and Traffic Engineering in Developing Countries*, E & FN Spon, London
(Culverts, Design, Maintenance, Site Construction) pp485
This textbook covers the planning, design, construction, maintenance and management of roads in tropical developing countries. It contains a section on drainage design which covers hydrology and hydraulic design and another section which discusses maintenance strategies and management.

TRL, 1988, *Bridge Inspectors Handbook Vol. 1 & 2,* (ORN7), Transport Research Laboratory, Crowthorne, UK
(Bridges, Culverts, Maintenance) pp40 & pp250
The object of these two volumes is to allow a district engineer to establish and operate an effective bridge and culvert record system. The guide explains the principles of record keeping and contains a series of proforma record sheets. The pocket size handbook (Vol. 2) deals with the actual inspection, highlighting, through the use of photographs and drawings, the items which should be checked and recorded.

TRL, 1992, *A Design Manual for Small Bridges,* (ORN9), Transport Research Laboratory, Crowthorne, UK
(Bridges, Culverts, Design, Hydraulics, Drifts, Materials, Maintenance, Erosion Protection, Site Construction) pp223
This manual prepared by TRL offers a comprehensive set of guidelines to highways engineers for the design of small bridges and culverts. It covers the whole process from the planning stage to the final preparation of detailed specifications and drawings. It is intended for practising engineers who may not be highway specialists. The designs

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

TRL, 1997, *Principles of Low Cost Road Engineering in Mountainous Areas* (ORN16), Transport Research Laboroatory, Crowthorne, UK
(Culverts, Environmental, Erosion Protection, Slope Stability) pp150
This manual describes and explains techniques for designing, constructing and maintaining roads in mountainous areas. It contains sections on drainage and retaining walls as well as methods to control erosion and maintain slope stability.

Tufnell R, 1995, *Dry Stone Causeways,* Appropriate Technology Vol. 22 No. 1, IT Publications, London
(Drifts, Materials) pp3
This article explains in simple practical terms, with sketches, how to build a masonry causeway or vented ford.

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

Selected publishers' addresses:

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

Global Transport Knowledge Partnership (gTKP), Chemin de Blandonnet 2, 1214 Vernier, Genève, Switzerland, www.gtkp.com

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

International Labour Organisation (ILO):
4 route des Morillons, Geneva, CH 1211, Switzerland, www.ilo.org/public/english/

Indian Roads Congress (IRC):
Sector 6, (Near RBI Quarters), R K Puram, New Delhi- 110022, India, www.irc.org.in

Institute of Agricultural Engineers:
The Bullock Building, University Way, Cranfield, Bedford, MK43 0GH, UK, www.iagre.org

Institution of Civil Engineers (ICE):
1 Great George St, Westminster, London, SW1A 3AA, UK, www.ice.org.uk

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

Natural Resources Institute (NRI):
University of Greenwich at Medway, Central Avenue, Chatham Maritime, Kent, ME4 4TB United Kingdom, www.nri.org

Transportation Research Board (TRB):
The National Academies, 500 Fifth Street, NW, Washington, DC 2000, USA, www.trb.org

Transport Research Laboratory (TRL):
Crowthorne House, Nine Mile Ride, Wokingham, Berkshire, RG40 3GA, United Kingdom, www.trl.co.uk