CHAPTER 3

TOOLS AND EQUIPMENT

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3.1 Importance of Tools and Equipment

Proper tools and equipment are essential for the effective operation of any civil works site. Equipping the construction site with the correct tools and equipment plays an essential role in achieving timely and good quality results. For every construction activity there is an optimal combination of tools, equipment and labour. Depending on the nature and content of the works, the technical staff needs to know which tools to use and how to effectively combine them with manual labour.

Once on site, equipment requires trained operators and supervisory staff who are proficient in its operation and maintenance.

Faulty equipment is a common reason for delays on construction sites. A major responsibility of the project management is to ensure that tools and equipment are maintained in a good condition and are readily available when required for the various work activities.

When applying labour-based work methods, the use of hand tools supported with selected items of light equipment can produce results comparable with those achieved when using only heavy equipment. For every construction activity there is an optimum combination of equipment and labour. In order to utilize the equipment and labour in the most effective way, the use of equipment needs to be carefully coordinated with the output of the work gangs.

For certain construction activities, particularly hauling of materials and compaction, high labour productivity and good quality of work may be difficult to achieve using only manual

labour and hand tools. In such cases, using light construction equipment can increase the efficiency of work.

Site supervisors need to know how to use the tools and how to operate the equipment in order to secure good work progress and the expected high quality results. It is also important that staff know the full potential, as well as the limitation, of the use of manual and equipment-based works methods.

Finally, tools and equipment need regular maintenance, requiring good workshop facilities, a reliable supply of spare parts and qualified mechanical staff.

3.2 Quality of Tools

Hand tools are the main instruments used by the workers to carry out the activities involved in building a road using labour-based work methods. It is therefore important that project staff know how to select and maintain the tools since they have a significant influence on the work outputs.

Hand tools are used much more intensively on labour-based construction work than in agriculture. Many tools commonly used for agriculture work are not strong enough for use on construction sites and will quickly break if used intensively. It is therefore essential that the tools used on a civil works project are properly designed to stand the heavy wear and tear of a construction site.

Providing workers with strong, durable tools helps to increase productivity. If the workers discover that their tools are not very strong, they will tend to use them more gently, and less productively so as to avoid breaking them. Broken tools on site cause interruptions to work, and reduces productivity, while the tools are repaired or replaced.

Ergonomically efficient hand tools are comfortable to use, well adapted to particular construction tasks and suit the physical characteristics of the workers. Ergonomically efficient tools and correct working techniques allow the workers to use the major body muscles effectively and make the most productive use of their energy. The proper use of suitable tools will also prevent injuries on site.

3.3 Characteristics of Suitable Hand Tools

Hand tools should be of good quality and designed so that they are efficient in use. The tools should be strong enough to withstand intensive use at the work site, and resistant to wear so that they have a long working life. For most tools this means that the metal head should be made from carbon steel, heat-treated to give the correct strength and wear characteristics. For the main excavation and striking tools such as hoes, pickaxes, mattocks and sledgehammers, the tool heads should be forged in a single piece. Cast or fabricated and welded tool heads do not provide sufficient quality.

The timber handle should be made from a tough, preferably light, seasoned hardwood. The wood should be straight grained, with the grain lying along the length of the handle. The handles should not have any splits or knots, since these lead to handles breaking when used.

Tool handles should be smoothly finished and carefully shaped with a raised grip at the end to prevent the workers hands sliding off. Long handled tools are generally preferred since they allow the workers to stand in an upright position, which is less tiring than having to bend or crouch down. The handle should be a tight, secure fit in the head of the tool.

Good quality tools are inevitably more expensive than poor quality tools. However, it is wrong simply to purchase the cheapest tools available. This will only result in problems on site, and the need for the frequent replacement of broken tools. Efficient hand tools allow workers to achieve the maximum productivity from their efforts. Efficient tool heads should:

- have the correct shape in order to work efficiently,
- be of suitable weight for the strength of the workers, and

Common Tools Used for Labour-based Road Works		
Clearing	bush clearing	bush knife, brush hook, saws and axes
	grass cutting	grass cutter, rake
	tree and stump removal	axe, saws, rope, pick axe, hoe and crowbar
	grubbing	hoe, shovel, spade, bucket, basket, wheelbarrow
	boulder removal	Crowbar, sledge hammer, chisel and wedges
Earthworks	excavation	hoe, mattock, pick axe, crowbar, spade
	hauling	basket, stretcher, wheelbarrow, shovel
	spreading	rake, spreader, hoe
	compaction	hand rammer
Gravelling	excavation	mattock, pick axe, crowbar, spade
	spreading	hoe, spreader, shovel, stretcher, basket
Setting Out		line level, ranging rod, profile board, measuring tapes, axe, hammer, chisel, string and pegs

- be properly sharpened along the working edges.

It is possible to obtain good quality, efficient tools manufactured locally. Before extensive purchases of tools are made, their cost, strength, durability and design should be carefully evaluated.

The optimal choice of tools also varies from place to place, depending on the site conditions, type of works carried out, type of soils and local skills and practice. Site supervisory staff needs to be trained in the proper use and maintenance of tools. Since the labour is temporarily employed, they are not provided with any formal training in the use of hand tools. However, the supervisors are responsible for instructing the workers and ensuring that tools are properly used and maintained.

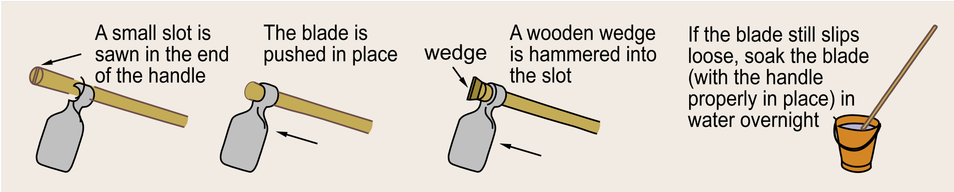
The workers are often very conservative concerning the use of hand tools. Local traditions may create some reluctance among workers to use new tools. When new tools are introduced, it is important to provide adequate instruction in their proper use. It is also worthwhile to assess the effectiveness of the new tools as compared to the local traditional work methods.

Hoes

The hoe, in addition to being very useful in agriculture, is also a commonly used tool when using labour-based work methods for rural road works. It can be used for excavating soft soils and is often used in combination with stretchers or head baskets. Hoes are also effective when excavating drains, cutting back slopes and removing topsoil. The most efficient way of using the hoe is when the workers can stand slightly below the level being excavated.

As it is commonly found and used in farming communities, its use is well known among the workers and would normally not need any instruction in how it is effectively used.

Hoes are produced in a variety of shapes.



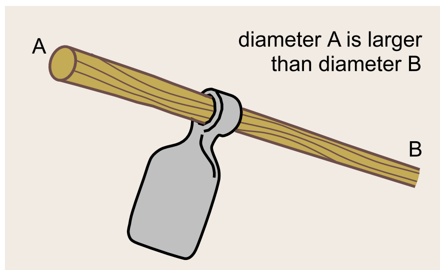
They consist of a blade and a handle. Both pieces are commonly found in local markets. Local workshops and blacksmiths can provide repairs and maintenance for this tool.

The blade of the common hoe has a straight cutting edge. Narrow blades are useful for excavating hard or stony soils, and are used as an alternative to the pickaxe. Wider blades are effective for spreading and levelling works. The standard digging hoe has a blade width of 20 to 25 centimetres and a length of around 25 cm.

The eye can be round or oval, although for excavation works the oval eye is recommended. Replacing the handle is easier with the round eye. The disadvantage is that blades with a round eye tend to turn while working in hard soils.

The hoe should have a handle of suitable length so that the worker can work standing upright. Handles used for hoes vary in length. The most common dimensions are from 70cm to 1.3m.

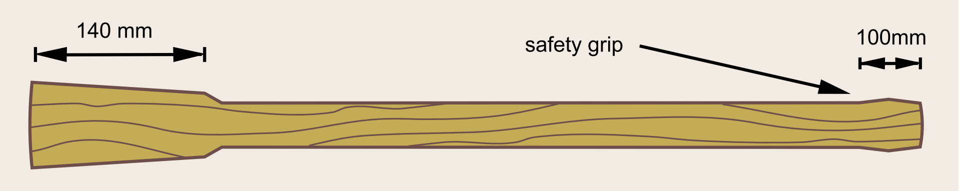
Good handles are manufactured from seasoned hardwood. Rather than producing spare handles on site, it is recommended to purchase quality handles made by skilled artisans using high-grade materials.



Pickaxes and Mattocks

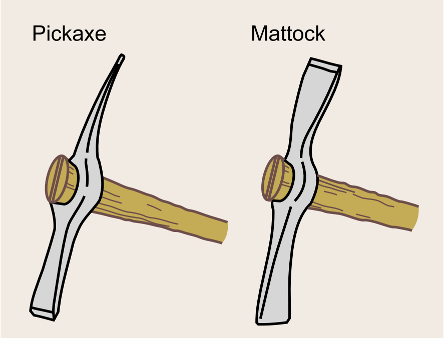
Pickaxes and mattocks are tools used for excavating hard or stony soils, difficult to penetrate with hoes. Pickaxes are effective when breaking hard or stony ground. When excavating side drains in hard soils, the pickaxe is particularly effective. Mattocks are useful for shaping slopes in hard soils, and also to cut roots. Make sure whoever is operating a pickaxe has sufficient space to operate by ensuring that all other workers are at a safe distance.

Both these tools always come with an oval shaped eye so that the handle



cannot turn in the eye. Both the pickaxe and the mattock are rather heavy. The pickaxe usually weighs between 2.7 and 3.6kg and the mattock between 1.8 and 2.7kg. For this reason, it is important that they are fitted with properly shaped, good quality handles. Loose handles on these tools are a potential hazard to the workers.

As they are double edge striking tools, they are fitted with a straight handle with an elliptical rather than circular cross-section. The handle should preferably be provided with a raised safety grip, which prevents it from slipping out of the worker's hands.



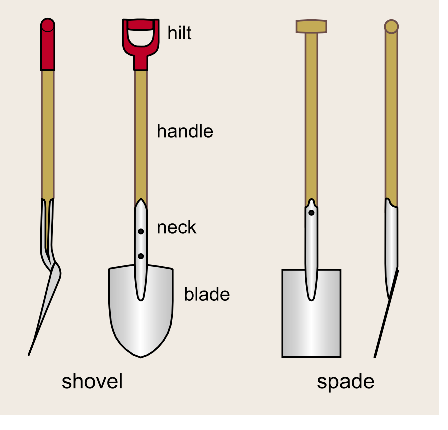
Shovels and Spades

Shovels are used for scooping up material and loading it on to a trailer, truck or wheelbarrow, or throwing it directly to where the material is needed. The shovel has a rounded or pointed blade making it suitable for both digging and loading purposes.

A spade has a stronger square shaped blade and is primarily intended for digging in denser soils and is less suitable for throwing or loading activities. The spade is essentially a heavy-duty forged tool. In hard soils, the spade is more efficient because it can be pushed into the ground without bending the blade. Placing a foot on the top of the blade and pressing it down increases the pushing force. This however requires that the worker is provided with boots or shoes with hard soles.

Handles for these tools are produced in a variety of lengths, each designed for specific work activities. Shorter handles, ranging from 0.6 to 1.2 metres in length, are commonly used on spades and shovels primarily used for excavation works. Longer handles (1.2 - 1.4 metres) are more useful when the tools are used for loading and throwing. The advantage of a long-handled shovel is particularly clear when loading into a high-sided truck or throwing material out of a deep trench. Long handled shovels are also used for cleaning culvert pipes.

Shovels and spades should not have sharp joints, which may damage the hands of the workers. Loose hilts or handles need to be repaired immediately, so they do not cause harm to the workers. Loose or faulty handles also compromise the performance of the workforce.



Spades and shovels provide an alternative to hoes. The optimal choice depends on the prevailing soil and working conditions and the choice of haulage methods. The advantage of using shovels is mainly related to their effectiveness when loading of throwing materials. A good example in this respect is when excavating side drains. Workers equipped with shovels can then throw the excavated materials from the drain directly onto the road surface, which is then used to form the camber.

Crowbars

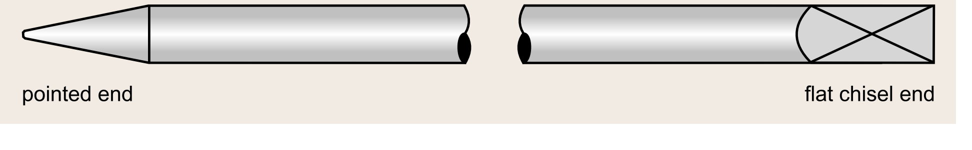
The crowbar, like the pickaxe, is mostly used for penetrating or breaking up stony or hard soils. It is also used for moving boulders or heavy items, by using it as a lever. The crowbar needs to be made from high-grade steel so that it does not bend easily.

Crowbars are usually manufactured either as round or octagonal section rods. For infrastructure work, a diameter of 30mm provides a good and firm grip. The length should be from 1.5 to 1.8 metres. With these dimensions, the crowbar gains sufficient weight to penetrate hard and compact soils and allows the worker to stand up right when operating it. The bar can be fitted with a pointed or a chisel end – or both. The pointed end is used to penetrate and break loose material, while the chisel end is more useful for leverage.

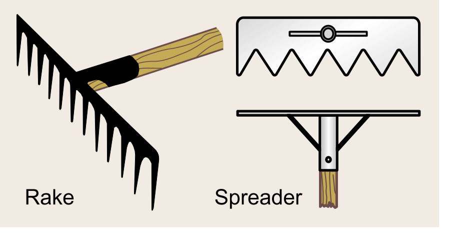
Rakes and Spreaders

Rakes are used in road works for raking out vegetation from loose soil. Commercially produced rakes have 10 to 16 teeth, each about 75 - 100mm long, with an overall length about 400 - 450mm.

Spreaders are useful when forming the camber and when spreading gravel. Spreaders are made of sheet metal (2 - 3mm thick) with ridges on one side, which are used to level the road surface according to set levels and gradients.



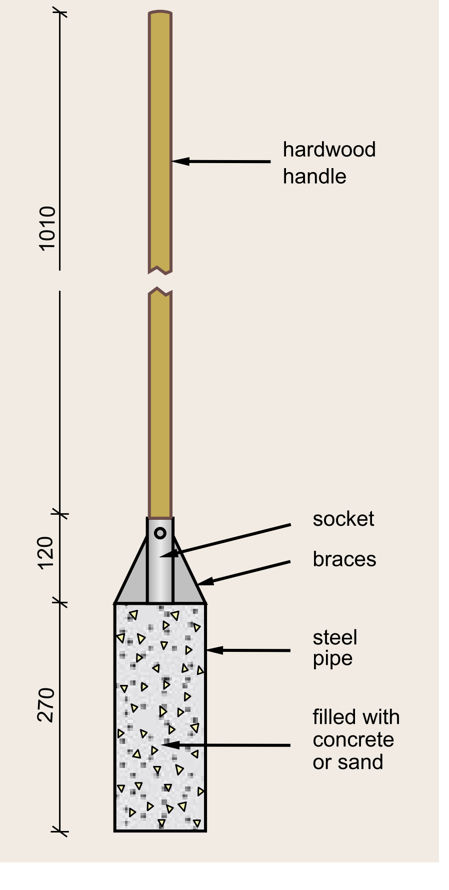
The handles for both tools should be long enough to allow the worker to operate comfortably in a standing position.



Hand Rammers

Hand rammers are used for compacting soil and gravel. It consists of a weight with a long handle.

The effectiveness of a hand rammer depends on its weight and the area that hits the ground. Ideally, the weight should be as heavy as possible and the area as small as possible (without the rammer penetrating the soil). The weight can be made of various materials such as steel, concrete or solid wood. Rammers made from concrete or wood can be manufactured locally.

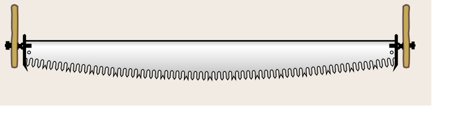


A rammer that can be handled effectively by a worker should therefore have a weight of some 6 – 8kg. The diameter at the bottom end should be between 13 to 15cm. The handle needs to be long enough to allow the workers to lift the rammer without bending their back.

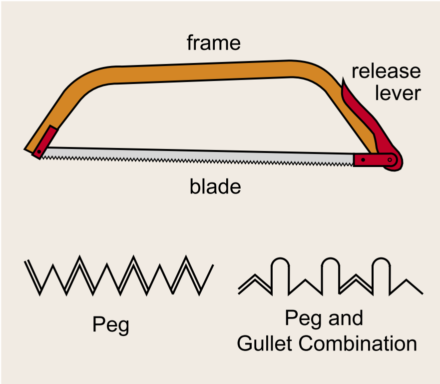
Using hand rammers on large surfaces is expensive and difficult to apply evenly. Hand rammers are most useful in small and confined areas such as around culverts, when filling potholes and other places where it is impractical or difficult to access with rollers.

Saws

Saws are manufactured in a number of varieties. Cutting trees and bushes requires a crosscut saw, i.e. a saw with a blade designed to cut wood at a right angle to the direction of the grain. The size of the trees will obviously determine the size of the saw. Larger saws require two operators while smaller versions can be used single-handedly.



Steel framed bow saws are commonly used for cutting small trees and branches. A narrow blade is held in



tension by the frame. A quick release lever applies tension to the blade. The lever, combined with an oval sectioned frame, provides a comfortable handgrip. Blades are 20-25mm wide and are produced in a standard length. The frame is made of mild steel and the blade is made of high carbon alloy steel. They can be supplied with various shaped teeth to cut different types of wood.

The advantage of the bow saw is that it is a relatively large saw, which can still be used by a single person. For larger jobs this saw can also be operated by two persons.

Peg teeth blades are used for cutting hardwood. The peg and gullet combination teeth blade is used for cutting soft wood. On most saws, the teeth are designed to cut when the saw is being pushed through the wood.

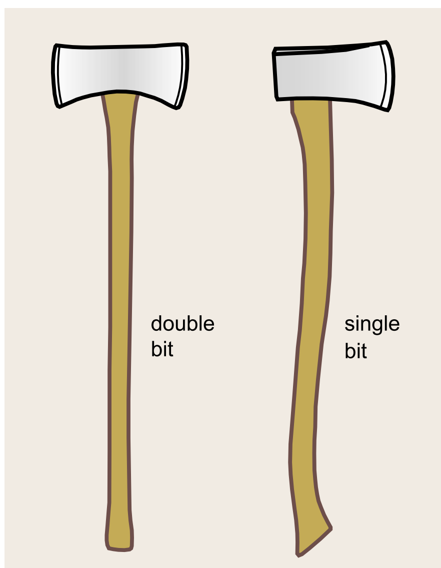
Recent years have seen a proliferation of light and inexpensive chainsaws. The current versions are fitted with air cleaners, chain brakes, etc. This modern piece of equipment has created a completely new approach to tree felling and stump removal. When in use, a skilled person should operate it, and the operator should use all the available protective gear.

Axes

Axes are essential tools when felling trees. They are also useful during bush clearing for cutting tree branches and stripping branches of felled trees. The head of the axe can be shaped with a single or a double cutting edge. Although the single bit is safer to use, the double bit with its two blades can be used for a longer duration before it needs to be sharpened.

The eye of the axe is oval and is fixed to the handle with a wedge. Handles are normally 70 to 90cm long made from seasoned hardwood shaped in an ergonomically sound fashion. Smaller axes, also referred to as hatchets, are often used for cutting small trees and branches instead of a bush knife. They are also used for producing setting out pegs.

The axe needs to be properly sharpened. A sharp axe will cut faster and is safer

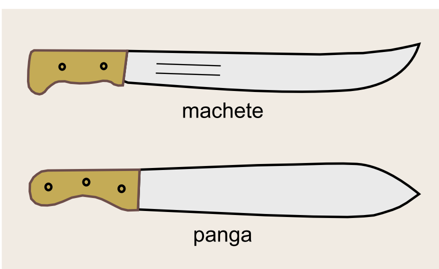


to use. When operating an axe, it is important to position yourself so that you are chopping in a direction away from your body. If the axe misses its target, the axe will not hit you. Also make sure that any other workers are at a safe distance. When transporting or storing an axe, the blade should be sheathed to protect it from being damaged as well as causing injury.

Bush Knifes

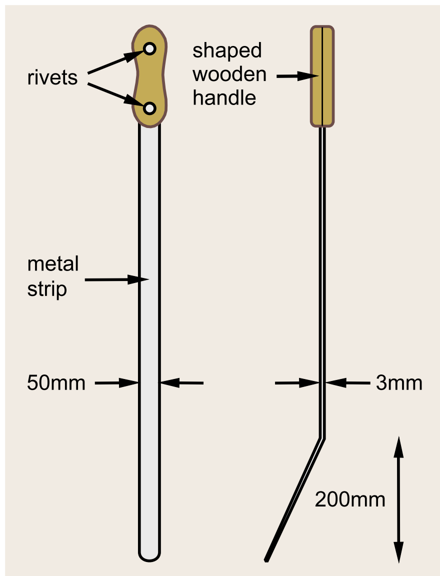
Bush knifes are used for clearing bush and dense grass along the road alignment. The shape and design of bush knifes vary from one country to another. To avoid supply problems, it is advisable to follow local practices and purchase the version commonly applied where the road is located, whether it is a panga, machete, cutlass or bush knife. As they are often used in agricultural work, local shops should have a good supply.

The bush knife consists of a steel blade with a round wooden handle. Pangas, machetes and cutlasses are made from a sharpened steel plate fitted with a wooden grip.

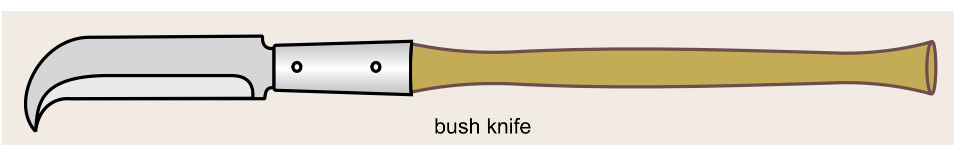


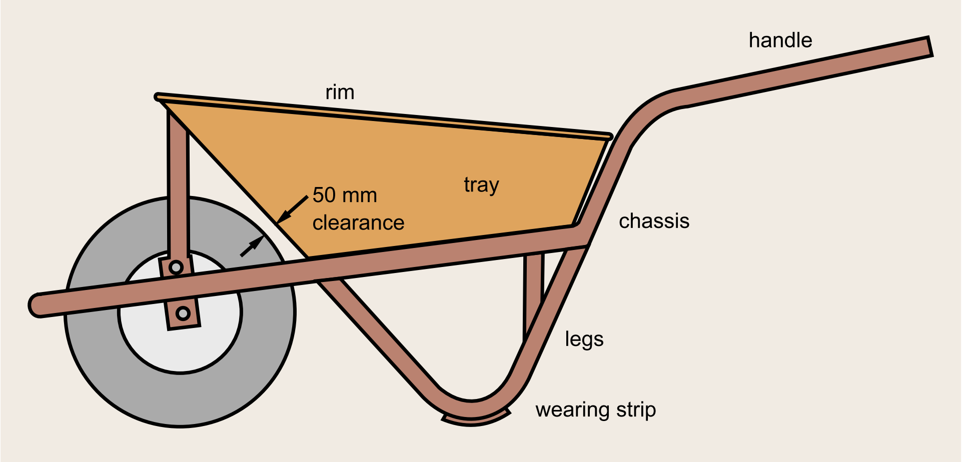
Grass Cutters

The grass cutter, or slasher, is a simple and inexpensive tool used for trimming light grass. It consists of a metal strip 50mm wide and 3mm thick. The bottom 20cm is cranked and sharpened on both sides. The slasher therefore cuts when swinging it in both directions, and can be held alternately with both hands. The top end of the blade is fitted with a wooden handle, riveted on to the metal strip.



Routine maintenance workers commonly use a grass cutter for clearing the vegetation on road shoulders and in side drains. It is also used when initially clearing the road reserve. It is an efficient tool for light and moderately dense grass or bush. Thicker and denser grass or bush would normally require a stronger cutting tool such as a bush knife.





Wheelbarrows

The wheelbarrow is a useful piece of transport equipment for short distances (up to 200 metres). Wheelbarrows are used for earth and concrete works, transporting construction materials such as soil, gravel, sand, aggregate, stone, concrete, etc. Wheelbarrows are made in many different types and qualities. A good wheelbarrow should be able to take a big load (struck capacity approximately 60 to 70 litres) and be easy to balance and tip.

A wheelbarrow consists of a body or tray that rests on a chassis with attached handles, a wheel and legs. The chassis is normally made from tubular steel, although wooden wheelbarrows are still common in some countries. The frame needs to be strong enough to carry the loads without bending or twisting. Check the handles for cuts or burrs that might catch unwary fingers.

The strongest and most comfortable wheelbarrows have a pneumatic rubber wheel and a tray made of 1.6mm to 2mm steel sheets. The tray should be reinforced around the rim and properly attached to the chassis with bolts, nuts and washers.

Wheelbarrows are used to transport materials over short distances. If the ground is soft or very stony, planks should be laid to provide a smooth and firm running surface. The use of planks is also good for helping wheelbarrows up steep sections. When using several wheelbarrows, the best performance is achieved when the hauling route is organised as one-way runs. Assigning a separate route for hauling the material to the dumping location and returning empty by a different route avoids any "traffic congestion".

Wheelbarrows should give years of service, provided they are used and stored properly. They should be stored upright or turned over in a dry environment, and never left holding damp items, or where they will catch rainwater. If they have been used for hauling concrete, they need to be thoroughly cleaned at the end of the day to avoid any concrete sticking permanently to the wheelbarrow. The tray is usually made of sheet steel and is susceptible to rust. Paint the outside when required, and oil the inside of the tray once a month.

The body is attached to the frame either by spot-welds or nuts and bolts. Check that welds are intact, or nuts and bolts are tight. If a bolt is lost, it should be replaced before the wheelbarrow is used again. Riveting on sheet metal patches can repair holes in the tray, provided the tray is still in a basically sound condition. Spare parts for the wheelbarrow should be available at site.

Wheelbarrows have either solid or pneumatic tyres. Although they are more expensive and liable to puncture, pneumatic tyres are recommended, as they are easier to use in muddy conditions. The storekeeper should be supplied with a pump and patching equipment.

The wheel is usually held on by two bearings bolted to the chassis. The bolts should not be over tightened, or attempts made to free the bearings with a hammer. The bolts should be oiled regularly to ensure they do not rust up and make removal difficult.

Stretchers

Stretchers are locally made devices for carrying soil over short distances. They are often made from rice sacks or similar materials. The easiest method of producing a stretcher is by cutting openings at both ends of a rice sack and threading two wooden or bamboo poles about 2m long along the length of each side of the sack. The soil is placed on the cloth (sack material), and the device is carried like a stretcher, hence it's name.

Soil Baskets

Soil baskets are also used for carrying soil over short distances. On some sites, it is the main tool for moving soil over short distances. A typical basket can be loaded with 5 to 6 kg of soil. It can be made from local basket making materials, used tyres or manufactured in plastic.

Baskets made from organic materials are only suitable for dry soils. Although they are not as durable as the ones made from plastic, they can be manufactured from local materials and cost about half the price. Plastic and rubber tyre baskets are more durable and are not damaged when used to carry wet soils.

Stretchers and soil baskets are used as an alternative to wheelbarrows. A wheelbarrow can carry a larger load, and as compared to the stretcher, only requires one person to operate. The advantage of the stretchers and baskets is that they can be easily used in wet and soft terrain. Wheelbarrows need solid ground to run on. In soft and muddy terrain, the wheelbarrows will sink into the soils and require an improved running surface.

Standard Lists of Hand Tools

Earthworks

The number of tools described in the table below is required for carrying out earthworks activities, including bush clearing, top soil removal, soil excavation, borrowing and spreading using stretchers. Rollers are used for compaction of earthworks. When wheelbarrows are used, the appropriate amount depends on the haulage distance and the productivity in the excavation and spreading activities.

Tools for Earthworks				
Item	Unit	100 workers	200 workers	300 workers
Hoes	no	75	170	250
Shovels	no	20	35	50
Spades	no	20	35	50
Pickaxes	no	20	35	50
Crowbars	no	8	15	20
Bush knifes	no	10	20	30
Axes	no	10	20	30
Saws	no	1	2	2
Bow saws	no	2	4	5
Rope	m	20	20	20
Rakes	no	5	8	10
Hand rammers	no	5	8	10
Stretchers	no	40	90	130

Gravel Works

The hand tools described in the table below are used for the spreading of gravel and reshaping the sub-base. The equipment used for hauling material and compaction is described in Section 3.5.

Tools for Gravel Works			
Item	Unit	100 m^3 / day	300 m^3 / day
Hoes	no	20	60
Shovels	no	10	25
Spreaders	no	20	60
Pickaxes	no	5	10
Carrying baskets	no	20	60
Stretchers	no	8	20
Hand rammers	no	5	10
Axes	no	2	4

3.4 Maintenance and Repair of Hand Tools

Most of the implements required to carry out maintenance and repair of tools are inexpensive and simple to use. Depending on the number and types of tools on site, a set of tools for repair work should be made available on site.

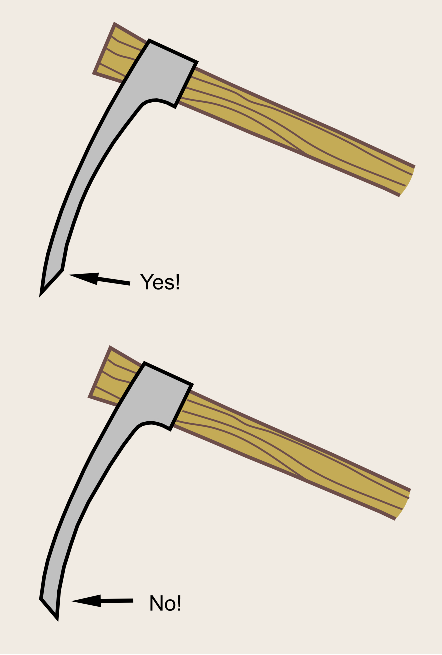
Although the hand tools on site may be of good quality, they still need regular maintenance to remain effective. When tools have been used for some time, handles eventually need to be replaced and cutting edges require sharpening. If the workers are equipped with poorly maintained hand tools, their performance will be compromised. Establishing repair facilities on site is therefore justified through the savings made by repairing tools rather than buying new ones, and through an increase in worker productivity when supplying the workforce with tools in good condition. The cost of the services of a blacksmith and a carpenter to sharpen tool cutting edges and carrying out other repairs can therefore easily be justified.

On projects with a large workforce, it is useful to employ a person specifically to maintain and repair the hand tools. Alternatively, it is always useful to check in the local villages if there are any blacksmiths or carpenters who can provide repair services.

The site camp will need a work place for repairing tools, equipped with effective sharpening instruments and a sufficient supply of spare parts.

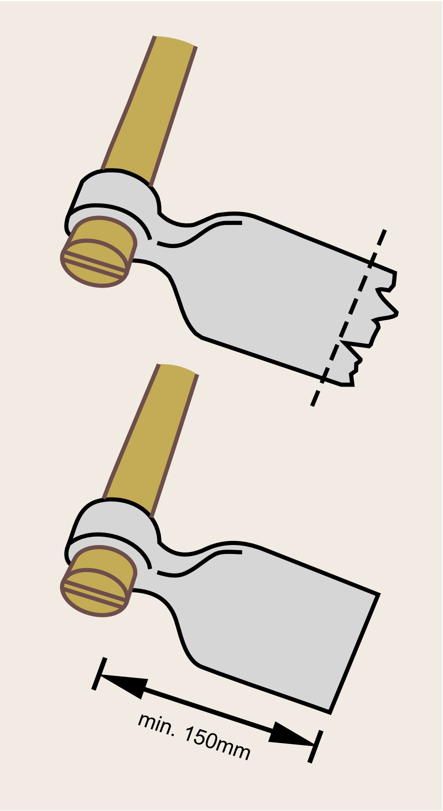
The fine cutting edges of axes, bush knifes and grass cutters are normally maintained by sharpening with whetstones.

The edges of earthworks tools, such as hoes, pickaxes, mattocks, shovels and spades should be sharpened with a grinding stone or by filing. The cutting edge of a hoe or a mattock should be sharpened on the side facing the operator of the tool.



If the blade has been chipped or pieces broken off, the hoe should not be used until it is repaired. The repair can be done by cutting or filing off the edges to re-establish a straight edge and then sharpening it.

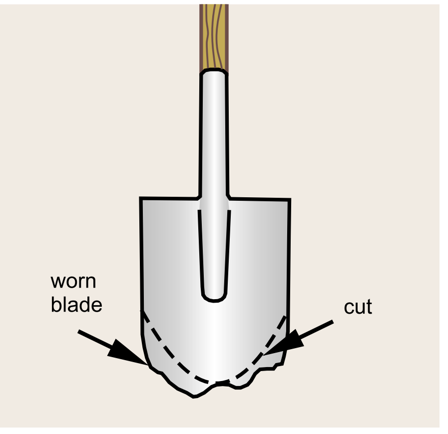
When the length of the blade is less than 150mm, the hoe is no longer efficient for digging. However, it can still be useful for other purposes, such as grubbing and levelling works.

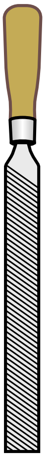


The blade of a good shovel will not bend or crack but will wear. The edge of the blade will eventually be so worn that it becomes blunt and for this reason difficult to push into the soil. To improve the worn blade it can be cut and sharpened so that the shovel can be used effectively again. This requires very strong tools and should be done in a workshop.

For saws, small triangular shaped files with a side about twice the depth of the teeth are appropriate for sharpening. Bow saws are easier to deal with as the blades can be replaced. Axe blades are best sharpened using a grindstone and files.

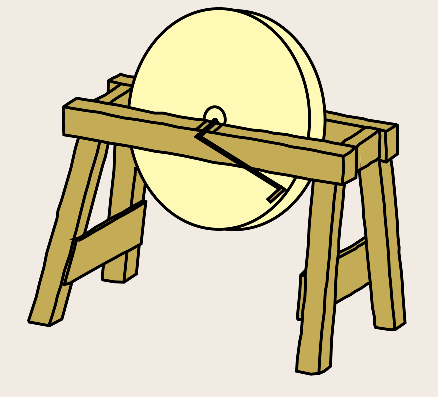
The axe is fixed to a vice, to allow for the use of both hands when using a file for sharpening. File into the edge,





toward the centre of the axe handle, as this creates the least amount of burr to remove on the other side. After reshaping the blade edge, the final sharpening is carried out using a whetstone. When applied by skilled workers, this final process puts a razor sharp edge on the blade. Finally, it is useful to coat the blade with oil or wax to protect it from rusting.

When axes and other tools used for earthworks have been severely blunted it may be necessary to grind a new cutting edge. A manual or treadle operated grinding wheel, which is continuously moistened with water, is the best tool when axes, mattocks, pickaxes, bush knifes and similar tools need major reshaping works. Avoid using electric grinders, as it will most probably draw the temper from the steel, leaving it too soft to hold an edge. A grinding wheel is slow enough to avoid removing too much and as long as it is moistened with water, maintains cool temperatures.



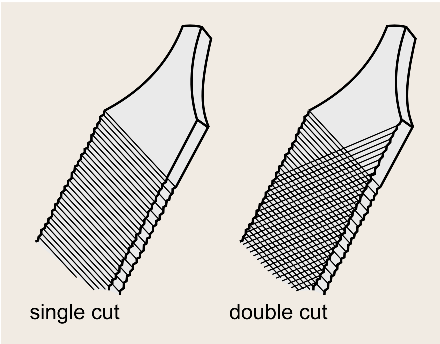
If a grinding wheel is not available, the sharpening should be carried out using files. Light sharpening can be carried out with the tool held in the hand, but removal of heavier burrs is best done with the assistance of a workbench and a vice.

A whetstone is used to provide the final sharpness to the edge. It is useful to equip bush clearing gangs with a whetstone so they can maintain the sharpness of their cutting tools while they are in the field.

Using Files

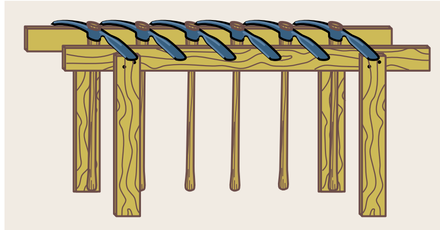
Files for sharpening tools come with a single or a double cut pattern. A single-cut file has one set of parallel teeth with an angle of 60 to 80 degrees _from the edge. Double-cut files have two series of parallel teeth set 45 degrees to each other. The double-cut file is used for restoring the shape of an edge, while the single-cut file is used for the final finishing work. Rounded blades require files with a round surface. In general, it is more effective to use large files, however, some tools, such as saws, need smaller files to fit into the grooves of the blade.

Files only sharpen on the push stroke. It should be lifted away from the surface on the return stroke. When applying a "sawing" motion with the file, it will fill with metal particles and not cut well. Files should be protected from each other and other tools when stored and transported.



Storage

Tools are issued to the workers every morning by the storekeeper, and returned in the afternoon after completion of works. The supervisors need to ensure that the workers are issued the correct type of tools according to the work activities they will be carrying out. The storekeeper is responsible for keeping full records of the tools and controlling the issue of tools to the workers. The total number of tools on site needs to be counted and reported regularly back to project management.



The size of the store depends on the quantity of tools to be stored. When the work site is very isolated, the store has to be well stocked and will therefore be larger.

Tools should be stored in a dry and secure place. They should be stacked neatly so that they can easily be counted. Stack different items and items of different sizes separately.

Employ a watchman to guard the stores when the storekeeper is off duty.

Reporting

Reporting on tools stocked on site is carried out using a standardised form. The table below shows an example of a tools inventory form.

Tools Inventory						
Description	Total Quantity		In Store		Total Quantity	
	Previous Month	Received	Good	Broken	Lost	Brought Forward
Hoe with handle	80	20	85	13	2	98
Shovel with handle	50	0	30	3	0	33
Stretcher	50	10	40	15	5	55
Axe	5	0	5	0	0	5
Bush knife	15	0	15	0	0	15
Measuring tape	3	0	3	0	0	3
Line level	7	3	9	1	0	10
Pick axe	10	10	20	0	0	20

3.5 Construction Equipment

In most rural road construction works, there is always a demand for a certain amount of construction equipment. Well-maintained equipment is important as it determines the productivity and quality of the works carried out. Malfunctioning or poorly performing equipment is the most common reason for slow progress of a road works project. Equipment is also expensive and can easily be destroyed if it is not operated correctly and supervised by competent staff.

Construction equipment also plays an important role on road project relying on labour-based works technology. By definition, labour-based methods consist of an appropriate combination of manual labour complemented with a limited use of equipment. Equipment used on labour-based road works projects is mainly for operations such as haulage of materials and water, compaction and rock breaking. In addition, there will be vehicles and possibly motorcycles used for work supervision.

A major concern when choosing the appropriate type of equipment for road construction works is:

- its availability in the region or vicinity to the work site,
- how to deliver it to the construction site,
- how easy is it to operate and how easily it can be reversed,
- its cost and reliability, and
- the availability of spare parts and repair facilities.

Hauling Equipment

Depending on the distance, haulage of material can be done in many ways, such as carrying it in baskets, using stretchers, wheelbarrows, two-wheel tractors or dump trucks. For rural roads carrying low traffic volumes, the main use of haulage equipment is for the delivery of gravel materials. Although rural road construction involves a substantial amount of earthworks, these soils are normally obtained in or very close to the road alignment and the work can normally be carried out using manual labour. The table below provides some indicative figures on the haulage distances for which it is feasible to use various means of transport.

Distance	Transport
10 – 150m	Wheelbarrows, stretchers and head baskets
150 – 500m 150 – 2000m 500 – 8000m	Animal carts Hand tractors Tractor-trailers
more than 1000m	Trucks

Dump Trucks

Dump trucks are the most common type of equipment used for hauling large quantities of materials from quarries and borrow pits to the work sites. They are available in various sizes, with a payload ranging from 3 to 15 tonnes. The main limiting factor when using dump trucks is the axle load limitations on the public road network. In most cases the trucks need to travel on public roads in order to deliver the materials from the quarries to the work sites. In order to adhere to the axle load regulations on the road network, the load in each truck needs to be limited.

Dump trucks are well suited for hauling long distances. They are readily available in the construction industry and provide a cost-effective means of transporting materials such as stone aggregate, gravel and other surfacing materials.

When using dump trucks for gravel surfacing, it is important to plan the operation to ensure that the trucks are properly utilized. This implies that the work activities in the quarry are correctly organised so that loading of the trucks can take place immediately when they arrive to collect materials.

Dump trucks are fitted with a tipping mechanism to speed up unloading. Trucks without this facility can also be used for transporting materials – the so-called flatbed truck. When using flatbed trucks unloading requires a team of workers on site to evacuate the materials from the vehicle. Flatbed trucks are more easily loaded by manual labour because the loading height is lower than on dump trucks. They are also less expensive to purchase and require less maintenance. Their disadvantage is the increased time spent on unloading.

Flatbed trucks are commonly used for transporting construction materials and equipment to site. On larger sites, it is common practice to allocate one

flatbed truck to the project for the purpose of delivering building materials and transporting other construction equipment.

Due recognition should also be given to locally manufactured small trucks. These often provide a very cost effective means of hauling supplies and materials. A strong argument for considering their use is that such vehicles are easy to maintain locally and subsequently have very low operating costs.

Tractors

Tractors are employed in labour-based works mainly to haul various implements. The original concept and rationale behind this choice of equipment was to utilize, to the extent possible, existing equipment found in the rural areas. Tractors are commonly found in farming areas and during their idle times can be used for rural road works, pulling different types of equipment such as trailers, graders, water tanks and compaction equipment.

The strength of the tractors and their ability to pull is related to their size and weight. In addition, larger tractors can be manufactured with four-wheel drive. While the smaller size tractors perform well in flat terrain, there is a need for more powerful versions in hilly or mountainous terrain.

The main disadvantage with the tractor as compared to the use of trucks is their limited speed. A standard agricultural tractor has a maximum speed of slightly over 20 km/h. A typical dump truck comfortably runs at 40 to 60 km/h on country roads, speeds unattainable by a tractor even when unhitched. For longer hauling distances, it therefore becomes more economical to use dump trucks.

Trailers

Trailers are commonly used in several labour-based works projects. They are mainly used for hauling gravel, but are also used for camp support activities. The advantage of the trailer is that is has a relatively low loading height and is therefore popular when loading materials by manual labour.

Standard agricultural trailers are too weak to be used for the transport of large amounts of road building materials. For transport of soils or gravel, the body frame and suspension on the trailer need to be designed for the extensive use and loads involved. Most projects use single axle trailers of size $3m^3$ to $4m^3$. Experience shows that a trailer with a simple design is more reliable, i.e. without a tipping mechanism and with fixed body sides.

Two-wheel Tractors

Two-wheel tractors or power tillers are common in the rural areas in some parts of the world. Although they have limited carrying capacity, they are suitable for smaller repair works where hauling distances and the required volume of materials are limited.

Similar to the conventional tractors, the power tillers can be used for pulling different types of implements such as small compaction equipment and water tanks.

Compaction Equipment

Several types of tools and equipment can be used for compaction. These include hand rammers, rollers and plate compactors. Rollers are more efficient when compacting large surfaces. Some rollers are equipped with a vibrating mechanism, while others simply rely on their weight to compress the materials. When compaction is required in confined areas, such as in trenches and around bridge abutments, plate compactors and hand rammers are more useful.

The selection of compaction equipment is very often governed by their availability. If used in the proper

manner, most types of compaction equipment will achieve the prescribed level of compaction. It is more a matter of using the equipment in the correct way, ensuring that the soils have the optimum moisture and that sufficient compaction is exerted on the materials. Watering the loose soils can regulate the moisture content. By limiting the thickness of each layer in fills and carrying out sufficient passes, most equipment will be effective.

It is obvious that larger equipment will carry out the compaction with less effort. With the use of larger equipment it is also easier to control the quality and uniformity of the works. Nevertheless, large equipment is not always appropriate for the work at hand. Smaller equipment is easier to transport between work sites. Equally, the nature of the work may be such that only smaller equipment can gain access to the surfaces which need compaction.

Vibrating Rollers

Vibrating rollers are the most efficient piece of equipment for compaction of soils and gravels. They come in a number of sizes, ranging from small pedestrian rollers to large self-propelled machines.

The one-tonne twin-drum pedestrian vibrating roller has proved to be very effective for rural road construction. These can compact soil layers from 10 to 15cm thick. With trials on the required number of passes and optimum moisture content, it is possible to define the most effective compaction procedure for different soil types.

Small vibrating rollers are very versatile pieces of equipment, used for a number of purposes and different working conditions. Due to their limited size, they can be transported easily on the back of a pickup truck. The pedestrian roller is commonly used for both earthworks and gravel surfacing activities. It is also useful for repair and widening works.

Plate Compactors

A vibrating plate compactor is most useful in small and confined areas such as around culverts, foundations and for mending potholes. It is also commonly applied at the outer edges of fills, which cannot be reached by rollers. The effectiveness of this equipment depends on the intensity of the vibrations, thickness of the layers and the type of material on which it is used. Vibrating plate compactors are most effective on granular soils.

On steep grades, two workers are required for operating the plate compactor. The first worker operates the machine, holding on to the control handle, while the second worker holds a rope tied to the

front of the compactor thereby helping to guide and control its movement.

Deadweight Rollers

There are several types of deadweight rollers, ranging from single or double steel drums, towed or self-propelled or with a load container to hold the deadweight.

Large towed rollers have good compaction qualities but prove difficult to turn and operate in hilly or steep terrain. Towed rollers need to be attached to vehicles with sufficient power and traction performance. This is particularly important in mountainous terrain with steep road gradients. Self-propelled rollers negotiate most gradients encountered on roads, and can be operated in both directions, however they are more prone to breakdowns.

Some rollers can be ballasted with weights of one tonne or more, using water, sand or stones. When using this type of roller, the first passes can be done with a relatively light ballast in order to avoid traction problems. After the first few passes, the ballast is increased.

Old rollers with a malfunctioning vibrating mechanism are often used as a deadweight roller.

Water Bowsers

Supply of water forms an integral part of the compaction operation. Dry soils needs additional water to reach the correct moisture content at which level the soils are more effectively compacted. In most cases this involves transporting water from an appropriate source to the work site. Water tanks or bowsers are normally fitted on a flatbed truck or mounted on wheels and towed by a tractor.

In order to fill the water bowser, it needs to be equipped with a pump and the appropriate amount of hoses. A spreader is often mounted directly to the tank. If large quantities of water are required, it may be more efficient to carry out the watering of the soils manually with a hose.

Supervision Vehicles

Road works sites are often stretched out over distances of several kilometres. In order to carry out regular supervision and inspection of works, the site management needs to be equipped with appropriate means of transport. Pickup trucks are useful for transport of tools and small items, in addition to providing supervisory staff with access to site.

Motorbikes provide a reasonable alternative to cars, and are commonly used for foremen and technicians who frequently move back and forth between the site camp and the work sites.

3.6 Maintenance of Equipment

Regular mechanical maintenance of the equipment prevents breakdowns and ensures a long equipment lifetime. The project manager must ensure that (i) the operators are aware of the required maintenance and service of their equipment, (ii) that the site has access to adequate workshop facilities, and (iii) that service and repairs are carried out at the right time.

Each piece of equipment comes with an operator manual, which specifies when and where lubrication and adjustments are required. The most common components in need of daily inspection and service are shown in the checklist below:

- lubrication oil levels
- radiator water levels
- hydraulic oil levels
- hydraulic hoses and couplings
- grease nipples/tracks
- battery terminals and battery water
- connections from the alternator
- V-belts and their tension
- tire pressure
- transmission oil level
- brake and clutch fluid levels
- nuts and bolts of buckets and tracks

With each piece of equipment, there should be a basic set of tools for carrying out preventive maintenance and minor repairs. These tools should be handed to the operator. To minimise any loss, he/she is held personally responsible for any loss of these tools.

Depending on the amount of equipment on site, there is a need to plan some form of workshop facility at the site camp where mechanical works can take place. In order to operate the construction equipment in an efficient manner, it will require regular service and repair facilities on site. To secure this, appropriate procedures are required on site, which ensures that the equipment receives regular preventive mechanical maintenance.

For large construction sites the contractor often chooses to assign a mechanic on a full time basis to the site. On smaller work sites, the contractor may opt for a part time arrangement in which the mechanic oversees the equipment on several construction sites.

In either case, it is important that the construction equipment is inspected on a regular basis by competent staff. Equally, it is the responsibility of the mechanic to instruct the operators in the proper use of the equipment and routine service requirements.

Spare Parts

The equipment on site requires a ready supply of spare parts. The spare part requirements depend on the type of equipment on site and to what extent the repairs will be carried out on site or alternatively contracted out to a local workshop. If the equipment on site is standardized, consisting of a few models and brand names, the amount of spare parts can be reduced.

Some parts are replaced more often than others. Fast moving items include:

- oil and fuel filters fan belts spare tyres and tubes
- spark plugs points engine mountings lamp bulbs
- fuses V-belts spring bushes air filters
- wiper blades ball joints radiator hoses shock absorbers

In addition, the site needs general consumables for servicing the equipment, such as oils and grease, brake and hydraulic fluids, assorted nuts, bolts and washers, patching materials, insulation tape and electrical wire.

While spare parts are expensive, running out of them and therefore not being able to repair the equipment incurs larger costs to a project. The site mechanic needs to advise the camp management on the type and amount of spare parts which are necessary to store on site.

For the same reason, all spare parts need to be stored securely to avoid any theft.

Reporting and Monitoring

The performance of construction equipment needs to be carefully monitored in order to ensure that they are operating at the highest capacity. Consumption of spare parts, lubricants and fuel is monitored in detail for each piece of equipment. Equally, it is important to monitor the usage of the equipment, thus (i) providing management with information on the specific activities to which the equipment was assigned, and (ii) avoiding misuse.

Monitoring of fuel and oil consumption is also a good indicator for the mechanics in charge of servicing the equipment. Equally, the service intervals need to be noted down to ensure that they actually take place at the right time and on a regular basis. With a proper reporting system, it is also possible to calculate the operating costs for the equipment.

Date	Details of Journey/ Work Activity	km/hr start	km/hr end	Total km/hr	Fuel Issued	Signature

Monitoring of equipment basically consists of carrying a separate logbook for each piece of equipment and the vehicles. The logbook would contain two forms, one in which the work activities and fuel consumption is entered, and a second, keeping records of all repair and maintenance provided to the equipment.

The daily movements of the equipment should always be recorded and signed by the operator. Repairs and service activities are logged and signed by the mechanic or whoever carried out this work.

Service Schedules

To maintain equipment in good condition, it is imperative that it is regularly inspected and serviced. The services need to be planned carefully so that the equipment can be transported to a workshop where qualified staff and the necessary tools and spare parts are available.

Maintenance schedules are based on kilometres or the total number of hours an engine has been operating. In addition, there are daily and weekly checks which need to be carried out. An appropriate time for carrying out checks and service activities is when fuelling the equipment. Equipment suppliers provide advice on the service intervals and the recommended activities. Make sure that the manufacturers recommended service intervals are not exceeded.

Although the major service intervals are based on the amount of usage of the equipment (km, hours), it may be more effective to plan the service when it is not in use, such as after normal working hours or in the rainy season when there is not much civil works taking place. The service and repair activities should be organised so as not to disrupt site activities.

Date	Details of Repair	Spare Parts	Consumables	Service Due	Signature

CHAPTER 4

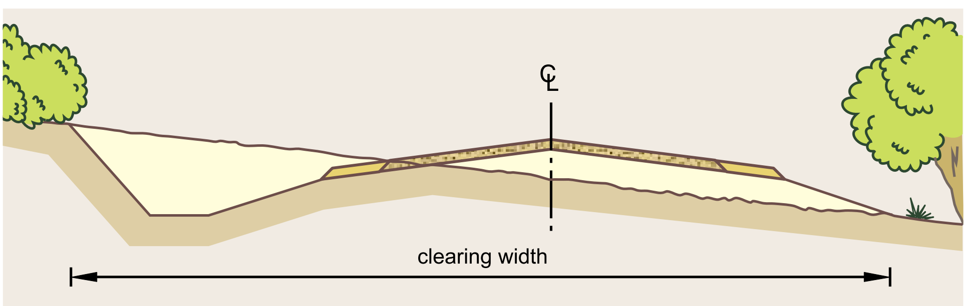
CLEARING

CLEARING

4.1 Site Clearing

Clearing is the first operation to be carried out once the detailed road alignment has been established. It consists of the removal and disposal of all bush, trees, roots, boulders as well as grass and topsoil. It consists of all preparatory activities before excavation and fill works commence for the road formation and drainage structures. Clearing is carried out covering the entire width of the road plus the space required for drainage and side slopes. This activity is also required before any borrow pits or quarries can be effectively utilised. Finally, clearing works are necessary when establishing a site camp.

When the road is set out, it is important to find an alignment that minimises the damage to the surroundings. Often, the least damage is done when the road alignment remains along the existing track or trail where the land has already been set aside for transport purposes. It may also imply that it is better to take the road around a group of trees, farmlands, a rocky section or a small hill instead of going straight through it. Still, when upgrading existing tracks



to properly engineered roads, there is often a need for additional land along the alignment in order to cater for the full width of the road and its drainage structures. Equally, there may be a demand for improving the road alignment by adjusting its curvature or for the purpose of avoiding difficult terrain. Such decisions may require access to privately owned land already in use for other economic activities. Before work activities commence, it is necessary to resolve all land use issues.

Compensation may also have to be paid for damaged crops or trees, so the clearing of cultivated land should be limited to the extent possible. If it is necessary to remove crops or trees, the owners need to be given adequate advance notice so they have the possibility to harvest the crops before commencing clearing works. All trees, crops and other assets removed belong to the original owner and should be made available to him/her without delay. It is important that the supervisor keeps a record of all crops removed in case claims for compensation arise later on. Similarly, if fences have to be removed along the road, the owner should be notified in advance, and given time to make alternative arrangements, e.g. seeking alternative grazing land.

Resolving compensation issues is the responsibility of the project management and has to be sorted out before the construction starts.

4.2 Bush Clearing

Bush clearing consists of cutting and removing bushes and shrubs within the road reserve. It is carried out as the first work activity when constructing a road, normally scheduled to take place just before the earthworks commence. If it is done too far in advance, the bush grows back and the exercise needs to be repeated. Some bush clearing may also be required during the surveying works in order to provide access and clear sightlines for the surveyors.

Applying Labour-based Work Methods

Bush clearing and grubbing are work activities easily organised applying labour-based work methods. When using manual labour, this often provides tidier results and allows for debris and materials removed to be discarded in a proper manner. The use of labour also allows for more selective bush clearing in which larger trees can be spared when located outside the road formation or where the drains are located. Equally, it is easier to separate topsoil from the underlying soils used for the sub-grade. This allows for the reuse of good topsoil and organic materials as it can be stockpiled without mixing it with other soil. The end result is that less soil is left to spoil, thus minimizing negative environmental effects of this activity.

Bush clearing is essentially carried out using bow saws, axes and bush knifes. Bush knifes are available in various shapes and designs. The final choice is very much dependant on local preferences and what models are available.

The bush should be disposed of well outside the roadway or stacked in a cleared area for burning. Removed bush and debris should be discarded at locations from where it cannot return to the road reserve and so blocking drains and cross-drainage structures.

Heavy grass turf can later be used to line side slopes in cross cut sections or on embankments, and should be separated from the soil to be used for other construction purposes. When properly placed the turf will start growing again, and form a good protection against erosion on the slopes and shoulders.

Bush clearing is also a common activity when carrying out road maintenance works. However, there are some important differences between construction and maintenance works. When clearing bush before earthworks operations, all organic materials need to be removed, while in most cases of road maintenance works, the bush clearing activity is limited to keeping the vegetation short and leaving the roots and organic materials in place. When carrying out periodic maintenance or spot improvement works, it is therefore important to limit the clearing works to where earthworks are envisaged.

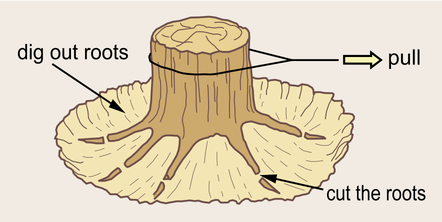
4.3 Tree and Stump Removal

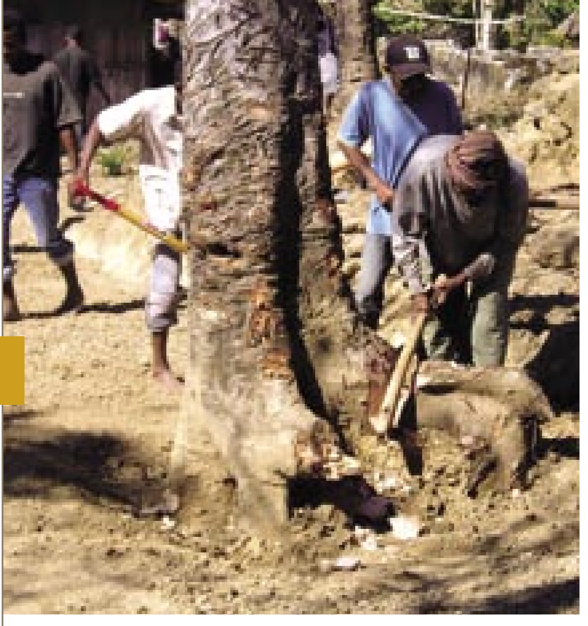
Removing large trees is an expensive operation, especially when it comes to digging out the roots. Trees are often a social amenity providing shade, fodder or firewood for the local community. If large trees stand in the way, realignment should be considered to avoid them. Trees growing near the road can have a good effect on the strength of the road because they can act as a countermeasure to soil erosion.

In hilly terrain, trees protect the exposed faces of cuts against erosion. Equally, trees can stabilize materials on the fill side. Before cutting down trees outside the roadway, it is therefore worthwhile considering letting them remain. For trees within the roadway, an assessment should be made whether it is possible to find technical solutions which still safeguard the performance of the road. For example, instead of cutting down a tree standing in the side drain, a solution may be to install a mitre drain (turn-out) in front of the tree and continue the side drains behind the tree.

Removal

Trees outside the roadway can normally be left, unless there is a danger of the tree falling when high winds are blowing. With small-sized trees within the roadway, a good way of removing both the tree and its stump is to pull down the whole tree. This is done by using a long rope attached to the top of the tree and removing the soil around the roots. Take care that the tree is secured and cannot fall until all workers are at a safe distance from it (at least twice the height of the tree). The combination of leverage and dead weight is very convenient.



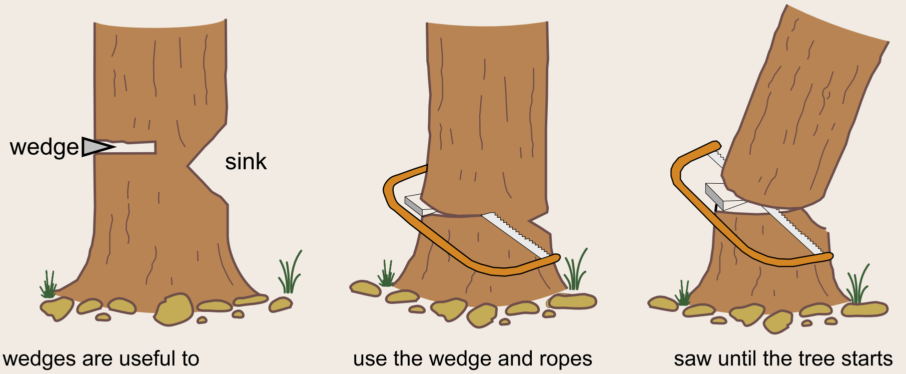


Felling trees can be dangerous and should preferably be done by experienced workers and always with proper supervision. When the felling takes place, all workers and equipment need to be evacuated to a safe distance away from the area where the tree is expected to fall. Only the workers assigned to the tree felling activity should remain. The site supervisor is responsible for keeping the rest of the

Deep roots may have to be dug out and then cut using axes, however, it is better if the tree can be pulled down with all the roots coming out. The roots left in the ground will eventually rot away and leave holes, which can undermine the strength of the road.

Larger Trees

Larger sized trees are first cut using an axe or a saw, and thereafter the roots are dug out and removed. Big roots, stumps or pieces of the tree trunks can be burned after grubbing has been done (the risk of bush fires is less when grass and vegetation have been removed).



wedges are useful to avoid jamming the saw. Cut a sink on the side where the tree should fall

use the wedge and ropes to ensure that the tree falls in the right direction

saw until the tree starts falling and then quickly move away.

workforce and any passers by or traffic at a safe distance.

Attaching ropes to the crown of the tree and pulling the tree when it is close to falling assists in ensuring that the tree falls in the correct direction. The ropes must be long enough to ensure that the workers pulling the rope are at a safe distance when the tree falls. Once the tree is felled, it is cut into smaller pieces and removed from site.

4.4 Grubbing

Grubbing consists of removing roots of grass and other light vegetation. It may also include the removal of topsoil containing considerable amounts of organic material. Roots need to be dug out to a depth that ensures that the trees or bushes do not continue growing and reappear in the road reserve.

If the topsoil consists of the same material as the soil below it, there is no reason to remove it. Topsoil should only be removed if it appears to contain organic material and small roots. On most sandy soils the surface can be left undisturbed. This may help to minimize erosion. On the other hand, if the soil underneath is to be excavated and dumped outside the road (spoiled), it is not necessary to carry out any grubbing.

Topsoil Removal

Topsoil removal is usually only needed where the topsoil is deep (10-15cm), very organic and appears to be inferior in strength than the soil below. If the topsoil layer is very thin, it has very little effect on the compaction

and resulting strength of the road. Most agricultural land and open areas are eroded, with a very thin topsoil layer, which can be mixed in with the earthworks for the road construction.

The materials removed need to be discarded at a location where it causes no future damage to the road or surrounding areas. If it is dumped on the high side of the road, it may be washed back into the drainage system of the road during heavy rains. Equally, it may cause damage to farmlands and residential areas. Topsoil can often be reused on the slopes next to the road or spread on adjacent farmlands. Similarly, organic soils can also be used at the end of the project when reinstating borrow pits and gravel quarries.

Topsoil removal is executed using task work on an area basis, determined by the thickness of the topsoil. The best tools to be used in this activity are hoes, mattocks, spades and rakes.

Anthills

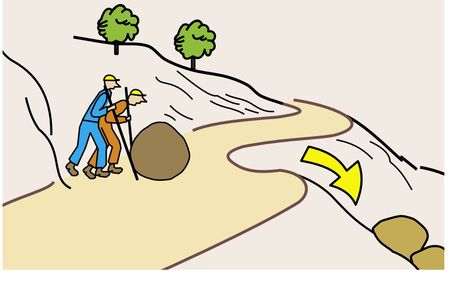
Anthills need to be removed to the full depth and treated, to avoid that they grow back out again. If the ants or termites continue their activities it may undermine the stability of the road, eventually leading to a collapse of the road formation above the voids created by the insects.

The voids resulting from digging out the ants need to be filled and compacted in layers similar to the method used for mending a pothole.

4.5 Boulder Removal

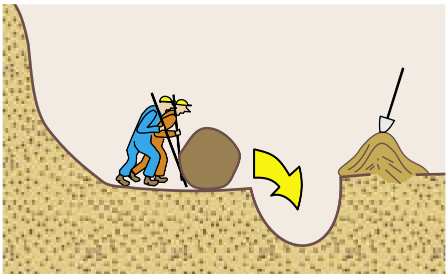
Some sections of the road may have boulder-strewn hillsides where boulder removal is an added challenge. When the alignment passes through rocky terrain with large boulders, it may involve considerable clearing work so it might be easier to re-align the road. This should always be considered before initiating any major boulder removal works.

There are several ways of getting rid of boulders. Boulders can be removed from the roadway, buried or broken into smaller pieces. The most suitable method will depend on the size, shape and position of the boulder, available tools and equipment and the skills of the workers.



The best method to deal with boulders is to move them away from the road alignment. If the volume of the boulder is less than half a cubic metre it can be dug out and moved using crowbars as levers. If it is not possible to roll them, pieces of rails can be placed under the boulder to provide a good surface to slide on. For moving bigger boulders a winch or a carjack can be useful.

Task work on a group or specific job basis is an effective way of organising the labour for this activity.



If it is too difficult to move the boulder, an alternative solution is to bury it close to where it is located. Unless the boulder is deeply embedded in the ground it is often easier to dig a hole next to the boulder. First try to estimate the size of the boulder so that the hole is made big enough. For this purpose, it is necessary to remove the soil around the entire boulder. This will also help in determining the best direction to tilt it.

If the ground is too stony to allow a big enough hole to be dug, or when the boulder is too big, the solution may be to raise the level of the road so that the stony area is covered underneath a fill. A combination of partly burying the boulders and raising the road level can also be considered.

The lifting and tilting of big boulders is simplified if carjacks are available but it can also be done using crowbars and long strong wooden poles as levers. Propping up the boulders with stones or wedges as they are lifted is usually necessary to enable the levers to shift position.

Cracking Boulders

If only the tip of a large boulder is projecting above the level of the road surface, the solution may be to remove only the protruding part. One method is to crack it by using fire. This method is, however, slow and expensive and should be used only as a last resort. A fire is built up above and around the boulder (under is best, if possible) and when the boulder has become very hot, cold water is poured on it. The heat makes the boulder expand and the cold water causes the rock to contract, which in turn causes the boulder to crack. By hammering on the parts near the cracks it should split.

If the rocks or boulders are already cracked, it is often possible to split them into smaller pieces by using chisels and a sledgehammer. Whenever rock is hammered, workers must wear eye protection.

Although not readily available, the use of explosives to crack rocks and big boulders is very efficient. The drilling can be done by hand provided the correct tools are available but the blasting requires skilled and licensed blasters.

Instead of explosives, there are also slowly expanding chemicals which can be used in the drilled holes to split the rock.

In hilly and mountainous terrain, boulder removal is a common activity in routine maintenance. As such maintenance is often organised using manual labour, the methods described above are highly relevant. With heavy construction equipment, the removal of heavy rocks are not a major challenge, however, with limited amounts of such works it may not be justifiable to mobilise heavy equipment from far away.

Planning and Reporting

Clearing works is often dealt with as a single cover-all activity, including both removal of vegetation and grubbing, however, if any of these sub-activities include excessive amounts of work, it is necessary to plan and monitor them separately. Alternatively, the works can be split into clearing of light, medium or dense bush and defining trees and boulders of a certain size as a separate activity. The project management will decide on the most appropriate arrangement during the design and survey stages. Unless there is extensive work expected under the individual activities, there is little advantage to be gained from over-detailed reporting. Usually, a cover-all clearing activity gives sufficient management control.

To simplify measurements of completed works, the clearing works are measured in square metres. Inspection is then limited to verifying that the required width has been achieved and that there is no remaining organic material in the road reserve.

CHAPTER 5

EARTHWORKS

EARTHWORKS

5.1 Definition

The most common form of earthworks consists of the preparation of a level base on which the road body is constructed. The existing terrain where the road passes is seldom flat. The ground on which the road is built therefore needs to be reshaped to form a level base on which the road pavement can be constructed.

Earthworks consist of both excavation

works as well as building up earth fills. It also includes related activities such as loading, unloading and transport of soils, as well as spreading and compaction when used to create a fill. It is the largest operation when building a road, often accounting for more than half of the construction cost.

For design and planning purposes, the terrain can be classified according to its overall characteristics, such as flat, rolling and mountainous. Flat or gently rolling terrain normally involves the least amount of earthworks. Road alignments are often selected to take advantage of gently rolling terrain with good natural drainage features. Entirely flat terrain may be prone to flooding, and in such conditions the level of the road needs to be lifted by building an embankment. To avoid excessive embankment works, it is useful to keep the alignment away from the lowest points in the terrain.

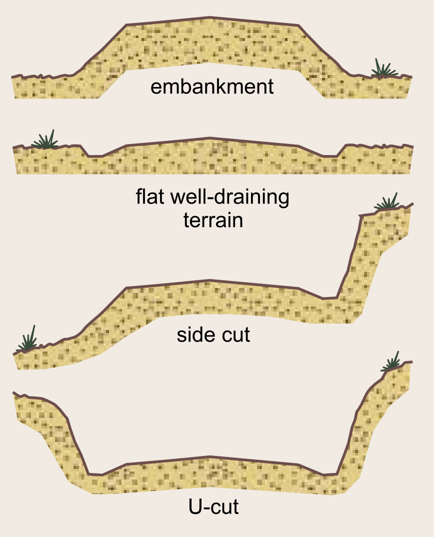
In rolling terrain the amount of earthworks may increase, however, it can usually be limited to side cuts and transferring surplus material to produce a fill on the opposite side of the road. As rural roads are designed with the purpose of providing basic access, the required design speed for such roads is relatively low. For this reason, the alignment can be designed to follow the terrain and thereby reduce the amount of earthworks.

Ideally, the alignment should be adjusted to the terrain so that most earthworks consist of excavating side cuts to build up a fill on the low side of the centre line. By carefully selecting the position of the centre line, it is possible to balance the cut and fill in rolling terrain and thus avoiding any major material transport along the road alignment.

Building roads through mountainous terrain involves more demanding earthworks. Due to the steepness of the terrain, the amount of excavation to form a level road base increases significantly. In such terrain, it is important to spend sufficient time to establish the optimal choice of alignment, which to the extent possible reduces the amount of excavation works.

For mountain roads, retaining walls are often required in order to obtain the necessary road base width. Retaining walls are also installed to stabilise steep and tall side cuts and to reduce the risk of landslides. To limit costs, the road width is usually reduced to the minimum standard width.

Earthwork is also a major activity when constructing the drainage system. Drains are essentially excavated trenches along the side of the road. The road camber or cross slope is usually created by utilising the material from the side drains. In flat areas prone to flooding, the road is raised on an embankment and there is no need for side drains. Instead the soils required for the earthworks are obtained from borrow pits close to the road.

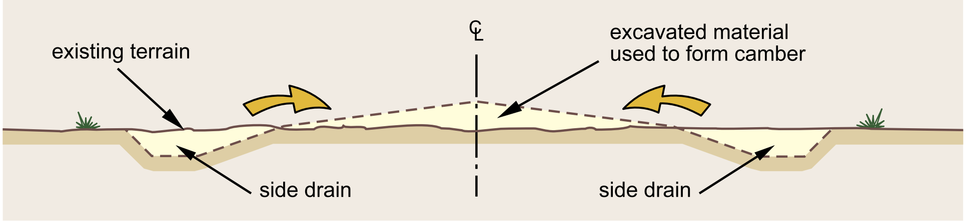


Most earthworks can be carried out using labour-based work methods. Since the quantities of works are easy to estimate, the work can be organised using incentive schemes such as task work. Appropriate tasks can be estimated once the basic soil properties, such as hardness and cohesiveness, have been determined.

5.2 Construction Principles

The earthworks operation is always carried out in a series of stages. The first step is to establish a level base wide enough to accommodate the full width of the road and its drainage system. In sloping terrain, this normally involves both excavation and fill works.

The fill is built up of well-compacted layers, thereby creating a stable foundation for the road. With a level base, the next step is to install the side drains and provide the side cut with a gentle back slope. Using materials excavated from the drains, the road surface is provided with a camber or cross slope. By following this sequence of work activities, it is easier to organise works and also ensure



that works are carried out to the right dimensions and quality.

The easiest situation is when the road is built on land that is level, or nearly level between the side drains – in other words with very little cross slope.

The required work is then simply to dig the side drains and use the excavated material to build the camber. The side drains should be designed large enough so that the excavated materials available from the drains are slightly more than the quantity required for building the camber. This allows for a surplus of material, which can cater for any low spots in the terrain, as the existing ground is never consistently level.

Cut to Level

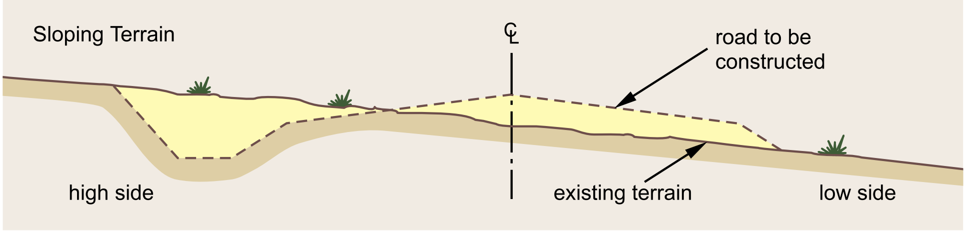
Building the road in cross-sloping terrain is more challenging. The steeper the cross slope, the more excavation is required to secure the required road width. It is therefore useful to find an alignment where steep cross slopes are avoided. Where possible, the road should be located on ridges or high points in the terrain, which have natural drainage. This will reduce the amount of earth and drainage works.

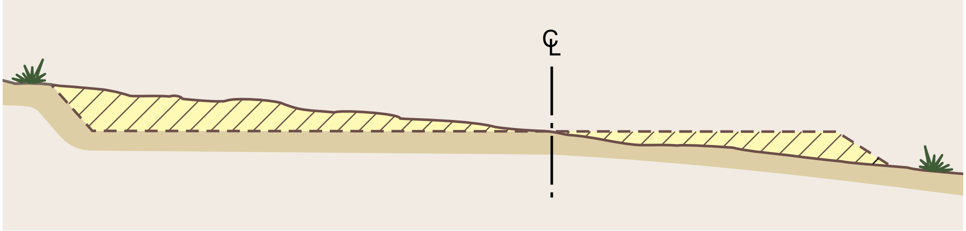
Road construction in sloping terrain has the following features:

- the drainage on the high side of the road will need to be designed to deal with the water from the slope as well as the road,
- there is normally no need for a side drain on the low side, and
- the road will require a fill on the low side of the centre line.

The earthworks are split into two separate stages. The first step consists of excavating the high side and building up the fill with an even side slope on the low side.

The second step consists of excavating the side drain on the high side and shaping the camber.


Sloping Terrain
CL
road to be constructed
high side
existing terrain
low side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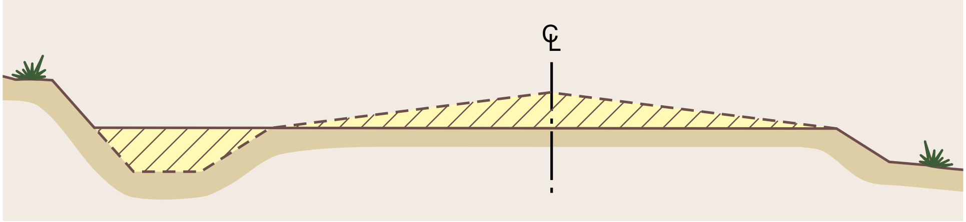
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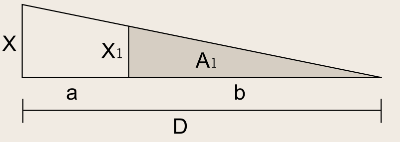
The main advantage of this method of working in stages is that the amount of excavation can be balanced with the quantity of fill needed. Secondly, the fill material can be obtained as close as possible to where it is required - eliminating the demand for longitudinal haulage.

The excavation and fill can often be balanced on each side of the centre line, however, the width of the excavation also has to provide sufficient space for the side drain. This fixes the setting out dimensions for the excavation on the high side.

The figure below shows the levelling works required on the cut side of a road with a 5.5 m wide carriageway. To secure a side drain 30 cm deep with the dimensions shown in the figure below, the total width of the side drain would be 0.3 + 0.6 + 0.6 = 1.5 m. Adding the inner side of the carriageway to the width of the drain gives a total width of 1.5 + 2.75 = 4.25 m, to be levelled on the high side of the centre line.

If the required side cut is not too deep, it is recommended to provide a back slope with a gradient of 1:1, similar to the back slope commonly applied to side drains. In hilly or mountainous



The total volume is equal to twice the volume for the first day:

$$A = 2 \cdot A_1$$

$$\frac{X \cdot D}{2} = 2 \cdot \frac{X_1 \cdot b}{2}$$

$$X \cdot D = 2 \cdot b \cdot X_1$$

Assuming that the slope of the terrain is uniform:

$$\frac{X_1}{b} = \frac{X}{D}$$

$$X_1 = \frac{X \cdot b}{D}$$

By combining the two equations, the width b for the first day of excavation is determined.

$$X \cdot D = 2\,b \cdot \frac{X \cdot b}{D}$$

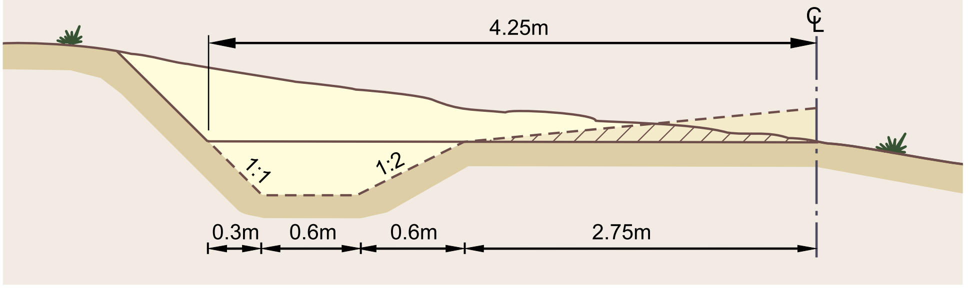
$$b^2 = \frac{D^2}{2}$$

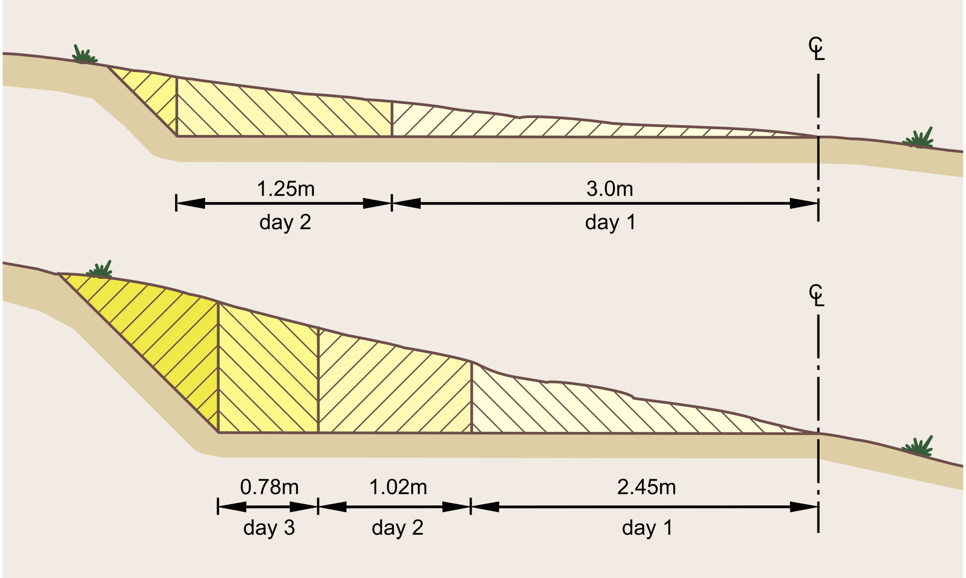
$$b = \frac{D}{\sqrt{2}}$$

If the work is split into three days, the width for the first day is:

$$b = \frac{D}{\sqrt{3}}$$

terrain, it may not be possible to obtain this gradient. Depending on the stability of the soils, the back slope may be set at a steeper grade, preferably not more than 2:1. If steeper gradients are required, it may be necessary to consider installing retaining walls.





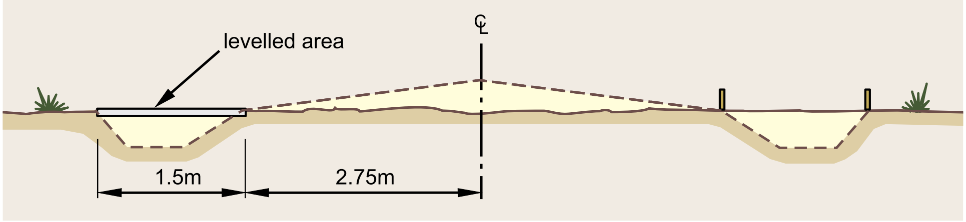
On steeper cross slopes, there may be too much excavation for a practically sized team of workers to finish in one day. The excavation is then divided into two or possibly three days of work.

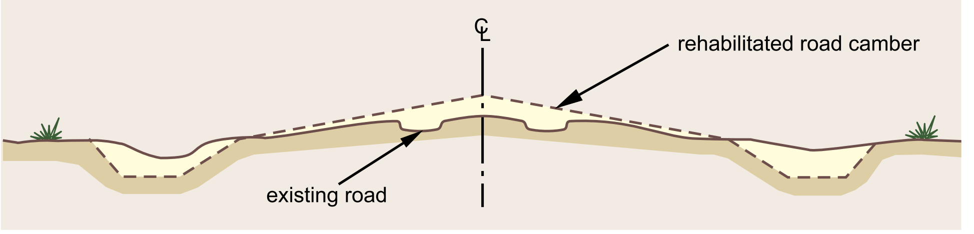
The equations described in the adjacent box explain how to divide the side cut excavation into two days of work with equal volumes, by establishing the exact width of the excavation required during the first day. Following the same approach, it is also possible to divide the work into three days.

With the road dimensions as described above, the setting out details described in the figure above provide equal amounts of work for each of the days involved.

In terrain with a very small slope gradient, it is possible to dig the high side drain without first levelling the full formation width. However, there are advantages in levelling the full width also in such conditions. The side drains are easier to construct to the correct shape and depth on a levelled surface. For this reason, it is common practice to level the entire width even when dealing with minor cross slopes.

A good compromise is to level the surface from the shoulder to the outer sides of the drains as shown in the figure below.





These levelling practices only apply for new construction. When rehabilitating an existing road, levelling works can be kept to a minimum as the full road width has already been established at an earlier stage. Leaving the existing road camber in place, the earthworks would then consist of re-excavating the drains and adding soils to the road surface where it has been worn down.

U-Cuts

The U-Cut is used when the alignment passes through a hill, roughly forming a U-shape. The road is cut through a hillcrest in order to reduce the gradient. If the U-cut is deeper than one metre, it will be necessary to mobilise some form of haulage equipment to transport the excavated soils to an appropriate location. For access roads with low traffic volumes it is good practice to minimise excavation and hauling as much as possible by adopting a reduced road width through the section where a U-cut is required.

As a general rule, the U-cut should be avoided as they involve extensive earthworks. In most cases, it is possible to find a better alignment, which does not require such extensive excavation works.

If the U-cut is deeper than one metre, the excavation work is best organised in several steps, similar to when excavating tall side-cuts.

5.3 Calculating Volumes

Calculating volumes of work is a central task when planning and managing civil works. It is carried out at a number of stages throughout the project, starting with rough estimates during the initial design stage when selecting the appropriate road alignment. During the detailed field surveys, all quantities are calculated in detail and entered into the Bill of Quantities.

During construction, volumes of work are estimated in order to organise work efficiently. Finally, the quantities are once again determined for reporting and payment purposes.

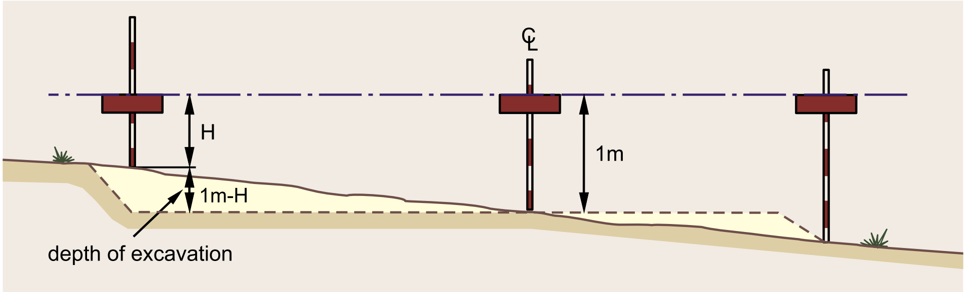
The basic principles applied in this approach are standard for all road works. There are a number of surveying tools available for surveying the terrain and measuring the quantities of works.

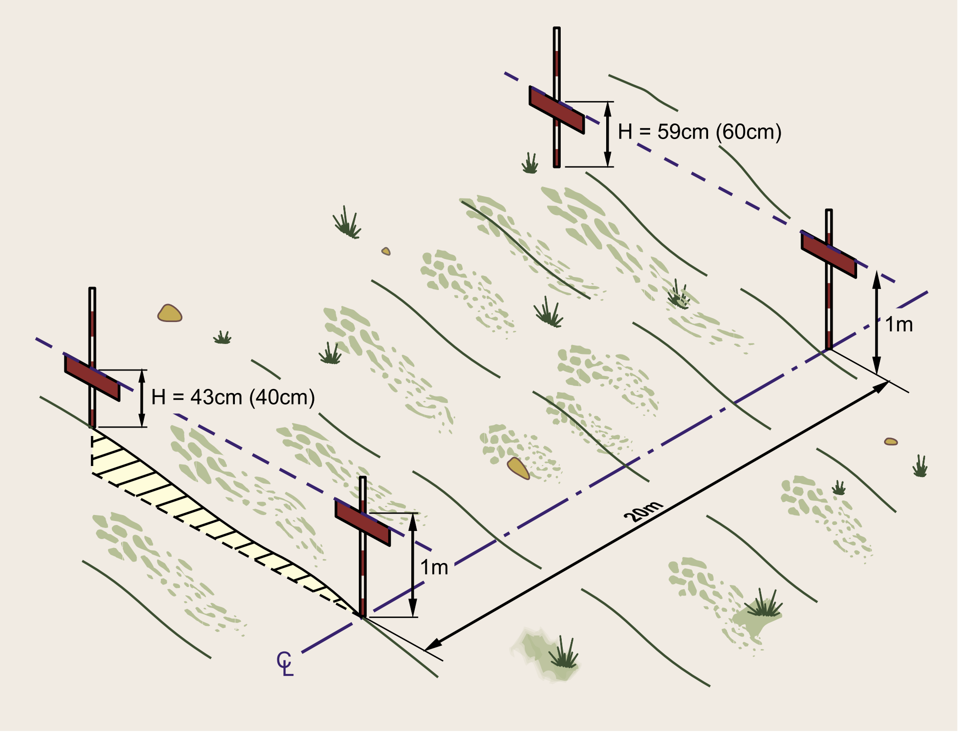
For rural roads, the use of a line level and profile boards to establish the levels and dimensions of the various road components is an efficient method to determine the depth and extent of excavation and fills. Although more accurate equipment is available, this method is easy to use, and provides sufficient accuracy for this type of works.

With profiles set out at the centre line and at the outer end of the side drain, it is possible to determine how steep the slope is and the required depth of excavation. On the basis of this information, it is possible to calculate the exact volume of the excavation works.

The slope of the terrain varies along the length of the road. To calculate the exact volumes of work, the road is divided into segments within which an average slope is estimated.

The sections normally correspond to the interval at which the centre line has been set out, and not longer than 20m. If there are considerable variations to the slope, it is useful to split the road into shorter segments.





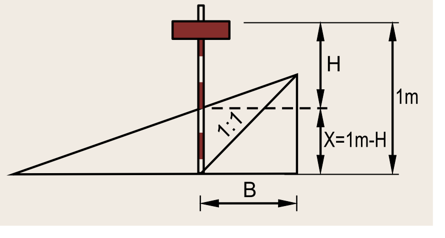
Once the average of the high side profiles have been established, the volume of excavation can be estimated. This is described in the following section.

The figure above shows a pair of profiles located at the centre line and two profiles placed at the far end of the cut side of the road. If the height of the profile on the high side is 43cm and the next profile is 59cm, the average profile height is:

$$\frac{59 + 43}{2} = 51\text{cm}$$

The average profile height needs to be deducted from the profile height at the reference point where the existing ground is at the level to which the road base is excavated.

With the reference profile 1m high, the depth of the excavation is then:



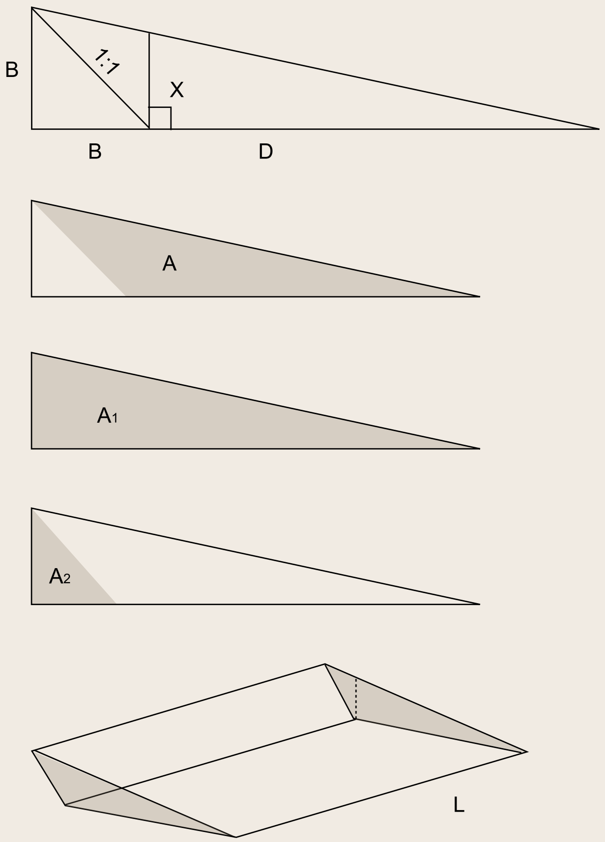
$$X = 100 – 51 = 49\text{cm}$$

Calculating the required width for levelling purposes is easy as the cross section of the cut can be described by a triangle with a right angle. With a drain width of 1.5m and a formation width of 5.5m, the total width to be levelled, is:

$$D = 1.5 + 5.5/2 = 4.25$$

This assumes that the excavation will be carried out to the level of the existing ground at the centre line. The volume of the cut is then L x D x X / 2, which in this case amounts to:

$$V = 20 \times 4.25 \times 0.49 / 2 = 20.83 \text{ m}^3$$



Width of back slope B:

$$\frac{B}{B+D} = \frac{X}{D}$$

$$B = \frac{D \cdot X}{D - X}$$

Area of cross section:

$$A = A_1 - A_2$$

$$= \frac{(B+D) \cdot B}{2} - \frac{B \cdot B}{2}$$

$$= \frac{D}{2} \cdot B$$

$$= \frac{D}{2} \cdot \frac{D \cdot X}{D - X}$$

$$= \frac{D^2 \cdot X}{2\,(D - X)}$$

Volume excavated over a road section L is then:

$$V = \frac{D^2 \cdot X}{2\,(D - X)} \cdot L$$

When including the volume of the back-slope, the calculation is more complicated. The box above describes how to determine the total volume including a back slope, B, set at a gradient of 1:1. For the sample described above, the total volume including the back slope would amount to:

$$V = 20 \times 4.25^2 \times 0.49 \,/\, 2(4.25 – 0.49)$$
$$= 23.54 \text{ m}^3$$

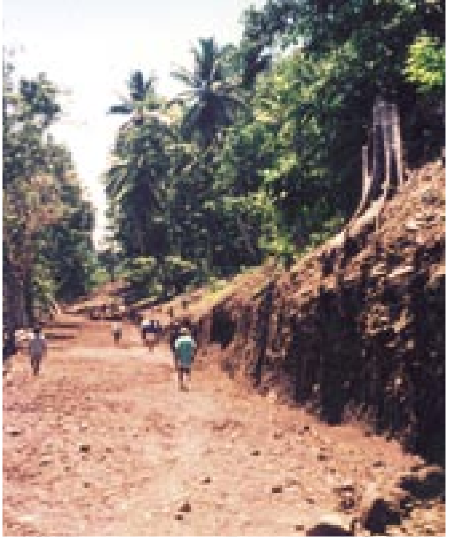
Volume Tables

Calculating volumes of earthworks is a major part of the design and planning of works. It is common practice to carry out this exercise for a number of alignments in order to arrive at a final selection that reduces the amount of earthworks to a minimum. This process can be carried out using advanced computer models, which generate the volumes automatically or alternatively, it can be calculated with the use of electronic spreadsheets.

For the purpose of organising the works on site and in particular allocating tasks to individual workers, it is useful to calculate volumes in advance for the most common profile heights. These volumes can then be provided to the supervisors in table form, and assist in organising the excavation works. These pre-calculated volumes can also be used when reporting the quantities of completed works.

The table below describes how standard volumes for excavation can be calculated in advance and collated into a table. This particular table applies to the road design as described above. For other road cross-sections, these volumes need to be re-calculated before the relevant table can be prepared.

When relying on a volume table, the heights are measured to the nearest 5cm – thereby corresponding to the figures given in the volume table. Rounding off profile heights to the nearest 5cm makes sense because the ground is uneven, and over a number of calculations any slight difference are cancelled out, thereby still achieving sufficiently accurate estimates for the work involved.



Using the previous example, the volume can be found as the 50cm average in the table, in this case 24.08m³. The table also includes other useful information such as the depth and volume of the back slope and variations of volume if the total width of the road formation is increased or decreased.

Excavation Volumes for 20m							
Profile Height h (cm)	Depth of Cut X (cm)	Back Slope B (cm)	Volumes (m^3)				
			Cut to Level	Back Slope	Total	Variation of Width	
						-1.0m	+1.0m
90	10	10	4.25	0.10	4.35	3.35	5.35
85	15	16	6.38	0.23	6.61	5.11	8.11
80	20	21	8.50	0.42	8.92	6.93	10.92
75	25	27	10.63	0.66	11.29	8.80	13.78
70	30	32	12.75	0.97	13.72	10.74	16.70
65	35	38	14.88	1.33	16.21	12.75	19.69
60	40	44	17.00	1.77	18.77	14.82	22.73
55	45	50	19.13	2.26	21.39	16.98	25.84
50	50	57	21.25	2.83	24.08	19.20	29.01
45	55	63	23.38	3.47	26.85	21.52	32.25
40	60	70	25.50	4.19	29.69	23.92	35.56
35	65	77	27.63	4.99	32.61	26.41	38.95
30	70	84	29.75	5.87	35.62	29.00	42.40
25	75	91	31.88	6.83	38.71	31.69	45.94
20	80	99	34.00	7.88	41.88	34.49	49.55
15	85	106	36.13	9.03	45.16	37.41	53.25
10	90	114	38.25	10.28	48.53	40.45	57.03
5	95	122	40.38	11.62	52.00	43.63	60.89
0	100	131	42.50	13.08	55.58	46.94	64.85

Notes: 1 Including the volume of a 1:1 back slope
2 The table above only applies when the centre profile heights are 1m above the existing terrain. For other situations when this is not the case, the volumes need to be re-calculated.

5.4 Organising the Excavation Works

Allocation of Labour

The number of workdays required is calculated by dividing the quantity of work with the appropriate task rate. In this example, if the task rate is 2m³ per day, then the number of workdays is:

24.08 / 2 = 12 workdays

It is then up to the supervisor to decide how to organise the work. 12 persons working on a 20m section is not practical. Instead, it is better to organise the work over a period of 2 or 3 days. If the work is done in 2 days, it is necessary to assign 6 workers each day.

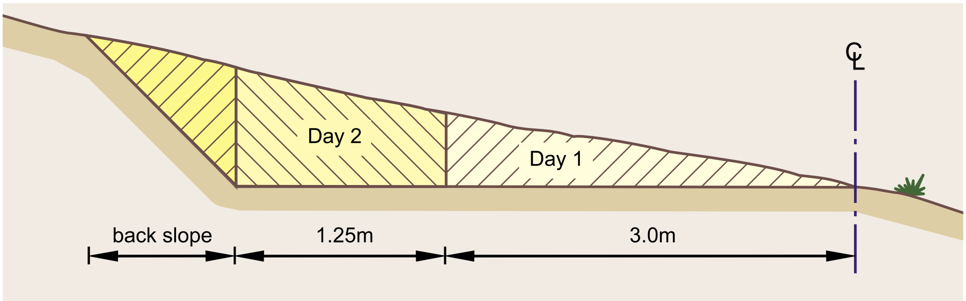
The excavation width for the first day is then set out. The widths of excavation are calculated so that the work involved is roughly the same each day. When splitting the works into two days, the width for the first day's work will be 3.0m measured from the centre line. The remaining 1.25m are excavated on the second day. In this way, the same number of workers is assigned on both days to this 20m road section.

Once the excavation up to 4.25m has been completed, thus accommodating the width of the road and side drain, the supervisor has to decide whether it is necessary to extend the excavation back further to produce more material to build up the fill and the road camber.

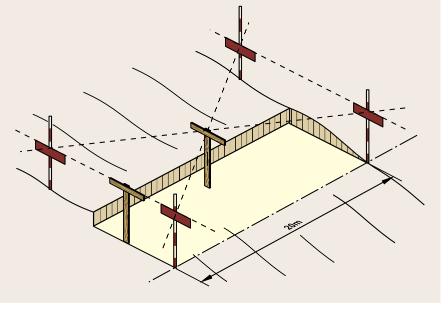
If additional material is required, the width of the road foundation can be increased, or the back slope can be given a less steep gradient. The volume table provides total volumes for an increased excavation width or if the width of the road needs to be narrowed down. The volume of excavation of the extra width is found by subtracting the volume for the standard width from the total extended volume. In this example, for an extra width of 1.0m it would be 29.01m³ - 24.08m³ = 4.93m³. From this, the supervisor would work out that two additional workdays are required to carry out the work.

Back Sloping

Once a level road base has been excavated, the next step is to provide the vertical cut with a reduced and stable back slope. It is useful to include the volume of the back slope in the volume table to avoid difficult calculations on site. The volume table provides a separate column showing



the volume of the back slope. In the example described above, the volume of the back slope for the 20m section is 2.8m³. This work can be carried out by assigning one worker to this section. Excavating the back slope is easier than the earlier excavation works, so it is reasonable to increase the task rate.



If the depth of the cut is 25cm or less, it is easier to include the back sloping when excavating the back slope of the side drain.

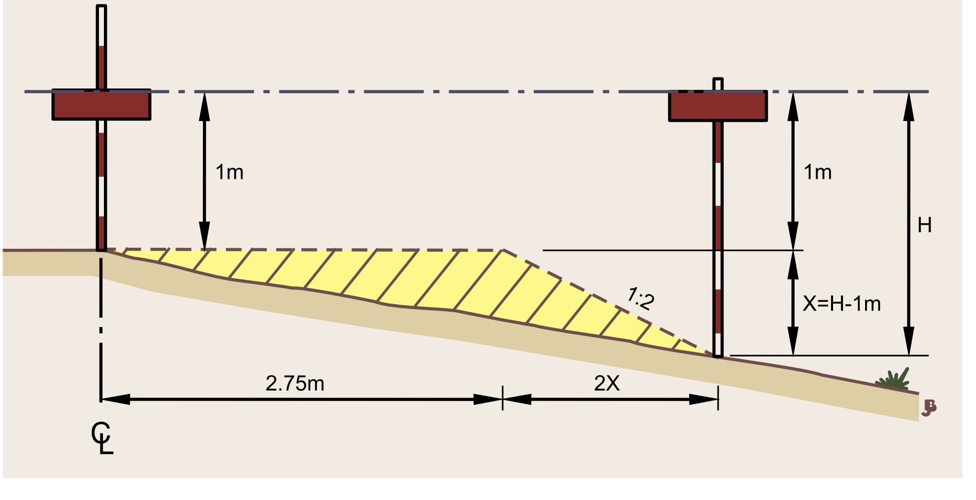
To ensure that the cut is fully excavated, use a traveller to control that the excavated ground is level and to the correct depth.

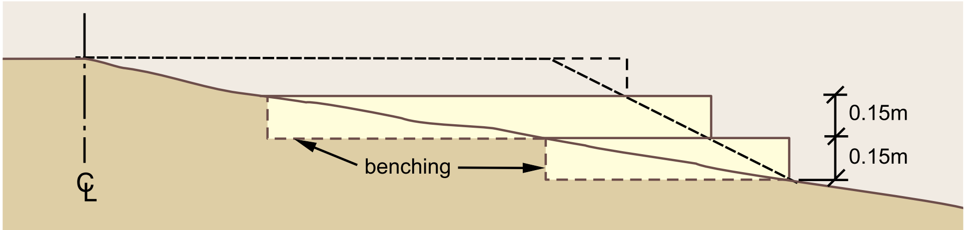
The Fill Side

The fill side is constructed using the materials from the cut side. If the fill at the low side road shoulder is higher than 0.3m, there is no need for any side drain on this side of the road. Make sure that the slope of the fill is neatly shaped with a gradient not steeper than 1:2, as shown in the figure below.

In order to produce a good quality fill, it is important that all soils are properly compacted. The fill is therefore built up in layers each not more than 15cm thick and properly compacted before the next layer is added. Watering may be required to secure optimum moisture content during compaction.

For relatively gentle slopes, the fill can be placed directly on the existing surface (after removing any organic materials). On steeper slopes, there is always the risk that the fill may start sliding when pressure is exerted on it. In order to stabilize the fill, the existing ground is reshaped into terraces, thereby providing the fill with a horizontal





base. Referred to as benching, this is a common practice for all fills in rolling or mountainous terrain. It is also required when widening an existing fill.

The number of workers required for spreading and levelling the fill is roughly half the number of persons carrying out the excavation of the cut. If the work simply consists of levelling across the road, then 3 workers will be sufficient in the above example. If the fill material needs to be carried from another 20m section, it may be necessary to assign 4 or 5 workers for the filling works.

5.5 Embankment Construction

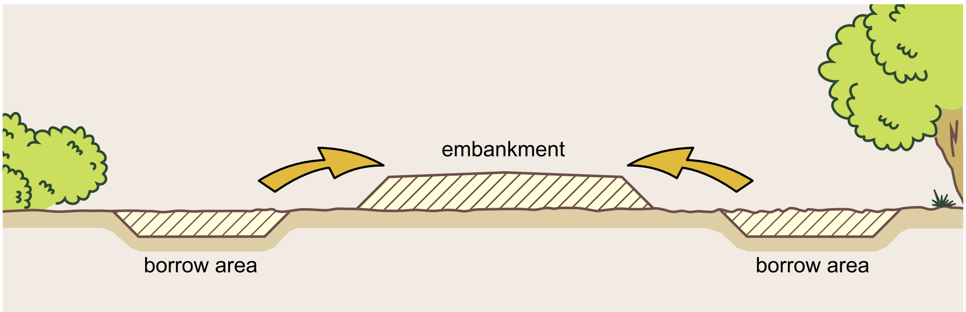
Embankments require large amounts of fill material and are expensive to construct. They should be avoided or minimised when possible by selecting an alignment following higher ground. This however, is not always possible in low, flat, agricultural land, where alternative routes are difficult to find.

Wherever possible, material should be excavated alongside the road and carried to the road in baskets, stretchers or wheelbarrows. Some distance should be left between the borrow area and the base of the embankment so as to avoid the borrow pit triggering any erosion of the side slopes. If land is not available for roadside borrow pits, or if the material is not suitable, the soils will have to be brought in from the nearest source using appropriate transport.

The borrowed soils should be of good quality. Organic soils, and if possible, poorly graded sands and silts should be avoided. If sand or silt are the prevalent materials in the surrounding area, side slopes need to be stabilised using appropriate measures such as protecting the slopes with a layer of clayey soils and vegetation and by choosing a gradient not less than 1:2 to prevent erosion.

To reduce the required earthworks, it is important to keep the embankment to the least required height. This is normally considered to be 0.5m above the level to which the surrounding terrain floods.

Flooding patterns vary from one year to another. The appropriate embankment height is based on the highest flood level which has occurred in the past. This information can normally be obtained from local inhabitants and should be



marked on pegs along the centre line when finalising the alignment.

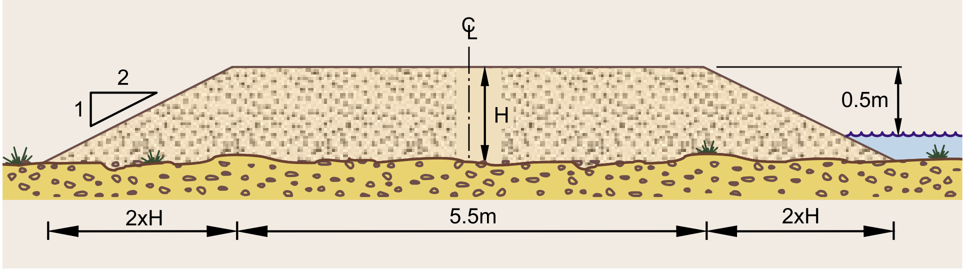
The centre line alignment should be carefully selected to avoid low areas requiring extra fills and areas where suitable material is not available from the roadside.

Earthwork Volume Calculations

Calculation of earthwork quantities is especially important for the planning and control of embankment construction activities. It is necessary to apply a simple and accurate method of estimating embankment quantities at the site.

The cross-section dimensions are fixed by national standards or project specific designs. In this example, we will assume some dimensions commonly used for rural roads, i.e. a road width of 5.5m, side slopes of 1:2 and a clearance above highest flood levels of 0.5m.

The height of the embankment, H, is determined on the basis of the expected flood levels. It is common practice to



raise the embankment another 0.5m above the flood level. The area of the standard cross-section is then:

$$2 \times (2xH \times H)/2 + 5.5 \times H =$$
$$(5.5 + 2H) \times H\ [m^2]$$

which is equivalent to m^3 per metre length when calculating volumes.

Example:

An embankment with an average height of 0.8m will have a cross section area of

$(5.5 + 2 \times 0.8) \times 0.8 = 5.68\ m^2$

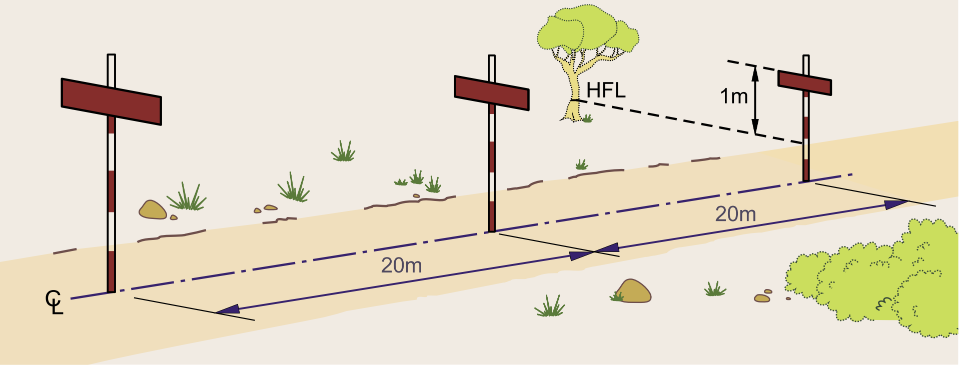
This is equivalent to 5.68 m^3 in a one-metre section of the road.

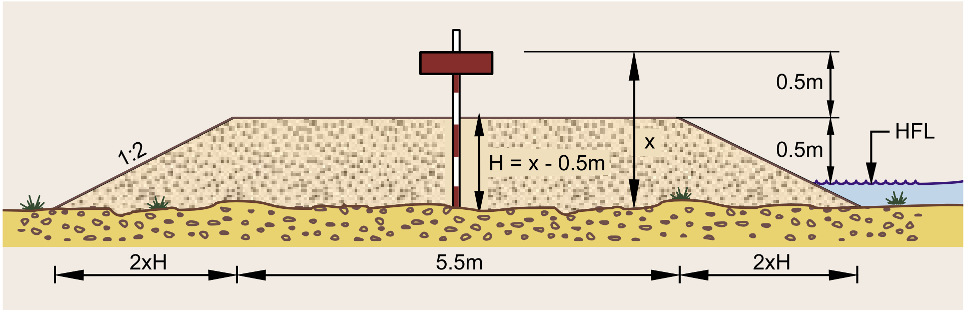
Embankments are only necessary on flood prone land where there are only slight variations in ground levels. In these conditions, it is quite safe to take the height at the centre line profile as the average height of the cross-section.

The height of the embankment at any point on the centre line can be established with the use of profile boards. The high water level is marked on trees or solid pegs at convenient locations along the route. The actual flood levels can be obtained through consultations with local residents. The centre line is then set out with ranging rods every 20m. Profile boards are fixed on these ranging rods at one metre above the nearest high water level mark.

The centre line profiles are then sighted to check that they line up and are horizontally aligned. Adjustments to the profile levels are made as necessary.

The full height of the embankment is established at each 20m section by measuring down from the profiles to the ground and subtracting 0.5m. The





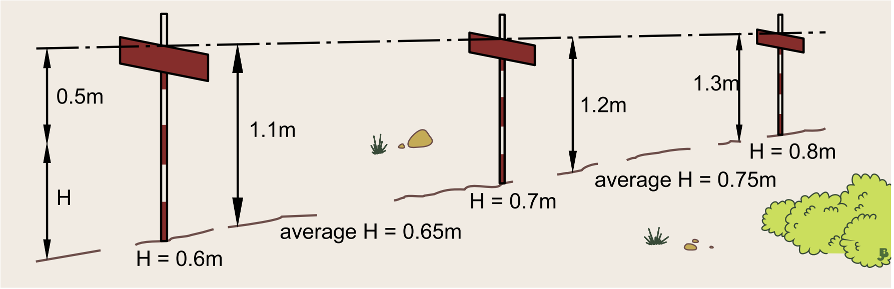
Embankment Height, H	1.00	0.90	0.80	0.70	0.60	0.50	0.40	0.30	0.20
Volume, m³/m	7.50	6.57	5.68	4.83	4.02	3.25	2.52	1.83	1.18

measurement is rounded off to the nearest 10cm.

To facilitate estimates while in the field, volumes of one-metre road sections can be calculated in advance for a series of embankment heights. The table above shows the volumes of various embankment heights for a one-metre road section with a carriage width of 5.5m and side slopes of 1:2.

These figures can be used to estimate volumes over longer distances, say 100m, during planning or route investigation stages, to get quick, reliable estimates of the volume of earthworks and the workdays required. The surveyor establishes the high water levels along the route, and adds 0.5m to allow for sufficient embankment height.

The height of the embankment may vary along the road line. Therefore, it is practical to use the average height over a section of 20 metres when calculating the volumes. Once the centre line has been established, it is possible, using profiles, to get a fast and accurate estimate of the volume of earthworks. The following example illustrates the method for the cross-section described above:



By taking the average height for each 20m section and applying these H values to the above table, the first section has a volume of

$$20 \times 4.02m^3 = 80.4m^3$$

The second section has a volume of: $20 \times 5.68m^3 = 113.6m^3$

For the supervisor this, however, does not give sufficient detail to organise the work on a daily basis. The embankment needs to be built up in compacted layers and the volume of each layer needs to be estimated in advance. The width of each layer varies, depending on the gradient of the side slope and the height of the embankment.

The maximum thickness of the layers depends to a certain extent on the method of compaction. Assuming compaction is carried out by a one tonne vibrating roller, it would be appropriate to build up the embankment in layers not thicker than 15cm.

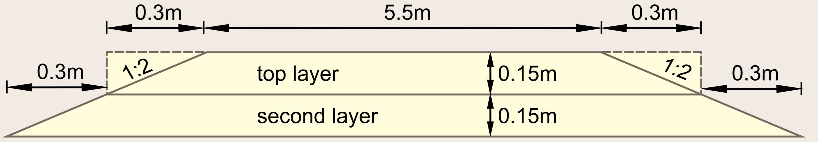
In most cases, the ground on which the embankment is built is not level and the height of the embankment may not always be exact multiples of 15cm. For this reason, there will be a need for one or two regulating layers before the start of building even 15cm layers.

When calculating the regulating layers, some practical assumptions are made:

- ground levels can be rounded off to the nearest 5cm, and
- the ground slope between points can be represented as a straight line.

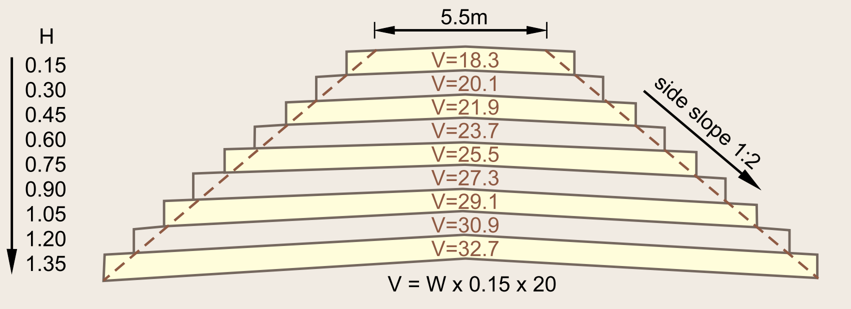
With these approximations, it is still

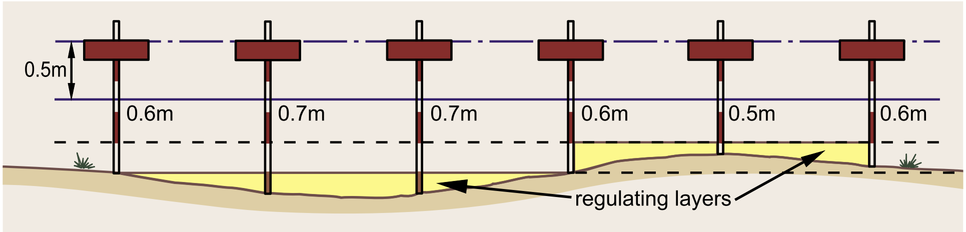
The volume of each layer needs to be estimated in order to allocate the correct number of workers for each day. This is calculated as follows:



The top layer	$(5.5 + 2 \times 0.3) \times 0.15 = 0.91m^3$ per metre or $18.3m^3/20m$,
the second layer	$(5.5 + 4 \times 0.3) \times 0.15 = 1.01m^3$ per metre or $20.1m^3/20m$,
the third layer	$(5.5 + 6 \times 0.3) \times 0.15 = 1.10m^3$ per metre or $21.9m^3/20m$.

Once again, it is useful to calculate these volumes in advance, and have them readily available on site when planning the distribution of workers and setting the tasks. The figure below shows the volumes for an embankment with the same 5.5m carriageway width:





possible to calculate the volumes of layers with varying thickness and shape with sufficient accuracy.

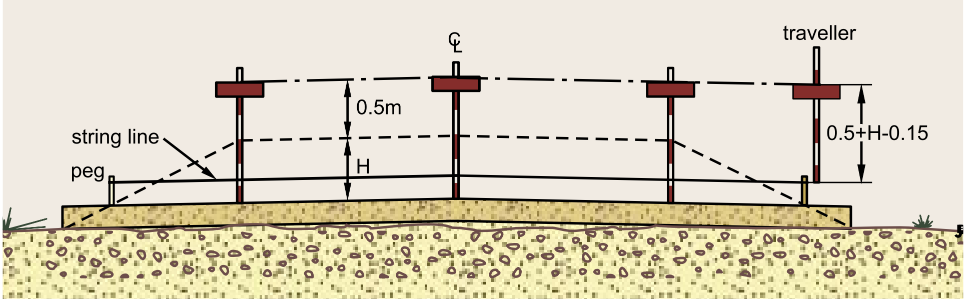
Organising the Workforce

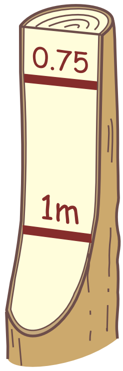
The volume of the various shaped layers depends on the width of each layer (W), which depends on the depth of the layers below the top of the embankment and the side slope gradient. This calculation is important for establishing the correct number of workers to be allocated to the embankment construction.

The fill is set out in layers measuring down from the top of the embankment and marked on string line pegs to aid the levelling works. The correct levels are established by using an adjustable traveller, and sighting off from the profiles located at the centre line and the shoulders.

When the supervisor is planning the construction of the embankment, the first step is to prepare a level surface at 0.45m, 0.60m, 0.75m, 0.90m or 1.05m below the top of the embankment, thereby allowing the build up of the fill to proceed in even 15cm layers to the top of the embankment.

At the base of the embankment, this involves the use of regulating layers. After the regulating layers have been levelled and compacted, the construction can proceed in layers each and all with a thickness of 15cm. The first full layer may also involve some regulating.





Once the centre line profile measurements have been recorded, profiles are set out at the edge of the road and the centre line profile level transferred to the road shoulders. The centre line ranging rods can then be removed to clear the work area. At the same time, a strong marker peg should be driven into the ground at each 20m section with the high water level clearly marked so that construction levels can be replaced when required.

When the exact earthwork quantities have been established in each layer and section, it is possible to organise the work force to carry out the work, including planning the number of workdays required.

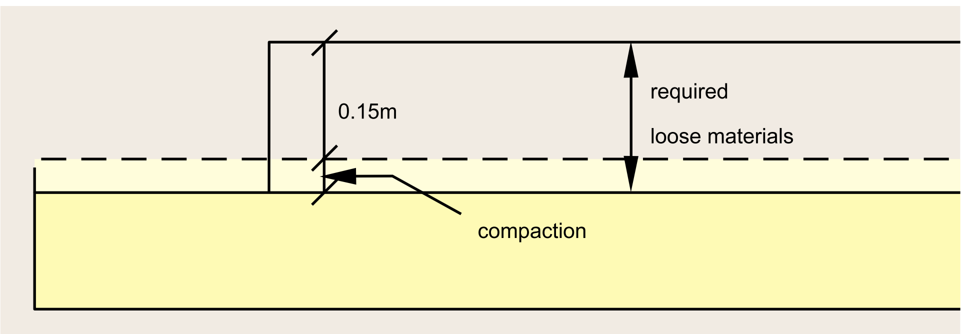
After each layer is compacted, the next layer will need to be greater than 15cm to fill up to the top of the next layer and make up for the compaction in the previous layer. However, the earthwork quantities are for excavated compacted soil, which will bulk ("expand") when loose and provide the extra material needed.

When building the embankment, it is useful to establish a camber already in the first layers of the road fill. This will allow for good surface water runoff also during the construction period.

Borrow Pits

The use of borrow pits is necessary when large fills are required. In rolling and mountainous terrain, any demand for fill materials should be sourced from within the road reserve by utilising soils from the side cuts. Widening the side drains or reducing the gradient on back slopes is also a feasible way to obtain additional fill material. In flat terrain, where the road needs to be lifted to a level above the surrounding terrain, it is often necessary to open a borrow pit.

Borrow pits are used for a limited period of time during the construction of the road. Once the necessary soils have been extracted, the borrow pit needs to be reinstated, thus allowing the land to be returned to its original use. The borrow pits are normally located close to the road works site in order to minimise transport demands. This often involves encroachment on farmlands. For this reason, the use of land for borrowing material needs to be resolved before commencing works.



It is also important to operate the borrow pit in a way which keeps the reinstatement works at a minimum.

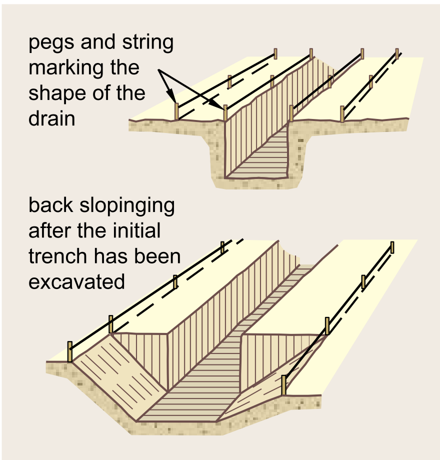
The correct use of borrow pits involves careful planning of the earthworks operation. To access appropriate soil materials, any vegetation and topsoil need to be cleared away. Topsoil should be stored at a safe distance from the work site and returned once the borrow pit is no longer in use. Excavation works in borrow pits need to be planned in a manner so it causes the least damage or interference to the normal use of the land. Deep borrow pits should be avoided as they may become a hazard to people and animals. Equally, deep pits will fill with stagnant water and thereby cause health problems.

When using labour-based work methods, it is possible to operate borrow pits in a more environmentally friendly manner by increasing the area of excavation and thereby limiting the depth of excavation. By limiting the excavation depth, it is easier to reinstate the land and allow the continuation of previous farming activities. Equally, the opening of a borrow pit should not commence before farmers have been allowed to harvest their crops.

Although it is preferable to be as close as possible to the road site, the borrow pit should be located at a safe distance from the embankment or fill thus avoiding that the borrow pit causes any damages to the road. The exact location of the borrow works is set out by the supervisors. When allocating tasks to the workers, the work is often set out in the borrow pit. Commonly, the task will also include the transport to a designated fill area, thereby allowing the task to be measured both in the borrow pit as well as at the fill location.

5.6 Side Drain and Camber Construction

Having completed the excavation and fill works and obtained a level road surface, the next step is to install side drains and a camber or cross slope on the road surface. These activities are usually carried out at the same time as the soils from the side drains and back slope are used to shape the final road surface.



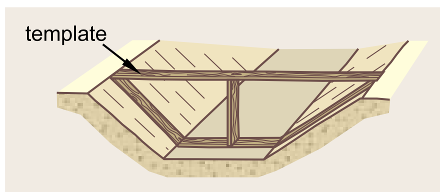
In gently rolling terrain, the side drains should be designed sufficiently large to cater for the material requirements of the road camber. Excavated soils from the drains are first thrown to the centre of the road, from where it is levelled out towards each road shoulder to form the camber.

When the road is built on an embankment, the final camber is shaped using material

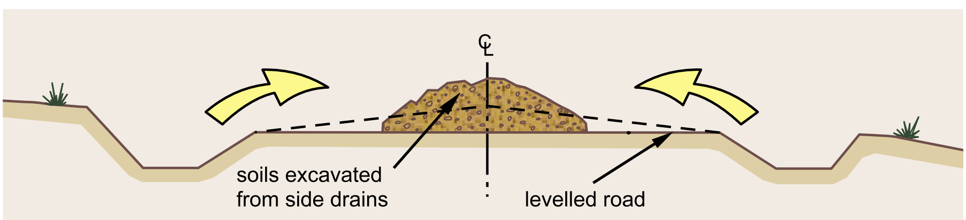
from the same borrow areas used for the previous earthworks.

Side drain excavation is best done in two stages. First, a ditch with a rectangular shape is excavated, then the side slopes of the ditch are excavated. Normally, one or two days are allowed between each stage to allow sufficient working space.

The excavation is set out using string line and pegs. During this work, a ditch template is useful for checking the



depth and shape of the drain. Equally, a measuring stick marked with the correct depth of the drain is

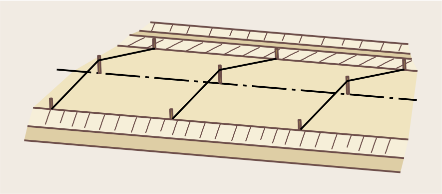


useful for guiding the work. A mark on a tool handle can also be used for this purpose.

Both the ditching and sloping tasks are calculated as a fixed length of the side drain. The sloping task is set at a rate higher than the ditching task, since excavating soils on the slope face is easier to carry out than excavating the ditch.

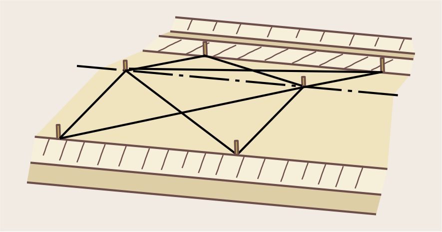
The camber is also set out using pegs and strings in order to achieve an exact and properly levelled surface. Once the soil has been levelled, the camber is properly compacted. It is important to make sure that the soil contains an optimum moisture content during compaction.

During the compaction work, the final levels are checked to ensure that the road camber is exact and to the prescribed standard and quality. This is best done by setting out the correct levels once again with profile boards, and controlling the levels between the profiles with a traveller. A quicker



method, though less accurate, is to use string lines to check the levels of the completed surface.

The soils will not compact evenly. Where the levels are inaccurate, the



irregularities need to be removed or filled in. If further filling is required, make sure that the patching is also properly compacted. Finally, repeat once again checking the levels to ensure that the earthworks have been completed to the prescribed quality standards.

Super-elevation of Curves

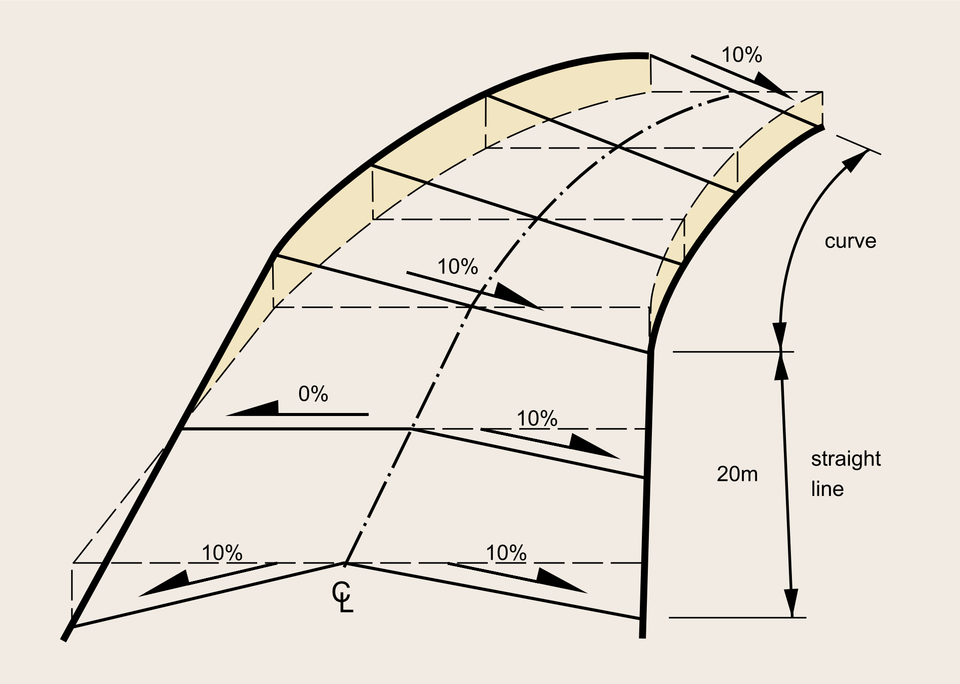
Super-elevation is applied to sharp curves to counteract the centrifugal force exerted on vehicles travelling through the curve. Super-elevation is created by inverting the camber slope on the outer half of the roadway, thereby preventing vehicles from slipping of the road while negotiating the curve.

For rural roads, the super-elevation can be built up over a 20m section before entering into the curve. Equally, the super-elevation is gradually run off over a 20m section starting at the end of the curve.

Throughout the curve, the super-elevation is constant. On gravel roads a cross slope of 8% across the road carriage width is recommended (10% before compaction).

Super-elevated curves require double the amount of materials to construct as compared to the standard camber formation. These additional materials should be obtained in close proximity to the curve to avoid any hauling distances. Ideally, this can be achieved by enlarging the side drains or by reducing the slope gradient of the side cuts.

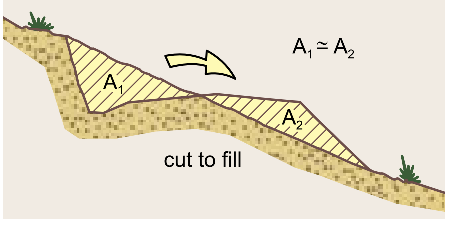
As with any fill, the super-elevation should be built up in compacted layers not thicker than 15cm.



5.7 Transporting Materials

Hauling, with the associated loading and unloading, forms part of the earthworks operation. In most circumstances haulage of materials for earthworks can be reduced to a minimum when building rural roads. The soils found adjacent to the road are in most cases of adequate quality for building the necessary fills, thereby keeping the transport distances short.

Through careful selection of the road alignment, it is possible to balance the need for excavation and fill works across the road. This limits the haulage to transporting the materials from the cut to the fill side. Equally, adjusting the vertical alignment to follow the existing terrain can reduce the need for transporting materials along the road line to a minimum. In flat areas, where the road needs to be elevated, the soil can usually be taken from adjacent borrow pits.



Even with these measures incorporated into the design of the road, there will always be some need for material haulage. If it can be limited to short distances, the transport can be organised using manual labour. Depending on the site conditions and volumes of work, hauling material over short distances can be organised

using stretchers, head baskets or wheelbarrows. Longer distances require some form of mechanized equipment. If the volumes required are limited, locally available tractors and trailers may be sufficient for the task. With larger volumes and longer hauling distances, the use of conventional trucks is more effective.

Haulage of materials is expensive, so minimizing the demand for this activity is essential when setting out the road alignment. By avoiding steep terrain or areas with poor drainage, it is possible to achieve significant cost savings, as the need for material transport can then be reduced. As compared to highways, rural roads have relatively relaxed curvature requirements. This should be taken advantage of when designing the road.

Hauling

Hauling involves the transport of soil from its sources (i.e. borrow pit, quarry, river, etc.) to wherever it is required at the work site. It may also involve removing excess or unsuitable materials from the construction site. The most effective mode of haulage varies with the distance and quantity of work. The transport of materials can be carried out using baskets, stretchers, wheelbarrows, animal carts, hand tractors, tractor-trailers or trucks. Efficient loading is important as the waiting time for equipment needs to be kept at a minimum.

Generally, the optimal or best mode of haulage depends on the hauling distance. The following table gives a general picture of the modes of haulage at different distances.

Not all these modes of haulage are always available and a second best solution may have to be applied. For smaller volumes of work, the choice of transport is often determined on the basis of what is available and can be quickly mobilized. When the transport needs for longer haul distances are limited, it may be sufficient to rent locally available equipment. In rural areas, there exists a great variety of haulage equipment which has a tradition of use in a specific area or region. All these modes of transport have not been listed, and the project management should always try to find the most effective way of dealing with the transport demands.

The loading arrangements should be matched to the capacity of the haulage equipment so that neither loaders nor transport vehicles have to wait unnecessarily. It is therefore important to plan the hauling operation carefully, thus ensuring that there is a good balance between labour and equipment during loading, hauling and unloading.

Tractors and trailers can be used effectively together with manual loading for distances from 500m to 5km. Each tractor should have two or three trailers so that when the tractor hauls one trailer another can be loaded.

When the loading is carried out using manual labour, it is essential that the time spent on loading is as short as possible. This can be done by stockpiling excavated materials in advance of the arrival of the transport

Hauling distance	Mode of haulage	Material to be moved
0 – 5m	Shoveling	Soil
0 – 20m	baskets	Soil, sand, stone
0 – 50m	stretchers	Soil, sand, stone
10 – 150m	wheelbarrows	Soil, sand, stone, concrete
150 – 1500m	animal carts	Soil, sand, stone, gravel, water
150 – 2000m	hand tractors	Soil, sand, stone, gravel, water
500 – 5000m	tractor-trailers	All types of construction material
more than 1000m	trucks	All types of construction material

equipment. Once the tractor or truck arrives the materials can be loaded from the stockpile.

For shorter distances, up to 150 metres, wheelbarrows can be used for transporting material. It is important that the wheelbarrow works are properly organised and supervised. Before the actual loading can start, the following preparations have to be made:

- locate the source of fill material and prepare the borrow area,
- estimate the volume of soil to be transported,
- obtain sufficient wheelbarrows and excavation tools,
- set out the place where the soil should be dumped (fill),
- prepare wheelbarrow runs.

The highest productivity is reached when the number of wheelbarrows is more than the number of workers assigned to hauling material. When a worker returns to the loading place with an empty wheelbarrow there should always be a loaded one waiting. The proportion of wheelbarrows per hauler varies with the hauling distance but an average of 1.5 to 2 wheelbarrows per hauler is the most effective configuration.

Each worker should be assigned to only one activity at the time, excavating, loading, hauling, spreading or compacting. It is good practice to rotate the workers between the different activities.

The wheelbarrow runs should be organised on firm and dry ground. Planks should be used to avoid wheelbarrows getting stuck in loose or wet soil. The runs can be built either by levelling and compacting an earth path or by placing wooden planks or metal sheet as runners. There should be different paths for going to and from the dumping site to avoid congestion. Ideally, the paths should form a circuit.

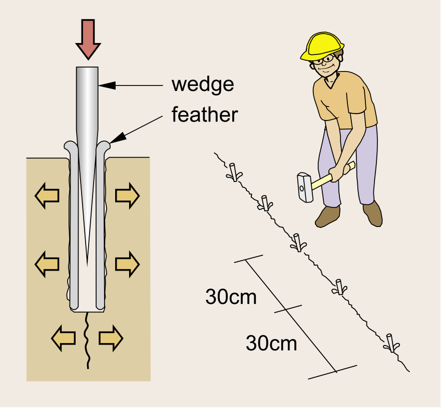
5.8 Rock Excavation

Rock excavation should as a general measure be avoided on rural road works. It is a costly activity and requires special tools, equipment and skills. For these reasons, the best way of dealing with rocky terrain is to realign the road to avoid it. When the road alignment passes through areas with limited sections of rock, the solution can be to raise the road levels, and place the completed road on a fill on top of the rocky terrain.

Soft rock can be excavated using the same methods as when working with soils. A backhoe will be able to rip limited outcrops of loose and eroded rock. Pneumatic jackhammers and chisels can also be used for the same purpose. Limited amounts of soft and eroded rock can also be excavated using manual labour, however, when the quantities of work increase, it is necessary to bring in mechanised equipment to limit costs and in order to secure adequate rates of progress.

Smaller amounts of rock can be

excavated manually with the use of pickaxes, crowbars, chisels and sledgehammers. Rocky outcrops and large boulders can be dealt with using feathers and wedges, splitting it into smaller pieces.



The use of plugs and feathers is a common method for splitting rock in quarries. This method is also used for limited excavation of rock on roadwork sites. The feathers and wedges are inserted into a seam of holes, and struck in succession with a sledgehammer.

Large boulders and rocky outcrops can also be broken up with the use of fire and water. This method of first heating the rock and then rapidly cooling it off with water, causing it to crack, is not recommended as it requires extensive amount of fuels and provides very limited outputs.

Rock can be broken up using several methods, with explosives, wedge and feather sets or expansion chemicals. The efficiency of these methods are very much dependent on the quality of the rock. Some rock types are softer and easier to drill and thereby make it worthwhile to use manual work methods, while in other situations, the rock is so hard that mechanised equipment is the only sensible solution.

Drilling and Blasting

Drilling and blasting is by far the most effective way of dealing with rock excavation. In mountainous terrain where there is not much choice in terms of alternative alignments, the amount of rock excavation may justify the mobilisation of proper drilling equipment and staff with the essential skills.

Before commencing any drilling and blasting work, make sure that the project has access to a certified blasting expert. Both the drilling and the blasting should be supervised by a person with a proven record of work experience in this field.

Drilling equipment for road works is normally pneumatic, powered by a mobile compressor. There are also petrol-powered hammer drills available on the market, which are appropriate for more limited drilling works.

The art of manual drilling is a skill, which has disappeared in most countries. If it is no longer in practice, it is not recommended to attempt to resuscitate this trade. Minor works can of course be carried out relying on hand drilling.

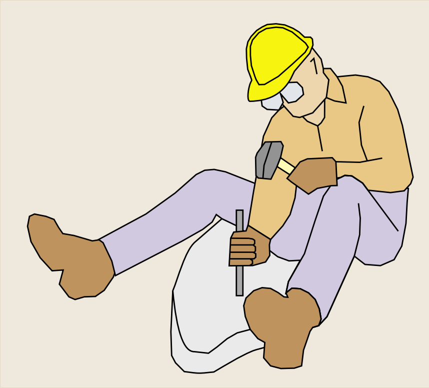
Blasting obviously raises a number of security issues, and regulations relating to the security of people and surrounding properties need to be observed in a proper manner. In some

Manual Drilling

Hand drilling is either carried out by a single person operating both the hammer and the drill rod, or by two persons, one handling the drill and another the sledgehammer (double jacking). Double jacking requires considerable expertise from both the driller and the holder and is not recommended unless labour with these skills is available.

The hand drilling hammer is essentially a 1 to 2 kg sledgehammer with a 25 centimetres long shaft. The head is made of heat treated high carbon steel, fitted on a fine-grained wooden handle. Larger driving sledges for double jacking have 3 to 4 kg heads and longer handles.

The drill rods are made from a high carbon octagonal steel bar with a sharpened end, similar to a flat blade chisel. The driller drives the drill rod by methodical hammering and turning. After each hammer blow, the driller turns the drill rod slightly and then strikes again. With each blow, the drill chisels away small amounts of rock, eventually producing the desired hole.



places, special permits are required before such works can commence. In areas with civil unrest or armed conflicts, the military authorities may have placed restrictions on the use of explosives.

Due attention should also be given to the safety and health aspects of the drilling operation. Both manual and pneumatic drilling require adequate protective clothing to be worn. With pneumatic equipment on site, the rest of the labour force should be directed away from the drilling works to avoid the noise caused by this equipment.

5.9 Slope Stabilisation

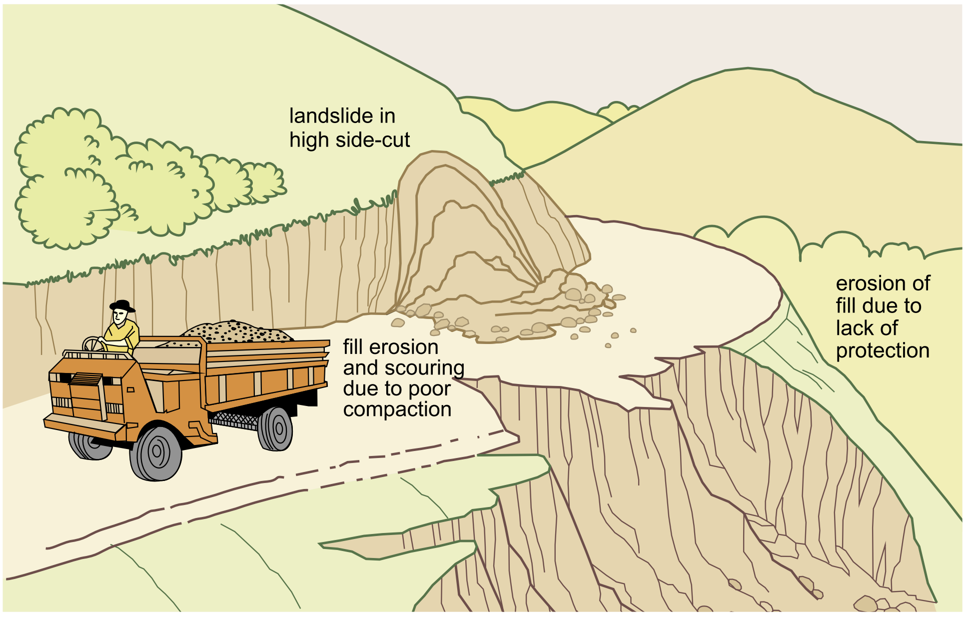
General Observations

When constructing a road through hilly or mountainous terrain, side cuts and fills are required to provide sufficient space for the road carriageway and side drains. The excavation cuts and fills need to be carefully designed to secure stable slopes, which can stand up to the wear and tear caused by the prevalent weather conditions. Appropriate slope stabilisation measures need to be considered as part of the design process in order to contain the amount of future maintenance and repairs required.

Landslides and erosion from slope surfaces not only cause damage to the road structures. It is a major source of sediments blocking up drainage systems and may also cause damage to the surrounding areas.

Soil erosion caused by surface water is the main cause of the deterioration of rural roads. Controlling the extent of erosion therefore needs to be incorporated into the design when the road is built. In general, the less intrusion the road construction causes to the surrounding terrain normally results in less erosion problems. Steep and high cuts and large fills generate more erosion problems, unless adequate protection measures are installed.

There are a multitude of solutions used for stabilising the soils along a road. The most effective measure is to find a road alignment which follows the natural shape of the terrain and which avoids steep terrain where extensive earthworks are required. When cuts and fills are necessary, the most common measure is to ensure that the slope gradients are not too steep. Equally, a tall cut can be split up by inserting terraces at appropriate intervals, reducing it into smaller slope surfaces. Diverting surface water away from the slopes reduces the chances of erosion. Equally, with proper



compaction the soils in a fill are more resistant to erosion.

The use of retaining walls can improve the stability of slopes as well as protect the surface from erosion. Ideally, both cut and fill slopes should be constructed so that they can be vegetated.

Landslides

Landslides are in most cases a result of poor design of side cuts. The excavation works are often carried out during the dry season, at the time when the soils are stable enough to allow for high cuts with steep gradients. Once the rainy season arrives and the rains saturate the soils, they no longer have the necessary strength to support the steep walls and the landslides start occurring.

Landslides not only cause disruptions to traffic due to soils blocking the road, they also block the drainage system. With blocked drainage, surface water will find alternative passages – often causing additional damage to the road. In areas where road maintenance is lacking, it is often the secondary damage which eventually leads to complete failure of the road.

A good road alignment avoids potentially unstable areas and thereby reduces the number of slope failures. When failures occur, the slide area should be stabilised by removing the slide, reducing the slope gradient, improving drainage and/or by installing retaining walls.

In difficult terrain, slope stabilisation is a major cost factor, amounting to up to 20 percent of construction costs.

Finding the best alignment in such terrain is often a matter of choosing a solution which causes the least problems. Not all slope problems are identified before construction works start, so it is useful to set aside some resources which can be used to deal with slope problems when and where they eventually occur. In order to limit up-front preventive works, one approach is to delay the installation of some of the retaining walls until after the road construction has been completed and the road is subjected to the first rainy season.

Scouring

In addition to addressing the stability of slopes, the road design needs to include adequate measures, dealing with the management of surface water. The construction of a road will in most cases distort the natural flow of water in the surrounding areas and may trigger new soil erosion problems. Equally, the design of the road needs to incorporate adequate measures to avoid surface water from eroding the various components of the road.

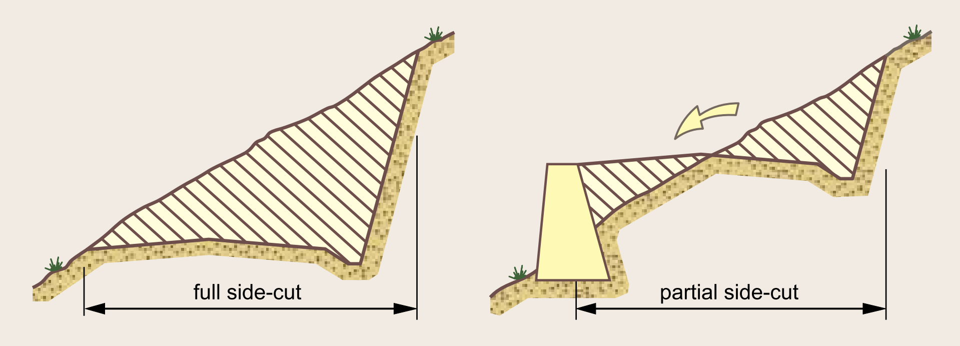
Scouring easily takes place on unprotected surfaces when sufficient quantities of water are travelling across the surface. Cuts and fills should be protected from erosion by leading water away from the slope surfaces. In addition, it is useful to protect the slope surfaces by planting vegetation or in some cases covering the surface with more durable materials such as stone or gabions. Measures such as aprons and check-dams are often required at points where drainage water is discharged from drains and culverts.

Choice of Cross-section Design

In gently sloping terrain, where cross slopes are less than 30 degrees, the road cross section can be placed into the terrain so that a balance is achieved between cuts and fills. This approach keeps the amount of earthworks to a minimum, eliminates the need for transport of materials over long distances and makes good use of excavated materials, rather than leaving it to spoil.

In steeper terrain, however, it is difficult to achieve a balance of cut and fill over the cross section. When encountering terrain with very steep cross-falls, it is not possible to establish a fill, so the entire road width is instead placed in a side cut. Although this may produce a stable foundation for the road, it has the disadvantage of increasing the risk of landslides and erosion of the cut slope and creates a problem in relation to disposing the excavated soils.

The alternative to the full cut cross section is to build a partial cut with



a fill supported by a retaining wall. This solution reduces the amount of excavation, allowing the excavated soils to be used in a fill behind the retaining wall and limits the amount of spoil materials.

Road Width

In mountainous terrain the costs of the road works increase significantly due to the additional earthworks. A wide carriageway will obviously lead to more earthworks due to the need for larger cuts and fills. For this reason, road design standards are adapted to the type of terrain, using its steepness as a determining factor. Equally, drainage structures used in mountainous terrain are designed to minimise the need for space. In very difficult terrain, it may be useful to consider reducing the road width along those shorter sections requiring very tall side cuts.

Soil Disposal

In some terrain it is difficult to avoid ending up with a surplus of soil. This material needs to be disposed off in a controlled manner. Spoil deposits are easily eroded by water and become a major source of contamination and silting of streams and rivers. Spoil deposits should be identified at specific locations and should by no means be dumped over the side of the road. The deposit needs to be located where it causes no disruptions to farming activities and does not obstruct the natural drainage patterns in the surrounding areas. The best solution is to find an alternative use for the materials, rather than throwing it away.

Slope Gradients

The most cost effective remedy against landslides is to design the road with an alignment which avoids the need for any steep and tall cuts. Natural soils, left untouched with its surface vegetation intact, will remain stable and cause no damage to the road. In general, cut slopes are more stable than fills. Natural soils have compacted and settled well over time and are therefore more resistant to erosion than a fill slope.

Material	Slope gradient (horizontal : vertical)
solid rock	1:5
fractured rock	1:2
in-place soils	1:1
clayey soils	2:1
fills using most soils	1.5:1 to 2:1
poorly graded granular soils	3:1
fills using angular rock	1:3

The maximum gradient on slopes varies with the local conditions, mainly depending on the soil type and weather. Well-graded and compacted soils are more resistant than poorly graded soils with a high water permeability. Excessive rainfall may cause soils to be saturated with water and thereby loose its cohesive properties.

Most soils are stable in cuts with gradients less than 45 degrees (1:1). Fill slopes are normally constructed with a slope of 1:2. In non-cohesive soils it may be necessary to reduce the slope gradient to 1:3. Steeper slopes will be difficult to stabilise and run the risk of scouring. On low cuts and fills, i.e. less than 2 metres, it is possible to increase the slope gradient.

In steep and mountainous terrain, it is unfortunately not always possible to maintain these gentle slope gradients. With good knowledge of the behaviour of local soils, it may be possible to increase the slope gradients, however, too often this results in added maintenance and repair works once the rainy season starts. Instead of pushing the limits of the soils, it is better to find other more sustainable solutions – such as building retaining walls.

Retaining Walls

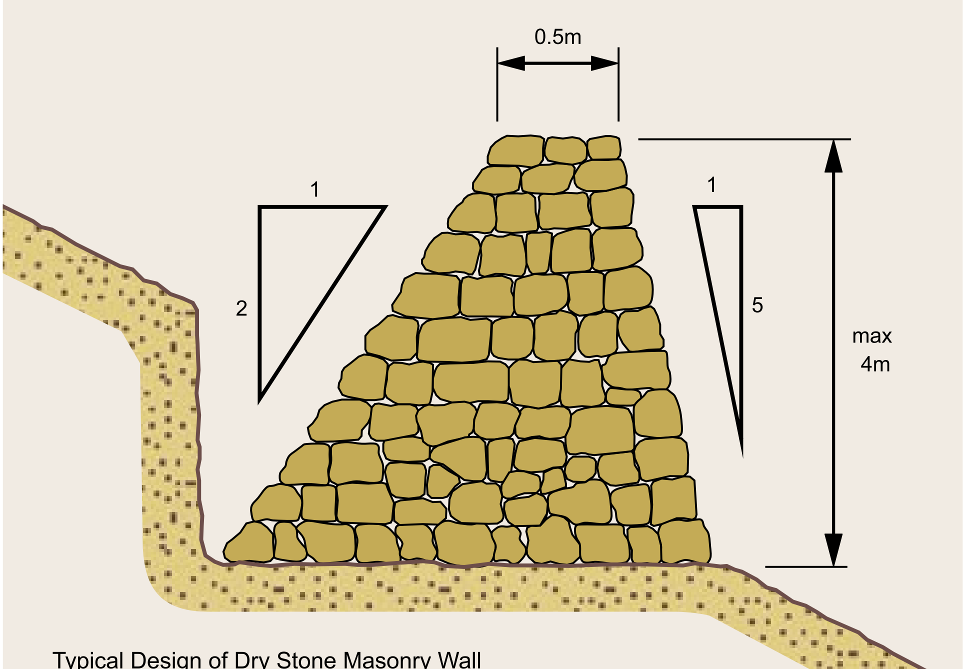
Retaining walls are used in steep terrain to (i) improve the stability of side cuts and fills, and (ii) provide the necessary roadway width on a steep slope rather than cutting deep into the hillside. In populated areas or through farmlands, retaining walls are also used to limit the extent of land required for a road fill.

Retaining walls can be built in a variety of materials. To limit costs, the most common materials used on rural roads are dry or wet stone masonry or gabions. Retaining walls made from such materials are designed as gravity walls. By the sheer weight of the structure, they stay in place and retain the soils behind the wall.

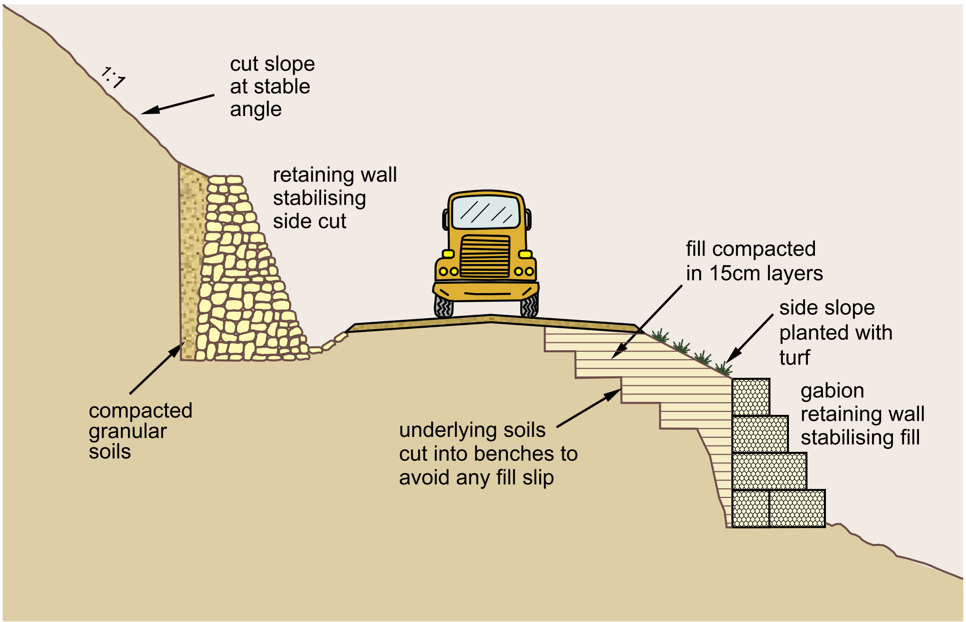
The choice of design and materials is very much dependent on the specific site conditions and availability of good building materials. Dry masonry walls are the cheapest and are suitable for heights up to 4 – 5 metres, depending on the quality of the rock and skills of the masons. The width to height ratio can be up to 0.6 for dry-stone walls. Suitable stone, producing a neat fit and good interlock, improves strength and stability.

Mortared rock walls are more durable and are well suited for steep rocky ground with limited space for foundations. They are also easier to build as the lack of fit between stones can be filled with mortar. For the same reason, it allows the use of more rounded stone.

Masonry walls are not very tolerant to settlements. Mortared rock walls need to be fitted with weep holes. In areas where the walls are founded on soils which are expected to continue to settle, it is better to use gabions.



Typical Design of Dry Stone Masonry Wall



Gabion walls perform better than masonry walls in conditions with poor foundations, wet soils and high groundwater. Gabions are more tolerant to the use of inferior stone and do not require skilled masons.

The backfill of walls needs to be well compacted. Ideally, the backfilling should be organised to take place at the same time as erecting the wall thus providing a better work environment for both the wall builders and the back-fillers.

Mortared walls should be backfilled with a free draining filter material closest to the wall.

The most suitable shape of the retaining walls depends on a number of factors such as available space, providing sufficient road width, foundation conditions, access to construction materials, locally available skilled labour and local construction practices.

Surface Protection

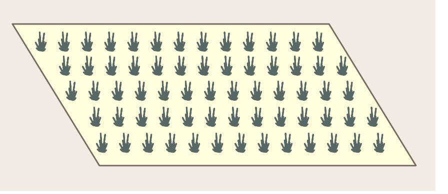
Newly formed slopes on fills and embankments are easily damaged by runoff surface water and animals. It is therefore necessary to protect the slopes as soon as they have been constructed. The erosion protection can be of different types, the most common being planting grass or other types of deep-rooted vegetation.

A more expensive but effective method is to use stone or gabions for protection. Such measures are normally applied when the stability of the slope also needs to be improved.

Grass provides effective protection against erosion if the correct method of planting and the right type of grass is used. The planting can be done in different ways, by planting grass runners, covering the whole area with turf or by sowing grass. If grass seed is available the last method is the easiest, but since this is rarely the case, only the first two methods are described here.

Grass Runners

Grass removed during the clearing activities can be used if it is dug out properly and kept moist. It should be protected from direct sun. The runners are cut in pieces of approximately 20cm in length and planted in rows in 10cm deep holes with a distance of not more than 30cm. To get the best results, the rows should be skewed so that a zigzag pattern is achieved. The soil should be compacted around the runners by hand.



Turfing

Covering the slopes with whole turf gives a more immediate and more effective protection, but is more time consuming to carry out. As with runners, the turf can be collected during the grubbing activity. For easy handling, the turf should be approximately 20 x 20cm. Care must be taken when cutting the turf so that the roots are not damaged. Turf also needs to be kept damp and away from the sun when stored. Before placing the turf, the surface should be watered if it is dry.

The newly planted grass needs to be protected from cattle and other livestock with a barrier of thorny bushes, twigs, branches, etc. Newly planted grass also needs regular watering.

CHAPTER 6

GABIONS

6 GABIONS

6.1 Introduction

Gabions are rectangular wire mesh boxes filled with stone and tied together to form basic structures. They are commonly used for anti-erosion and soil stabilization measures in rural infrastructure works. In road works, gabions are often used for retaining walls, bridge abutments, river training and aprons for river crossings as well as in a number of ways for soil protection.

The gabions are used as large building blocks to shape the structure required. The outer and inner faces may be straight or stepped. They are stacked in the same way as bonded dry stone masonry, providing a firm and coherent part of the structure. The walls normally have a plane outer face, preferably built to a batter for appearance and to increase resistance to overturning. Similarly walls with stepped faces can be tilted towards a backfill.

The main advantages of using gabions are:

- They offer a low cost solution for the design of a number of different parts and components of road structures. They are easy to build, using simple tools such as pliers, hammers and wire cutters. Gabion structures are built without any mechanical equipment and works can start immediately because the initial stages of excavation and laying of foundations are minimal and can be carried out by manual labour;

- The installation of gabions requires less skilled workers such as masons and carpenters. Moreover, the use of gabions can provide additional employment to unskilled labour in the vicinity of the road works sites. Local labour can be recruited for the collection of stone aggregate, and for the assembly and instalment of the gabion baskets;
- The material used is inexpensive mainly consisting of locally available stone. As compared with stone masonry, the quality and size requirements for the stone is more relaxed for gabions;
- Due to their size and weight, gabions provide a cost effective solution for installing gravity-based soil retaining structures;
- Due to their flexible features, gabions have the capacity to adjust themselves to the irregularities of the base surface. They will bend and deform to accommodate small settlements or movements in the soils on which they are placed and still remain structurally sound. This makes gabions preferable to a concrete wall which would crack and possibly collapse in such circumstances;
- Gabions provide free-draining walls and surfaces. This feature is particularly useful in retaining walls;
- Upon completion, a gabion structure takes its full load immediately without any waiting periods - of up to one month - normally associated with concrete structures. Furthermore, the works are not vulnerable to bad weather and can be continued when it rains. In locations with reasonably stable soil conditions gabions can be laid in water without excessive requirements for site drainage.

6.2 Size and Specifications

The sizes and specifications for gabions depend on their use and function. Gabion baskets can be purchased in a range of dimensions from specialized manufacturers. They can also be manufactured on site to the specific requirements of each structure in which they form a component. Alternatively, the supply of gabion baskets can be contracted out to local blacksmiths or metal workshops, detailing the specific dimensions required.

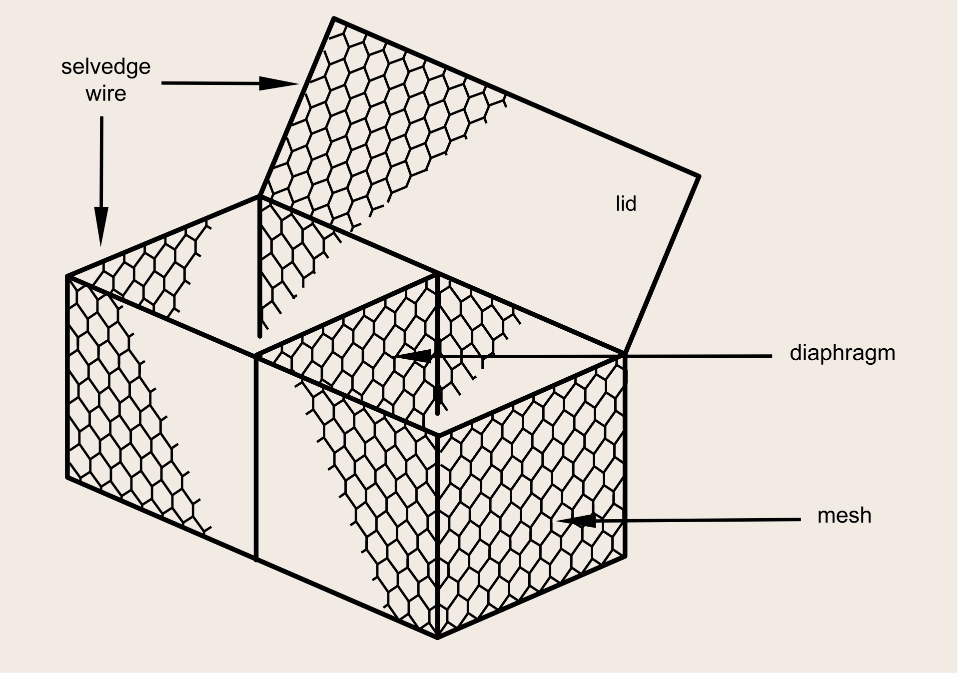
Gabion boxes are square ended, often with a one by one metre cross section. If larger dimensions are required, this can be achieved by either building a larger gabion or by tying together several smaller boxes. For gabion mattresses, the shape will be in the form of a large mattress, in the order of 3 x 1 x 0.2 metres. Gabion boxes, or baskets, are commonly used for retaining walls, while mattresses are used for aprons and river linings.

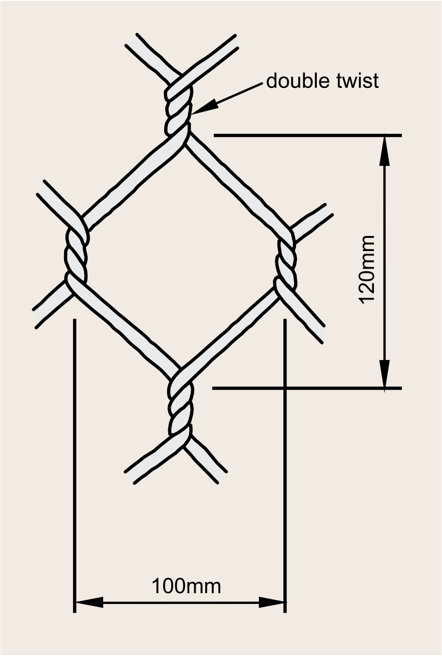
The gabion cage itself consists of a mesh with the edges and corners strengthened with selvedge wire. To reinforce the shape of the cage, diaphragms are fitted at regular intervals inside the cage.

Mesh Size and Design

The standard gabion mesh is made from galvanized double twist mesh wire with a gage of 100 x 120mm. On the market, there are a number of variations to this standard, such as welded mesh and PVC coated mesh.

Smaller-sized mesh exists – 80 x 110 mm and 50 x 70 mm – but should be used when only small stones or pebbles are available or where a structure needs to be exceptionally resistant. Provided that





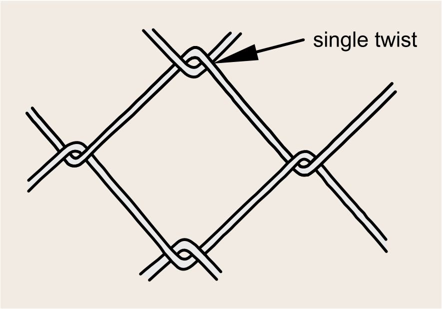
there is adequate supply of the correct size rock, it is more economical to use large-sized mesh gabions (120 x 100mm) filled with large stone.

The thickness of the mesh wire should be more than 3mm.

Mesh should be of the hexagonal double-twist type. With the double twist, the mesh increases in strength, and retains its shape and strength when the gabions are subjected to settlements and deformations.

Gabions can also be made using single-twist square mesh, also referred to as diamond mesh, which can be manufactured locally from rolls of iron wire.

Although less expensive, these types of gabions are not as solid as the double-twist mesh. The use of single-twist mesh is therefore not recommended for



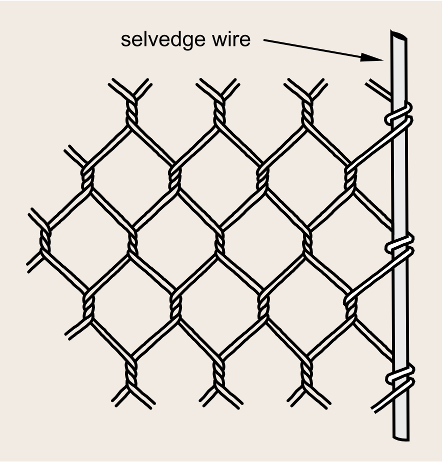
large structures which are expected to stand up to significant stresses.

Single mesh, however, can be used for constructing low-stress structures, such as small supporting walls, one to two metres high or gabion mattresses.

Selvedge and Binding Wire

The edges of the gabion mesh are strengthened with a 6 mm galvanized selvedge wire. The selvedge wire is also used for binding together the cage sides.

Binding wire, used to assemble the cage and for connecting several gabion boxes, should be of 4 mm diameter.

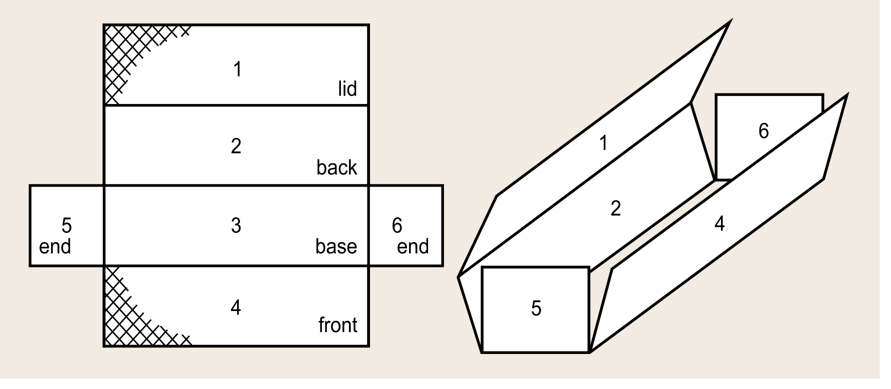


6.3 Assembling the Cages

STEP: 1

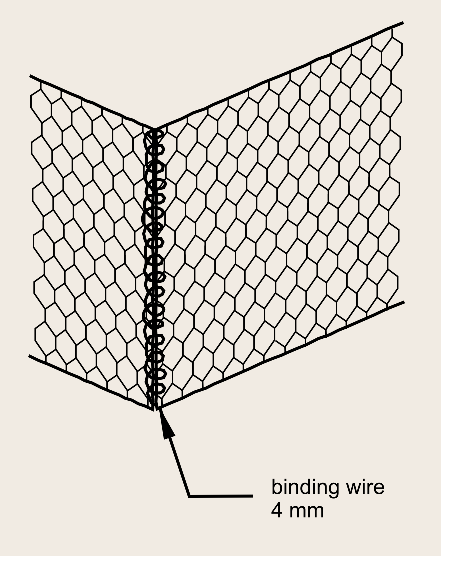
To save space and in order to pack the gabions more effectively, gabion boxes are normally assembled after they have been transported to the work site. The cages are unfolded in a suitable location where there is sufficient space for their assembly. This can either be at the site camp or in close proximity to the actual location where the gabions will be installed.

If the works project includes a considerable amount of gabion works, it is useful to set up a temporary assembly at the site camp with dedicated workers allocated for this purpose only.



STEP: 2

The sides are connected using 4mm galvanized binding wire securing all edges every 15 cm with a double loop. To avoid damaging the surface of the wire, avoid using wire cutters. Pliers alone should be used for this purpose, as these will not damage the wire. To ease binding, the 4mm wire can be replaced with a double binding of 3mm wire. If the gabion is fitted with diaphragms, they should be fixed using the same method.



STEP: 3

The basket is then placed in its final location. The empty gabion baskets should be placed on a smooth and firm foundation. Once the filling of the basket starts, it is no longer possible to adjust its position. The cage should be oriented so that the open lid does not hamper the filling of the cages.

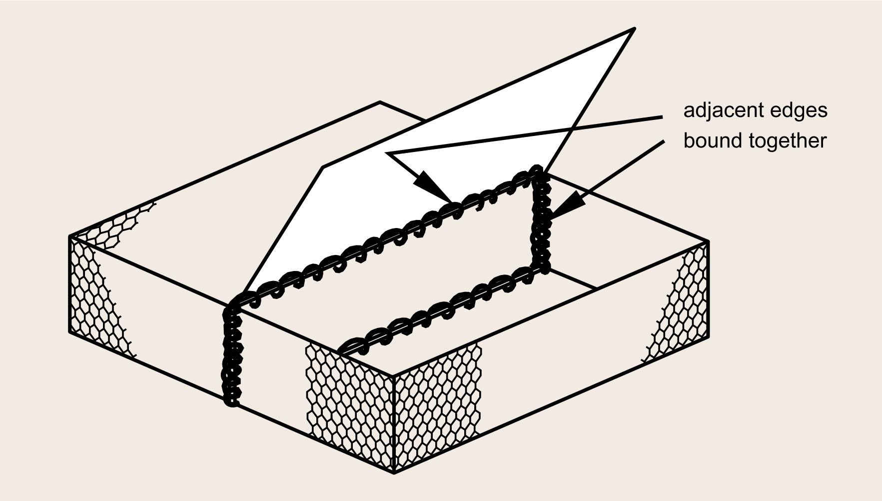
To secure continuous and even surfaces, all the gabions boxes required for each row or level should be put in place at the same time. The gabion should be stretched to its full size using wooden pegs to hold the base layer of gabions in position. A crowbar can be used to stretch the gabion cage, by placing it through a mesh hole near the corners of the cage and thereby forcing the free sides of the cage into their final positions. Before filling the next layer of gabions, the cage should first be properly stretched and tied to the underlying layer.

STEP: 4

The empty gabion baskets are fastened to the adjacent baskets along the top and vertical edges. Each layer should be fastened to the underlying layer along the front, back and ends. The joining of cages should be done at the selvedge wires and not through the mesh itself.

Along the length of the structure, the vertical joints between basket units of adjacent tiers or layers should be staggered horizontally and vertically by at least one cell.

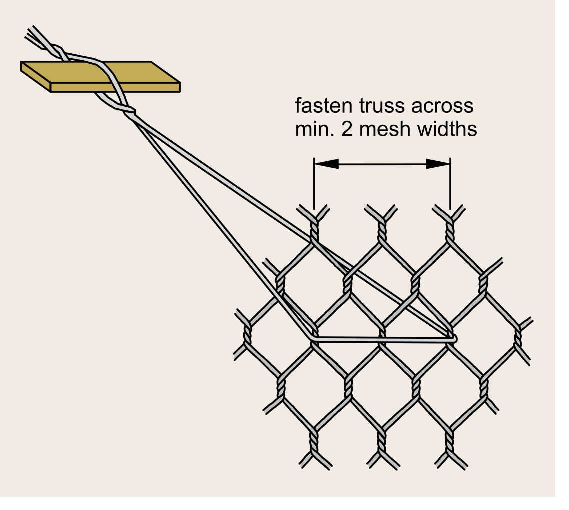
Proper binding between the cages provides a solid overall structure.



STEP: 5

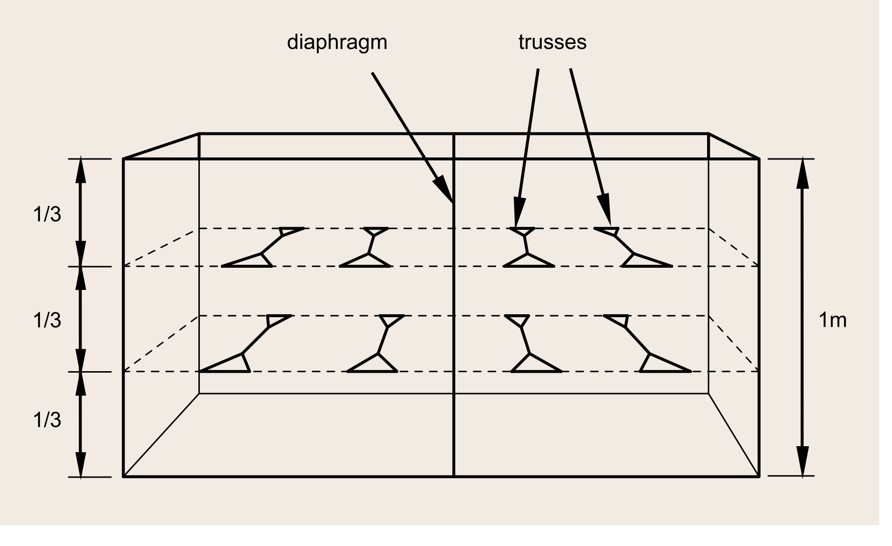
In order to increase the rigidity of the gabion, trusses are fitted into the cage. The trusses help maintain the shape of the gabion and reduce bulging of the vertical sides of the cage. Trusses are more important inside the outer gabions, which provide the overall outside surfaces of the structure.

When fitting the trusses, they should be attached to two or three wires of the mesh to prevent them from stretching or breaking, thereby spreading the traction borne by them over a sufficiently wide area of the mesh.



Trusses can be installed both horizontally and vertically. Vertical trusses are attached to the bottom of the cage, their other end being left free until the gabion has been filled with stones. They are then attached to the closed lid.

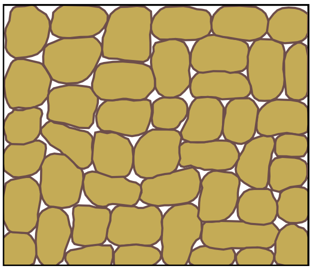
When using good angular rock, which is properly packed into the baskets applying similar methods as when building dry stone masonry, the need for trusses is reduced. The use of trusses is more important when the gabions are filled with round river stone.



STEP: 6

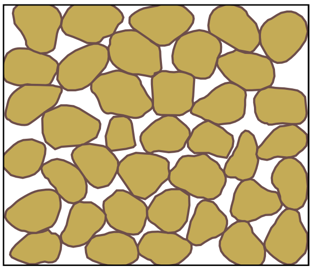
Filling the Gabion with Stone

Stone can be obtained from quarries, riverbeds or gathered and extracted from the ground. The supply of stone can be organised by recruiting local labour paid on a piece rate basis. The collected stone is stockpiled close to a road or track where it is then loaded and transported to the work site.

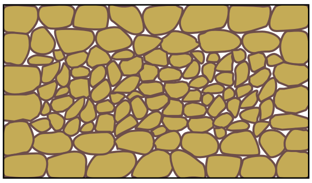


correctly filled gabion

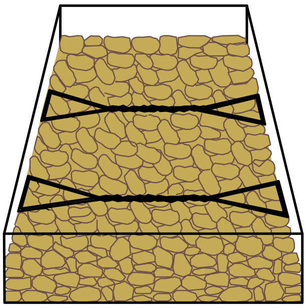
The requirement of the stone is basically that it is of sufficient size so it does not slip through the wire mesh, and that it is hard enough to withstand the pressure of the stone loaded on top of it. The size of the stone can be easily checked using an iron ring (a gauge made from an iron rod), the diameter of which is 1.5 times larger the size of the wire mesh. Filling should be carried out by hand and the stone should be individually and tightly packed with a minimum of voids. They should not just be tipped into the baskets. Smaller-size stone can also be used, provided they are not placed next to the mesh but are put at a distance at least three times the size of the wire mesh. However, on no account should stone of less than 8cm diameter be used to fill the gabion, even if they are placed well inside. Start the filling at the corners and edges and work in. The filling is carried out up to the first level of trusses. Boxes one metre high are filled to one third of their height before the first set of trusses are installed.

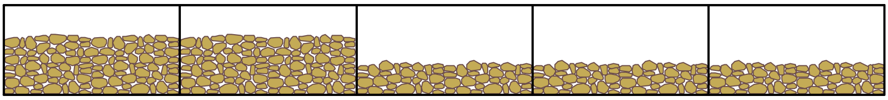


poorly filled gabion



Horizontal bracing wires are fitted and tensioned with a windlass to keep the vertical faces even and free from bulging. The adjacent baskets are then filled to the same level before filling to the next level of trusses. The top of the stone fill must be level and no stone should protrude against the mesh. The stone should be carefully packed to about 30-50mm above the top of the box walls to allow for settlement.

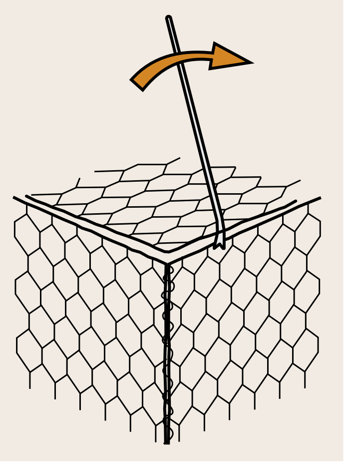




STEP: 7

The final operation consists of placing the lid, tying the vertical trusses to the lid, and binding the edges of the lid to the body of the gabion.

The edge wires of the gabion are stretched together using a crow bar, to join the lid to the rest of the gabion. The lid is finally secured by binding the joint using a single length of 4mm wire.



6.4 Common Layouts for Structures Using Gabions

In the context of rural road works, gabions are mainly used for retaining unstable soils. The poor stability may cause the collapse of steep side cuts or erosion close to various bridge and culvert structures. Erosion may also be caused by rivers or streams, requiring protection of roads close to riverbanks, or erosion of the riverbeds itself which in the next turn may cause undermining of bridge and culvert foundations. Finally, it is worth mentioning the use of gabions to protect soils from scouring due to concentrated water runoff from culverts and other cross-drainage structures.

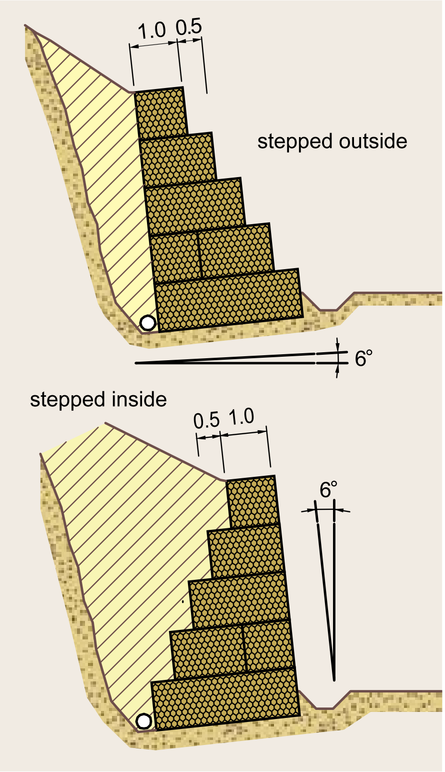
Retaining walls

When road construction is carried out in steep mountainous terrain, it is often necessary to cut the road into steep side slopes to obtain the required road width. Retaining walls are used to stabilize cut slopes vulnerable to landslides and to control erosion of the surface of the side slope. Retaining walls are also used for stabilizing the fill side of the roadway. Equally important, the retaining walls can limit the area of earthworks surrounding the road by controlling the erosion of land on the hillside above the road, and by containing the fill area on the lower side of the road.

The most common retaining wall is the gravity walls. Gabion retaining walls are easy to construct and rely on the weight of the stone to provide the required stability. Once installed, vegetation can be re-established on and around the gabions, allowing them to blend into the surrounding landscape.

Gabion walls follow typical design standards for gravity retaining walls. The wall base width is normally between 1/2 to 2/3 of the wall height. A conservative rule is to use a base width equivalent to 2/3 of the height of the wall. Additional stability is achieved by placing the foundation 0.3m in depth to better absorb the compression and shear stresses. The surface of the wall can have continuous sloping or be stepped back with each successive course. When using a smooth front face, the wall should be placed on a 6 to 10 degree batter. Gabion walls should have a minimum of 0.5m horizontal set back for each metre vertical lift.

Backfill behind the wall should consist



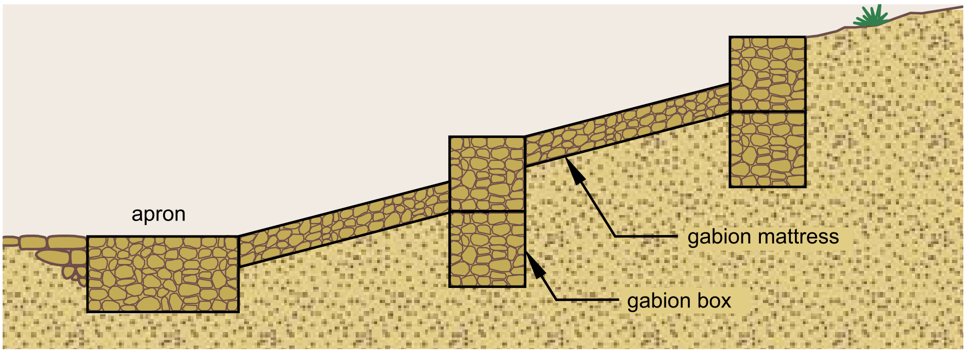
of self-draining materials such as sand, course gravel or stone. The soils should be compacted in layers, and if possible using mechanical equipment. The foot of the backfill should be fitted with adequate drainage to avoid the soils from saturating with water.

6.5 Drainage Structures

Gabions are commonly used for erosion protection on cross-drainage structures such as drifts, culverts and bridges. The gabions are used for protecting road approaches, abutments and piers and can also be used for building cut-off walls and aprons. Gabion mattresses are often used as part of these structures to provide a stable riverbed close to the structure. Mattresses are also used as a foundation on which protection walls of gabion boxes are built.

Gabions are also useful when building weirs to stabilize eroding gullies and the downstream areas of cross-drainage structures which may trigger erosion and the formation of gullies. The gabions are then used to protect the soils from scouring as well as controlling the flow of the water.

Similar to scour checks in side drains, gabion boxes can be used to construct check dams to slow down the flow of water in gullies. Gabion mattresses can be used as aprons below the check dams.



6.6 Bank Protection

Protecting riverbanks from soil erosion is often carried out using gabions in various shapes and designs. This includes bank protection against flooding where the road is situated close to rivers and streams. Gabions are also commonly placed downstream of culverts to prevent spill water from causing erosion to the land areas below the road.