Irrigation Manual
Module 13

Construction of Irrigation Schemes

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Harare, 2001

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AC	Asbestos Cement
c/w ratio	cement/water ratio
HPC	Height of Point of Collimation
PE	Polyethylene
SABS	South African Bureau of Standards
uPVC	unplasticized Polyvinyl Chloride
ZGCC	Zimbabwe General Conditions of Contract

Chapter 1
Introduction

Irrigation projects, like any other project, have a promoter who is responsible for the provision of funds with which to execute it. This could be a government, a donor, or in some cases the users themselves, such as a group of farmers or even an individual farmer. The promoter appoints an engineer to assume the overall engineering responsibility for implementing the project on their behalf.

The responsibility of the engineer starts with the design of the project and extends through the supervision of its construction. The engineer participates in the preparation of the feasibility report of the project, which shows the scope of work and estimated project costs. Once the promoter and farmers or end users accept the project, the engineer can proceed to prepare tender documents for the execution of the works (see Module 12). Tenderers submit offers, showing the cost of and time schedule for the construction. The engineer will then make a comparative analysis of the tenders and make recommendations to the promoter. The promoter, also called the client, will then accept one of the tenders and sign a contract with the selected tenderer. At this point, the tenderer becomes the contractor and the client or promoter becomes the employer of that contractor. Construction activities then start.

Irrigation projects are capital projects that need to follow general contract procedures during their implementation. At the centre of these procedures is the employer-engineer-contractor relationship. This relationship defines the contract management between the parties involved, one which is bound by the general conditions of contract (see Module 12). In order to accomplish the job as per the contract, the contractor needs an effective project management system at the organizational level as well as at the operational level on the site (Chapter 2). Time scheduling or programming of activities for construction shows how the works should be organized and what resources mobilized in order to meet the targeted objectives in the implementation of the project (Chapter 3). Finally, this module will look at the way some of the most common construction activities are actually carried out (Chapters 4-7). In reading these last four chapters, the reader will need to refer to the modules dealing with the design of surface, sprinkler and localized irrigation systems (Modules 7, 8 and 9).

Chapter 2
Contract management

Contract management comprises the management of the construction site, its activities and its resources under the agreed conditions of contract.

The construction of an irrigation scheme should be viewed as a project in itself. A project is defined as a set of activities that are linked together over a period of time and are carried out to produce specific goals. Project management is the planning and the control of the project activities to ensure that the goals are achieved in time and within the budget.

Management includes the following three processes:

1. Organization: refers to roles, responsibilities and reporting structure
2. Planning: refers to resource planning and activity planning
3. Control: refers to control meetings and control points

These three processes are a necessary part of project implementation. They apply to irrigation projects as much as they apply to any other civil engineering project and are important to both the employer and the contractor.

There are two levels of project management:

❖ the organizational level, usually at the head office, involving the contractor and the engineer, who is appointed by the employer

❖ the operational level on the site, involving the contractor's site agent, also called site manager, and the engineer's representative at the site, also called resident engineer

From the contractor's point of view, the contract manager and the site agent are responsible for the management of the contract. From the employer's point of view, the engineers are responsible for managing the contract. Therefore, the management of the contract is a joint responsibility of the two parties at both project management levels.

2.1. Overall project management

The contractor has to put in place an effective project management team in order to execute the project on time and within the budget. It is therefore important at this stage to define the relationship between the employer, the engineer and the contractor so as to understand how the construction project has to be managed (Figure 1). The roles and responsibilities of these three parties involved should be well defined and spelt out in the general conditions of contract. They may vary from country to country but they largely address the same issues.

The following definitions help to clarify the role of the different actors in managing a contract:

❖ **Contract**: A contract is a legally binding agreement entered into between the employer and the contractor for the execution of the works desired by the employer. It is also an expression of the willingness of the employer to pay the contractor and of the contractor to do the work as per the agreement.

❖ **Contract documents**: Contract documents consist of the following documents: conditions of the contract, specifications, drawings, priced bill of quantities, schedule of timing of works, schedule of rates and prices, the tender and the contract agreement. Signing of the contract agreement is an endorsement that both parties are happy with the contents of the contract documents.

❖ **Employer**: The employer, also called the promoter or initiator of the project, is responsible for providing the funds for the project.

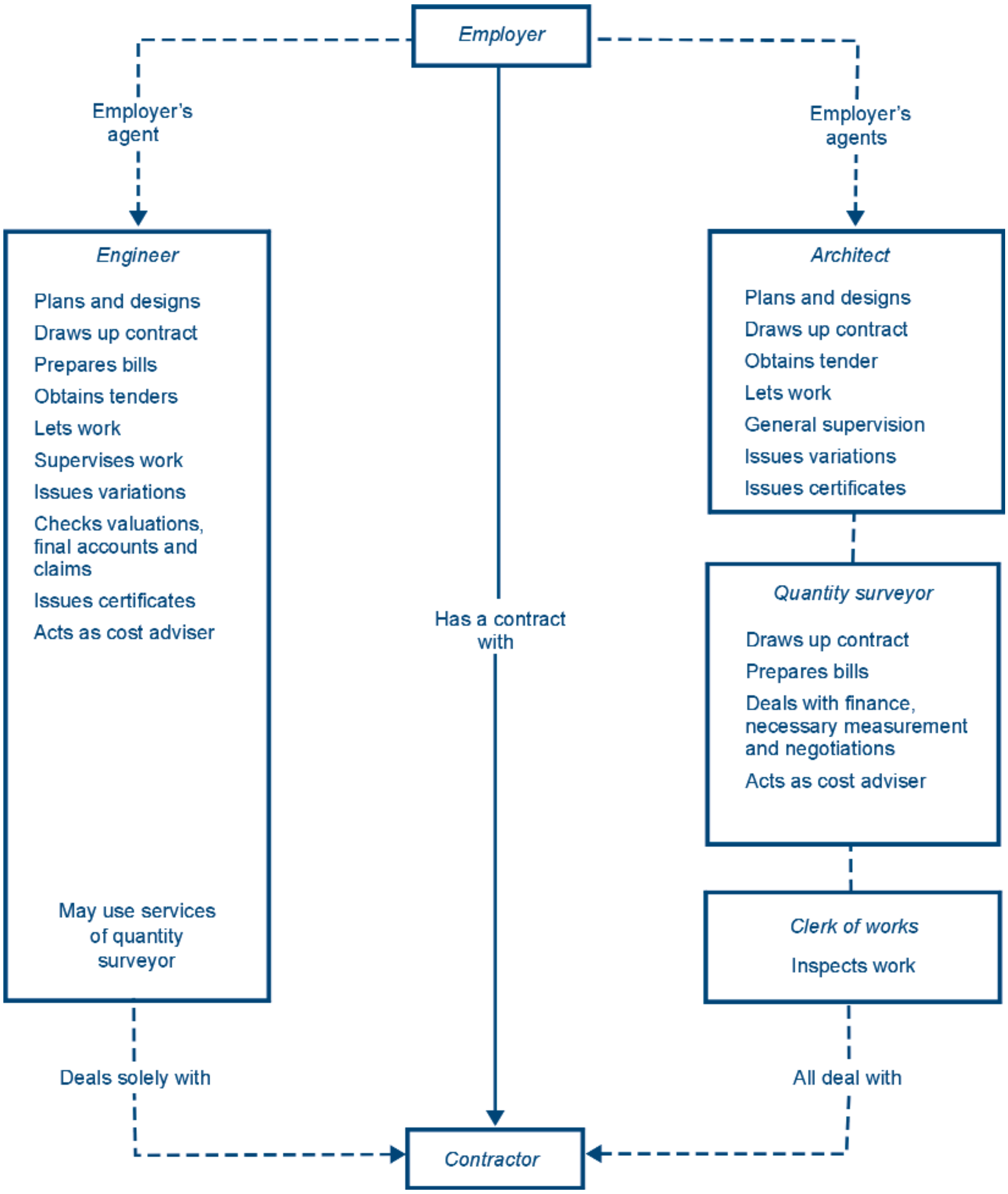
❖ **Engineer**: The engineer is the person appointed by the employer and notified in writing to the contractor as having the overall engineering responsibility for the design and supervision of the construction of the project.

❖ **Resident engineer**: A resident engineer is the engineer's representative on the site of the works. The resident engineer discharges the functions of the engineer upon delegation of such powers and authority by the engineer in writing to the contractor. Otherwise, the duties of the resident engineer are to watch, supervise the works, test and examine materials to be used and the workmanship in connection with the works. As shown in Figure 2, the engineer may appoint persons to assist the resident engineer. The contractor should be notified of such persons and their functions.

They do not have power to issue instructions to the contractor.

- **Contractor**: The contractor is a company, firm or individual who undertakes the execution of the works. From the contractor's point of view, the contract manager and the site agent are responsible for the management of the contract. The site agent is directly responsible for managing the contract on site. From the employer's point of view, the engineer is responsible for managing the contract. Therefore, the management of the contract is a joint responsibility of the two parties at both management levels.
- **Project or contract manager**: The project manager, also known/referred to as the contract manager, is effectively responsible for contract management from the contractor's point of view and provides back-up services to the site agent. If the employer so wishes, they can also have a project manager.
- **Site manager or site agent**: The site manager, also known as the site agent, is the representative of the contractor on the site of the works. The agent is a legal requirement for most contracts. They receive instructions from the engineer, which become binding on the contractor. As far as the contractor is concerned

Figure 1
Overall employer-contractor roles and responsibilities



the agent is primarily responsible for the successful completion of the works with due regard to time, workmanship, safety and the cost. The site agent is responsible for a whole host of activities, chief among which are: planning, organizing, administering, engineering, personnel and plant management, and financial control. Site management is in fact the management of resources. The resources are known as the 5 M's, being: Methods, Men, Machines, Materials and Money. Besides this, the site agent also has to manage time. This is the reason why there is a need for the site engineer to have good resources and activity plans prior to the commencement of construction work. This has to be backed up by competent site staff and regular control and progress assessment meetings. The resource and activity plans are obtained by time scheduling for construction, which will be discussed later.

- **Sub-contractors**: The main contractor may decide to sub-contract part of the work to some other specialist firms. Such firms, not forming part of the contract, are known as sub-contractors. The engineer should approve the choice of the sub-contractor. The main contractor controls sub-contractors. The site personnel of the engineer, main contractor and sub-contractor should be conversant that the aspects of the contract agreement and conditions, which govern the employment of sub-contractors.

Figures 1 and 2 present the relationships between the different parties involved.

Table 1 presents the division of the responsibilities between the contractor and the engineer during the different stages of the project, while Table 2 presents the responsibilities of the contract manager and their site manager.

Table 1
Division of responsibilities between contractor and engineer

CONTRACTOR	ENGINEER
Head Office	
Arrange insurance, etc.	Check and approve
Appoint site representative	Ensure employer has advised contractor of the appointment of the engineer
Site	
Execution of work:	Supervise:
– Establish site	– Establish site
– Set out works	– Check and approve
– Site preparation, earthworks, foundations, etc.	– Test, check and approve
– Execute specified details	– Supervise, check and approve
– Manage sub-contract work	– Supervise, check and approve
– Query specifications and drawings	– Clarify and issue variation order if necessary
– Differ on instructions	– Give opinion
– Claim where necessary	– Agree or otherwise and pay if valid[1]
– Order materials	– Approve
– Comply with labour regulations	– Ensure
– Manage and operate plant	– Check ownership and approve
– Measure work	– Check, agree
– Apply for payment	– Check and authorize payment by issuing an Interim Payment Certificate[2]
– Clear site	– Issue Completion of Work Certificate[3]
Head Office	
– Maintain throughout maintenance period	– Carry out final inspection
– Apply for Final Certificate	– Issue Final Certificate[4]

1 Head office may have to be involved.

2 The payment by the client should be within the specified time.

3 Completion of Work Certificate is usually accompanied by refund of some retention monies..

4 Refund of all retention monies becomes due and the contractor is relieved of their contractual obligations save for latent defects for which the contractor becomes liable in perpetuity.

Figure 2

Diagrammatic presentation of employer-contractor lines of communication

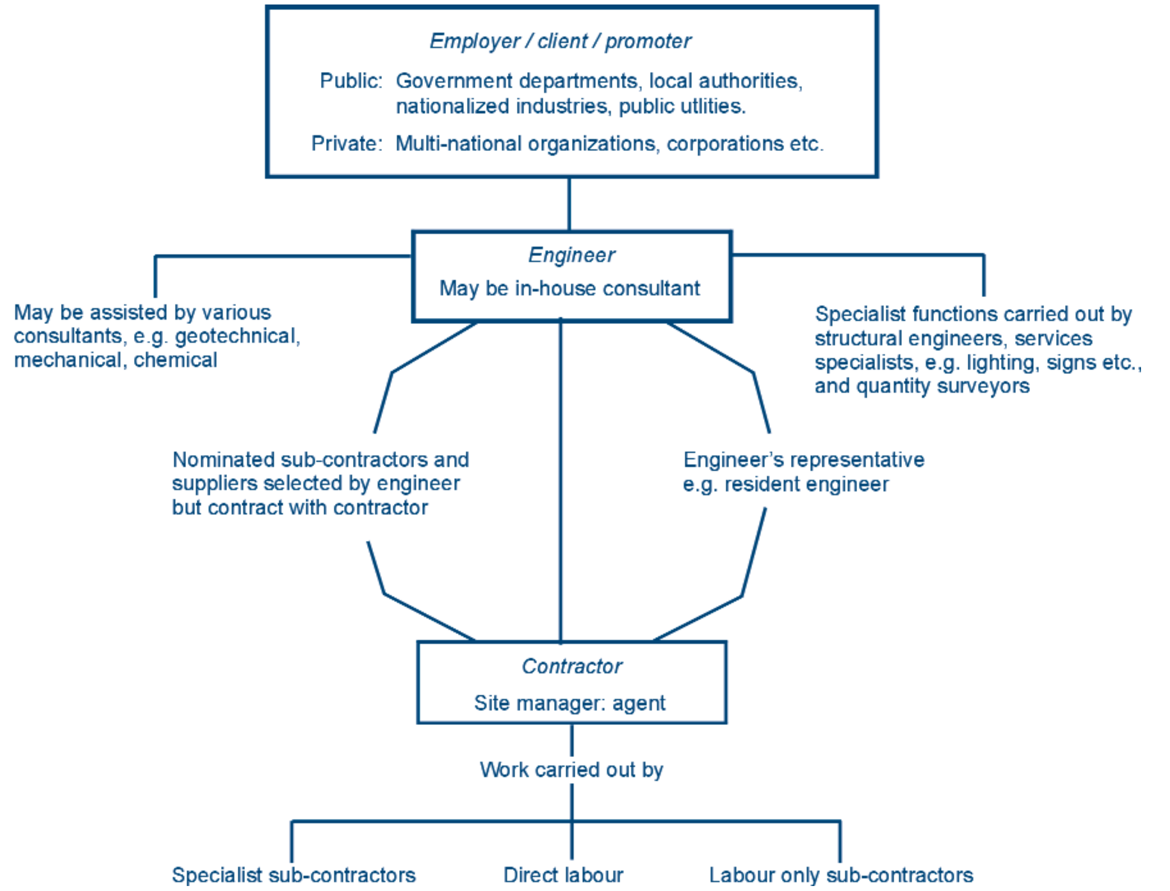


Table 2

Responsibilities of contract manager and their site agent

CONTRACT MANAGER	SITE MANAGER
– Implementation of company mission	– Implementation of the contract
– Maintenance of capital base	– Supervision of work
– Financial control, budgeting and reporting	– Compliance with contract specifications and drawings
– Creditor and debtor control	– Setting out of the works
– Insurances and bonds	– Quality control
– Purchases	– Liaison with engineer and their representative
– Selection of sub-contractors	– Programming and scheduling activities
– Liaison with employer and other bodies	– Resource scheduling
– Inter-departmental coordination	– Materials management
	– Stores control and stock taking
	– Measurement and certification of works
	– Variations/claims for additional expenses
	– Price variations
	– Maintenance of contract correspondence and records
	– Control of sub-contractors
	– Design of temporary works
	– Compliance with statutory regulations
	– Maintaining site diary
	– Labour and plant control
	– Welfare and safety of workers on site
	– Returns to head office

2.2. Site management

The contractor's site manager has a lot of responsibilities. For small projects they could just have an engineer, general foreman, transport foreman, cashier, timekeeper and storekeeper under their supervision. For large projects, they can be the chief executive of a site management team, comprising a compliment of professional technical and administrative staff. In general, the larger the project the larger the number of staff.

2.2.1. Staff management

The composition and responsibilities of the staff under the site manager are generally as follows:

- **Engineering staff**: Responsible for the design and general guidance of all engineering works, such as programmes of construction and setting out.
- **General foreman**: Responsible for the day-to-day distribution of plant and labour, supervision of flow of materials and upkeep of site communication systems. They are also the link between management and labour.
- **Plant and transport managers**: Responsible for the running and maintenance of transport and equipment on site. Uninterrupted transport and use of equipment will help improve the progression of the construction activities.
- **Office managers**: Carry out administrative responsibilities of the project. These include accounts, stocktaking, cash transactions and generally ensuring that the standing instructions from head office are adhered to.
- **Timekeepers**: Record labour force attendance and prepare pay-sheets to submit to the office manager. They need to liaise closely with the foremen in order to keep track of attendance of the labour force.
- **Storekeepers**: Duties include checking in and out and safeguarding all materials at the construction site. They also receive and issue tools that will be used during construction.

2.2.2. Materials management

Materials constitute a large proportion of the cost. The contractor needs to take care to purchase the right quality and quantities at the correct place, time and price.

The employer's engineer specifies and approves the materials. The contractor's site manager processes the requisitions, places orders through their relevant staff, receives and holds the materials in store. The contractor's accounts section then pays for the materials and maintains the receipts and records.

There is a need to ensure that the materials are correctly used for the jobs they were purchased for in order to avoid waste and theft. It is necessary to carry out random checks to ensure that the quantity received is equal to the quantity in works plus the quantity in stores. Storage facilities for the equipment and materials should be designed in such a way as to minimize thefts or damage due to bad weather and breakage. Materials should always be checked against their invoices.

2.2.3. Equipment management

Construction equipment or machinery is mainly selected on the basis of technical performance and economic viability of utilizing that particular equipment instead of another equipment or instead of manual labour. The considerations for either hiring or buying equipment for the contract depends on:

- The scale of works in terms of value and volume of works
- The construction period
- The methods of excavation, concreting, erection, etc., envisaged in the contract
- The type of equipment required and its market availability as well as cost of hire

The most important factor determining whether one buys or leases equipment is its utilization. Owning equipment means being subject to the following costs: capital and depreciation, residual value, interest and insurance. Operating the machinery involves costs such as maintenance and repair, fuel, lubricants and other consumable costs as well as the operator's costs.

The manufacturer provides the basic data on the output of machines. However, other factors, such as operator fatigue, site conditions, climate and others, have an effect on reducing the output as indicated by manufacturers.

When planning the purchase of new equipment or models, it is advisable to beware of the fact that some literature provided by suppliers may be misleading. Sometimes demonstrations may be rigged and therefore it may be wise to first hire the model for some time before actually purchasing it.

2.2.4. Maximizing profits

Profit is the difference between the income and the costs. From the point of view of the contractor, site management should maximize income and minimize costs. Good planning in order to avoid crisis management, making the correct choice of methods, good equipment and material management, good quality control and good relations with the workforce all minimize costs. Ensuring correct measurement and claims and increased production can maximize income.

The quality of work sets the platform on which the engineer and the site manager base their relationship and therefore it determines the ultimate success of the project. This can be a major source of disputes and can lead to high costs. Safety can be a high cost due to the cost of accident claims. The project costs are also related to the duration. Good programming and progress control are the tools to be used to minimize the progress-related costs.

2.2.5. Settlement of disputes

It is important to look at how disputes between the contractor and the employer could be dealt with, as they can be a cost to either party if not addressed carefully.

It is essential to document communications between the engineer and the site manager at each stage. Sometimes, what may appear to be a minor issue to the engineer may be handled as a major issue by the contractor and vise versa. The engineer should copy all letters and communication notes to the employer so that they are well informed about the possibility of a growing dispute. The most important thing is to be as diplomatic as is possible. The following guidelines on settlement of disputes can be followed and in this order:

1. **Conciliation**: This is an informal gathering of interested parties who try to solve the problem by reciprocally giving some room to each other. If this fails, either party could go for mediation.
2. **Mediation**: Mediation is a formal gathering with an experienced chairperson as the mediator. The mediator will give an opinion, which is not binding to either party. If mediation fails, the next option is arbitration.
3. **Arbitration**: The arbitrator has to be acceptable to both parties. There are rules in every country of how arbitration should be conducted. Generally, the recommendations of the arbitrator are binding and there is no appeal. However, any of the parties could still decide to go for litigation.
4. **Litigation**: In such a case the matter is brought to court. This is invariably an expensive and drawn-out affair. Therefore, by all means and wherever possible, solutions for the disputes between the employer and contractor should be found in-house.

Chapter 3
Programming construction activities

The process of programming construction activities is a continuous one. It involves organization, planning, control and re-organization. It incorporates all estimated resources required and the estimated time of completion of the activities. Planning, involving activity and resource planning, is deciding what is to be achieved and how to achieve it. It is a process of looking forwards and anticipating the future.

Control is comparing what has been achieved against what was planned and therefore looks backwards and taps on previous experience. Re-organization is the re-orientation of the requirements according to the findings of the control process. There are several techniques of programming, such as cumulative progress charts which are also known as 'S' curves (Figure 3) or bar charts (Figure 4).

Figure 3
Cumulative progress charts or 'S' curves

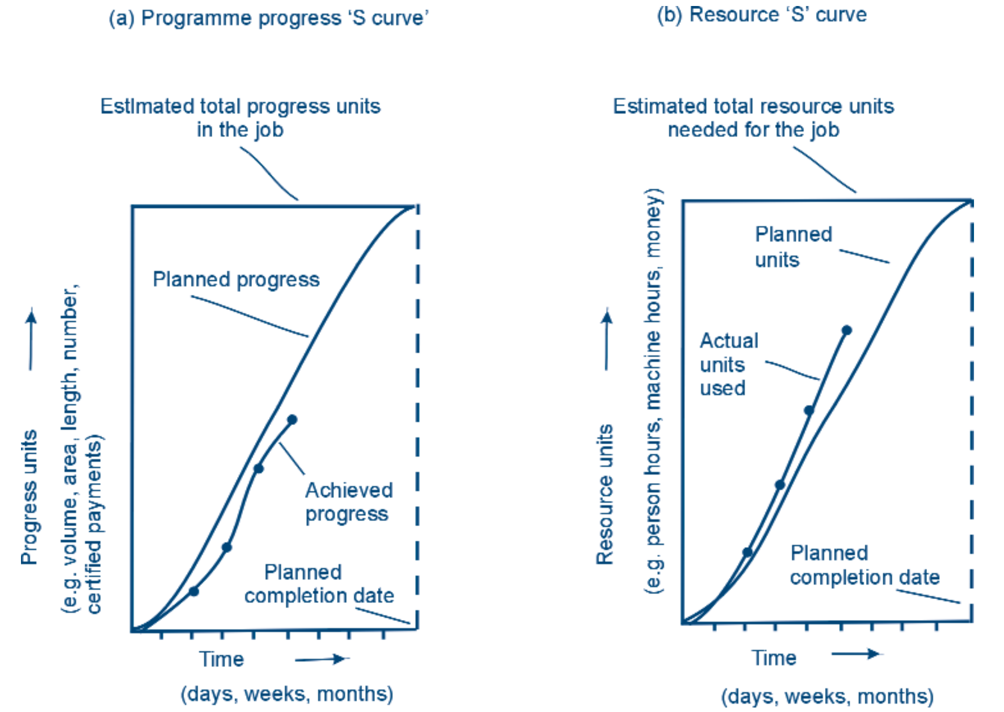
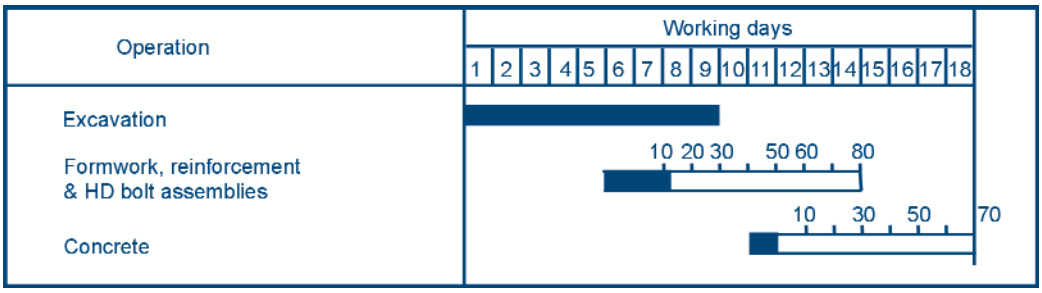


Figure 4
An example of a bar chart



Before any activities commence, an activity plan and a resource plan have to be produced. The activity (or programme progress) plan shows the activities completed, such as volume of trenching, pipe length laid and canal length constructed, depending on what detail is required. The resource plan shows the person-hours, the machine hours and the money used. The activity and resource plans cannot be made without knowing the performance of equipment and labour to be used on the project.

3.1. Equipment requirements

Below follows a short description of different types of equipment that could be deployed for the construction of an irrigation project and their common uses:

- **Bulldozer**: Used to carry out works such as bush clearing, movement of soil for short distances, cutting thicker layers of soil during land levelling, levelling of anthills, making drains and flood bunds.
- **Scraper**: Wheeled or crawled tractors pulling a wheeled bucket of up to 30 m^3 volume. The scraper cuts soil with a sharp blade at the front bottom of the bucket. The soil is stored in the bucket and can be released at the required location. These are ideal for carrying soil over long distances, for example during land levelling operations or to make up canal embankments.
- **Grader**: A machine with a blade approximately half way its frame. It is used to construct drains, roads, etc., and to carry out more accurate land levelling operations than a scraper can do. Graders can be motorized or towed by a tractor. The latter are much slower in carrying out the jobs and, depending on the job, a powerful tractor is required for towing these graders.
- **Dragline**: A machine with a bucket attached to ropes. The bucket can be thrown over a distance of up to 15 m away. Draglines are used for excavation works in construction pits, for digging and cleaning canals, etc.
- **Excavator**: A machine with a bucket, which is hydraulically operated. It is usually crawler mounted for ease of working in muddy conditions. It can carry out the same jobs as the dragline although its reach is shorter, usually not exceeding 10 m. It is often used for canal and pipe trench excavations and to load soil onto tippers.
- **Land plane** : Consists of a long-wheeled frame with a blade. The blade is tilted forwards at the top. It is used for final land levelling and can be accurate to 2-3 cm.
- **Loader with backhoe**: A large tractor-like machine with buckets in front and behind. It is used for excavations of canals and trenches for pipes, loading soil, etc.
- **Lorry**: Used to carry materials and equipment to the project site.
- **Tipper**: Used to carry materials and equipment to the project sites. They are suitable for transporting soil, sand and coarse aggregate as the back of the truck can be hydraulically lifted, thus facilitating easy offloading of bulky materials.
- **Lowbed with horse**: A large, flat trailer usually pulled by a heavy vehicle, the horse. It is used to transport large machinery, such as bulldozers, scrapers and graders over long distances to project sites.
- **Tractor and trailer** : Used for transporting materials and small equipment, usually within the project area.
- **Dumper**: A small vehicle with a container in front. The capacity of the container can vary from 300 to 1 300 litres. It is used to carry materials, such as concrete, on the project site.
- **Concrete mixer**: Has a pan or drum driven by an engine and is used for mixing concrete. The blades inside the pan or drum facilitate the mixing of the concrete. Some mixers have weighing equipment attached, to mix the concrete by mass rather than by volume. The size of the mixers can vary from as small as 35 litres yield to well over 100 litres yield per mix.
- **Poker**: A mechanically-moved stick used for the compaction of concrete through vibration.
- **Bowser**: A tank for storing water, fuel, etc., on project sites. Bowsers have varying capacities and are normally mounted on wheels.
- **Roller or compactor**: A heavy cylinder, which is moved mechanically or by hand. It is used for compacting soil. A compactor is also used for compacting the soil, using a vibrating plate.
- **De-watering pump**: This is a small pump used to pump water away from the construction site, for example trenches or construction pits.

Figure 5 shows drawings of some of the equipment expected to be relatively available in most countries in the region. More sophisticated equipment than shown here is of course available in richer countries. Figures 6-11 are pictures of some of this equipment.

Figure 5
Examples of the different types of equipment used in construction works

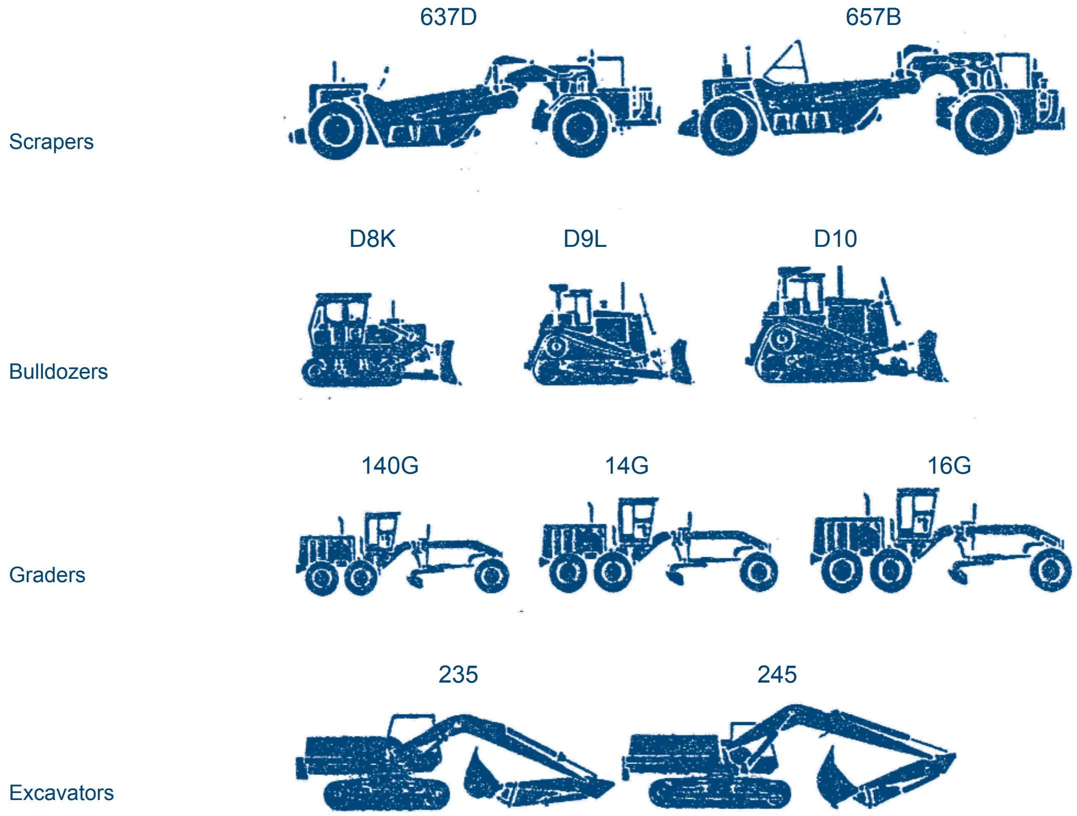


Figure 6
Wheel-tractor scrapers at work, CAT621G and CAT627G (Source: CAT, 2001)

Figure 7
D10R Dozer (Source: CAT, 2001)

Figure 8
A hydraulic excavator (Source: CAT, 2001)

Figure 9
A motorized grader, CAT120H (Source: CAT. 2001)

Figure 10
Wheel loader at work, CAT928G (Source: CAT, 2001)

Figure 11

Articulated truck or tipper, CAT730 (Source: CAT, 2001)

3.2. Performance of some equipment

The manufacturer will provide the data pertaining to the performance of a particular make of machinery. A big difference can occur between the performance quoted by the supplier and the actual performance. This can be attributed to a number of factors, such as the skillfulness of the operator, availability of a continuous supply of spare parts, lubricants, fuel, maintenance and repair, climatic factors and site conditions among others.

For the purpose of this module, some data for estimating earthworks have been provided, which can be used for estimating machine requirements for different jobs. Since time is needed for re-fuelling, repairs and other maintenance work on the machines, it can be assumed that the net working time per machine is 5 machine hours per shift of 8 hours.

3.2.1. Bulldozer

For an average dozing distance of 50 m, the performance would be:

- Average soil (loose) : 60 m^3/machine hour
- Average gravel : 40 m^3/machine hour

3.2.2. Scraper

The capacity of scrapers per load may vary from 6 m^3 for a model 613B to 30 m^3 for a model 851B, thus the performance will also vary. Figures 12 and 13 show typical performance curves from manufacturers for a caterpillar wheel tractor-scraper.

Figure 12

Hourly production versus cycle time performance curves for a wheel tractor-scraper

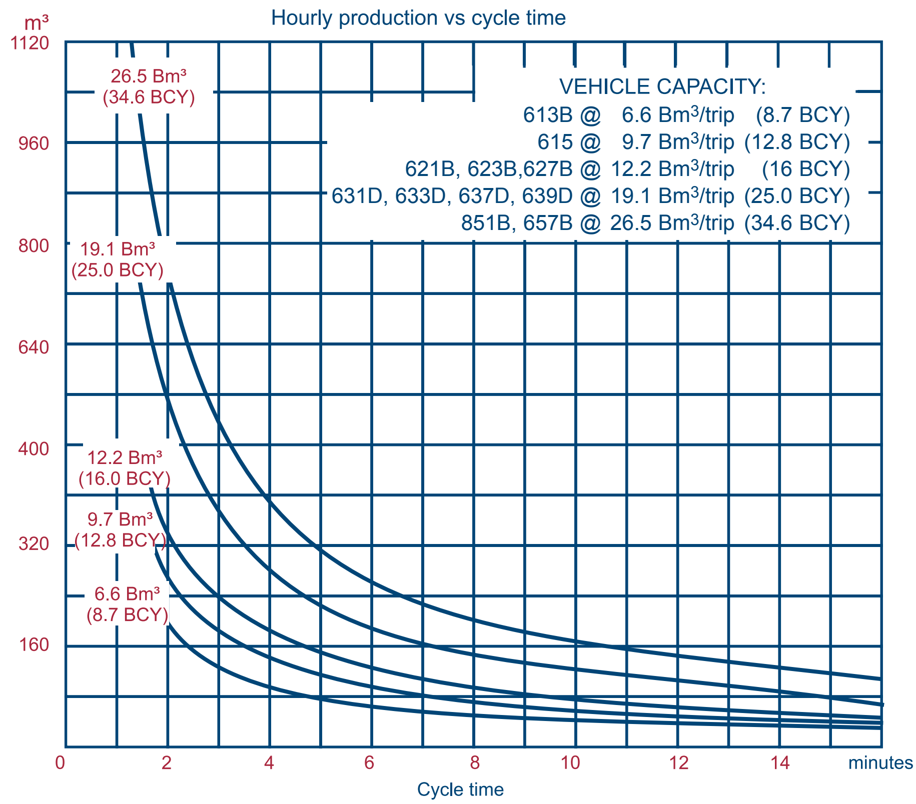
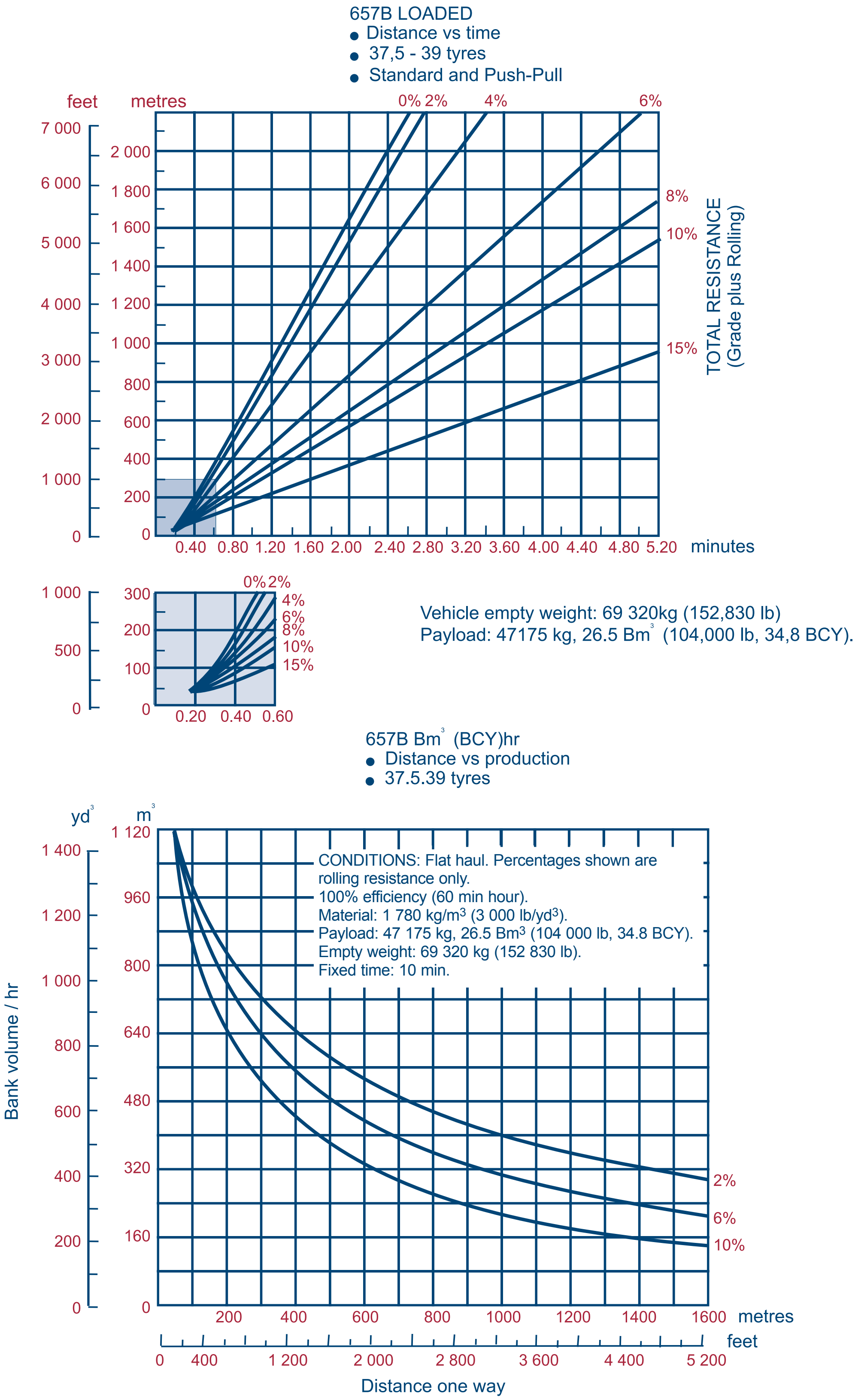


Figure 13
Typical performance curves for a wheel tractor-scraper



3.2.3. Grader

With a relatively experienced operator, a grader can level approximately 0.5-1 ha per working day, assuming a cut and fill of up to 20 cm. The required time depends on the soil type and the distances of soil movement. It is estimated that 50 m of 1.5 m wide field drains together with 50 m of 2.5 m wide infield roads can easily be done per hour.

3.2.4. Dragline

Table 3 gives estimates of excavation quantities for draglines.

Table 3
Excavation quantities for draglines

Category	Bucket size (litres)	Excavation per machine hour (m^3)
a	350	20
a	700	35
b	350	30
b	700	50
c	350	24
c	700	45

a *Digging or clearing of drainage channels with heavy weed infestation in wet conditions and dumping soil sideways.*

b *Digging channel in average soil in dry conditions and dumping soil sideways.*

c *As b but loading soil in dump-cart or lorry.*

It should be noted that there should be a relationship between channel size and bucket size. As an example, there is no need to employ a dragline with a large bucket for the excavation of a small channel.

3.2.5. Excavator

An excavator can be slightly more efficient than a dragline, but it has a smaller reach. A CAT215 excavator could perform as follows:

- ❖ Excavating and loading on a dump-cart or lorry: 45 m^3/machine hour
- ❖ Excavating and side dumping of soil: 65 m^3/machine hour

3.2.6. Front-end loader with backhoe

The performance of a front-end loader with a backhoe depends very much on the power of the machine. The buckets of a tractor-powered machine should be much smaller than the ones of a large caterpillar 992C wheel loader with a bucket of up to 10.3 m^3. Typical performance of a caterpillar 931B track-type with a backhoe is as follows:

If using the front-end loader:

- ❖ Loading stockpiled average soil: 33 m^3/machine hour
- ❖ Loading stockpiled gravel: 28 m^3/machine hour

If using the backhoe:

- ❖ Excavating canal and loading tipper: 13 m^3/machine hour
- ❖ Excavating canal and dumping soil sideways: 18 m^3/machine hour

3.2.7. Tipper

The performance of tippers to carry materials such as soil depends very much on the distance between the pit and the construction site, the road condition, etc. Under field conditions on dirt roads, the average carrying capacity of a 7-ton tipper is 3.5 m^3 and the average speed is approximately 15 km/hr loaded and 30 km/hr empty.

Example 1

Calculate the number of 7-ton tippers required to transport stockpiled soil, loaded by CAT931B using front-end loader, over a distance of 2 km.

Capacity of 7-ton tipper	=	3.5 m^3
Performance CAT931B	=	33m^3/machine hour
Loading time	=	3.5/33 hours or (3.5/33) x 60 minutes = 6.5 minutes
Traveling time (loaded)	=	2 km at 15 km/hour = (2/15) x 60 minutes = 8 minutes
Reversing and dumping	=	estimated at 2 minutes
Return traveling time (empty)	=	2 km at 30 km/hour = (2/30) x 60 = 4 minutes
⇒ Total time	=	6.5 + 8 + 2 + 4 = 20.5 minutes

The ratio of the loading time to the cycle time = 6.5 minutes : 20.5 minutes = 1 : 3.15

Thus 4 tippers are required to match the loading time of the loader.

3.3. Labour requirements

3.3.1. Labour for earthworks

Table 4 presents the output of manual labour in person-hours for different conditions. It is important to remember that a person-day may be considered as 60-70% of the actual hours worked, that is, for an 8 hour working day, the productive hours would be 4.8-5.6 person-hours. The number of productive hours depends on:

- The physical condition of the labourer
- The climate
- The type of tools used
- The length of the working day
- Motivation

3.3.2. Labour and equipment for the construction of concrete-lined canals

The activities to be carried out for the construction of a typical small concrete-lined trapezoidal canal (dimensions 0.25 to 0.50 m bed width, 60° side slope, 0.30 m water depth and 0.05 m freeboard) are:

- Excavating or filling, levelling the bed, forming the canal embankments
- Casting the concrete lining
- Curing

A gang of 5 skilled workers (bricklayers, surveyors) and 40 unskilled labourers, including 10 for miscellaneous jobs like sand collection and curing, could construct on average 50 m of canal per day.

The equipment required would be:

- 1 concrete mixer
- 2 tractors and trailers
- 2 water bowsers
- 1 lorry or tipper.

3.3.3. Labour and equipment for the construction of structures

Small-scale schemes often have one or more of the following types of structures:

- Measuring device
- Diversion structure
- Saddle bridge
- Drop structure
- Culvert
- Tail-end structure
- Inverted siphon

The structures could be built with concrete blocks or bricks, except for the floor, which should be concrete. A gang of 2 bricklayers and 6 unskilled labourers could construct one structure per day, except for the larger saddle bridges for which a lot of concrete casting is required. Saddle bridges could be completed in 2 working days.

The equipment required would be:

- 1 tractor and trailer
- 1 concrete mixer
- 2 water bowsers

Table 4
Output of manual labour in earthworks

Nature of work	Labour required per m³ in person-hours				
	Soil types*				
	1	2	3	4	5
1. Excavation thrown in wheelbarrows	1.0	1.6	2.0	3.0	6.0
2. Excavation filled into tippers	1.6	2.2	2.8	3.6	6.6
3. Trench excavation not deeper than 1.5 m	2.0	3.6	4.0	5.0	10.0
4. Throwing out of trench for each 1.5 m height after the first	2.0	2.0	2.6	2.6	2.6
5. Wheeling in wheelbarrows per 20 m	1.0	1.1	1.2	1.2	1.4
6. Spreading and ramming** in 15 cm layers	1.0	1.0	1.2	1.0	1.0

* *Soil types: 1. Loose soil excavated with a shovel without spading.*
2. Firm soil excavated with a shovel and spading.
3. Clay or heavy soil excavated with a shovel with spading.
4. Compact soil or gravel requiring the use of pick and shovel.
5. Soft rock requiring the use of a crow bar, pick and shovel.

** *Clay and rock can not be rammed by hand labour; therefore, in the case of clay the person-hours are for breaking up clods and spreading and in the case of rock the person-hours are for spreading the broken stones in layers.*

The normal practice is that a gang makes a number of foundations and slabs a few days in advance, after which they construct the walls and finish structures one by one. Thus the estimates above are working figures for planning purposes. They can be modified during the control process. The sequence of construction can also vary.

3.4. Use of bar charts for programming construction activities

After having calculated the time required to complete a certain job, one of several methods of programming construction activities can be employed. As an example here, the bar chart is used. The inputs to programming activities and resources are obtained from the estimates that are used in the preparation of bill of quantities for the different irrigation systems (see Module 7, 8 and 9). Since the manner in which programming is done is the same for any construction activity, the surface irrigation system is used as an example for drawing up the time schedules for construction. Where more detail is required, activity and resource plans could be drawn up separately.

In order to be able to plan the activities well, it is necessary to know which activity leads to what and how the machinery can be allocated to those activities without overlaps. The number of machines and size of the labour force depend on when the job has to be completed. It is important that all the materials and equipment necessary to start the work and keep it going are on site when required.

Table 5 presents the bar chart for construction activities of infield works of the Nabusenga smallholder surface irrigation system (15 ha) that was designed in Module 7. This was a small job, as can be judged from the resources required and the construction period. In this case, the government implemented the scheme and the irrigation engineer was at the same time the site manager and did both the technical and non-technical work with the backup of head office staff.

The construction works to be done were as follows:

- 1 measuring device
- 980 m of trapezoidal canal with a bottom width of 350 mm
- 725 m of trapezoidal canal with a bottom width of 250 mm
- 1 400 m of drainage channel
- 1 600 m of perimeter road
- 15 ha land levelling
- 3 diversion structures, one-sided

Table 5

Bar chart for the construction of a surface irrigation scheme for smallholder farmers

No	Activity	Month					No. of days	Resources required	
		April	May	June	July	Aug		Labour	Main machines
1	Site establishment	---					5		7-ton lorry
2	Procurement of materials and transport to site	--------------					42		7 & 30-ton lorry; train; tractor & trailer
3	Setting out grid and irrigation layout		------				10	irrigation engineer; surveyor; 5 unskilled	
4	Canal construction (980 m + 725 m)		--------------				35	5 skilled; 40 unskilled	7-ton lorry; concrete mixer; 2 tractors & trailers, 2 water bowsers
5	Land levelling (15 ha)			--------------			30	2 skilled; 2 unskilled	grader; land plane
6	Drains (1 400 m)				-----		5	2 skilled; 2 unskilled	grader
7	Roads (1 600 m)				-----		6	2 skilled; 2 unskilled	grader
8	Structures (12)			--------			16	2 skilled; 2 unskilled	concrete mixer; 2 tractors & trailers, 2 water bowsers
9	Fencing (2 500 m)			-------			10	2 skilled; 20 unskilled	tractor & trailer
10	Finishing, clearing				------		11	2 skilled; 20 unskilled	tractor & trailer

- 1 canal-road crossing
- 3 saddle bridges
- 5 tail-end structures
- 2 500 m of fencing

It was assumed that 1 month has an average of 21 working days (if work is executed by a private contractor, 7 days per week may be worked). The materials to be procured were: fine and coarse aggregates, cement, steel, fencing materials, formers and templates, grain bags, concrete pipes, sliding gates, check plates and siphons.

Chapter 4
Types and use of construction materials

During the design process the engineer already begins selecting the materials that are most likely to be used during construction. The selection of materials is not only based on the cost, but also on the availability of those materials, the availability of skilled labour and the adherence to standards. This chapter briefly discusses some of the most common materials used for constructing irrigation schemes, such as:

- Concrete
- Gabions
- Bricks
- Cement and concrete blocks
- Timber
- Reinforcement rods/wire

If piped sections are constructed, the following materials may be used:

- Different types of pipes (uPVC, PE, AC, steel and aluminum)
- Different types of fittings
- Flow control, measurement, regulating devices
- Automation devices, etc.

4.1. Concrete

Concrete is a mixture of fixed proportions of cement, fine aggregate (sand), coarse aggregate (crushed stone or natural pebbles) and water. It is a favourable construction material because it can be formed into almost any shape when it is still fresh and, when hardened, it has the strength required for many types of structures.

4.1.1. Important properties of concrete

A properly prepared concrete mixture should have the following properties:

- *Good workability*: It should be easy to place and compact
- *Cohesiveness*: It should be sticky enough to prevent the coarse aggregate from separating from the rest of the mixture when it is being transported, placed and compacted
- *Not too much bleeding*: When setting, water rises to the surface since the other mixture materials are heavier than water. This process is called bleeding. Too much bleeding gives poor finishing and can reduce the strength of the concrete

The important properties of hardened concrete are:

- *Strength*: This depends on the age of the concrete, the cement/water ratio, compaction and curing. The strength development is fast during the first few days, after which it gradually slows down until 28 days when there is little further gain achieved
- *Durability*: Concrete should be durable, which depends on the cement/water ratio, compaction and curing

4.1.2. Concrete components

Concrete is made up of cement, fine aggregate (sand), coarse aggregate (stones) and water.

Cement is made from limestone and shale, which are burnt at a high temperature to form cement clinker, which in turn is ground to the fine powder that is cement.

Sand is referred to as fine aggregates and is used to designate aggregates in which the nominal maximum size of particle is 4.75 mm. The sand particles should be smooth, rounded and hard. The sand required for the lining of canals is normally available in nearby rivers.

Stones are referred to as coarse aggregates and have diameters ranging from 4.75 mm to 40 mm. The stone diameter selected for the preparation of concrete depends on the structure under construction. For example, for 5-cm thick concrete-lined canals the ideal stone size is 19 mm (¾ inch). The stones should be round or chunky, hard and strong. Poorly-shaped stones, such as those that are flaky and long, should be avoided as this would mean that more of the other materials are needed. The stones should be about the same size.

Water used for making concrete should be clean. As a rule, water suitable for drinking is suitable to be used for concrete.

4.1.3. Batching

Batching is defined as the measurement of the quantities of the materials (cement, sand, stone and water) that go into each concrete mix. Batching should be done correctly as it affects the workability, strength and cost of concrete.

Quantities can either be measured by volume or by mass. The most common method used is measuring by volume, as no expensive weighing equipment is required. Measuring by volume, also known as volume batching, is based on loose volume. It can be assumed that a 50 kg bag of cement is equivalent to 40 litres of loose volume and that the yield of the mix is 60% of the loose volume of cement, sand and stone. This means that about 1.68 m^3 of cement, sand and stone is required for the preparation of 1 m^3 of concrete.

4.1.4. Concrete mixtures and mixing

Table 6 shows the approximate material requirement for some of the most common concrete and mortar mixtures. This table can be used for calculating the materials required for the job intended. Mixing sand, cement and water gives mortar, which fills the spaces between the stones and coats them thickly to keep them apart.

Thus 1 m^3 of a 1:2:3 mixture requires 7 bags of cement, 0.56 m^3 of sand and 0.84 m^3 of stone.

Concrete should be properly mixed to the required workability. This depends on the amount of water. Concrete must have the correct cement/water (c/w) ratio.

Table 6
Common concrete and mortar mixes by volume

Mixture (cement : sand : stone)	Cement (bags) (1 bag of 50 kg = 40 litres)	Aggregates Fine (m^3)	Aggregates Coarse (m^3)
Concrete			
1 : 2 : 3	7	0.56	0.84
1 : 2 : 4	6	0.48	0.96
1 : 3 : 3	6	0.72	0.72
1 : 3 : 6	4	0.48	0.96
1 : 4 : 8	3	0.48	0.96
Mortar			
1 : 2	14	1.12	
1 : 3	10	1.20	
1 : 4	8	1.28	
1 : 5	7	1.40	
1 : 6	6	1.44	

Example 2

What are the material requirements in volume per m^3 for a mixture of 1:2:3?

A 50 kg bag of cement is equivalent to 40 litres of loose volume.

The yield of the mix is 60% of the loose volume of cement, sand and stone, which means that 1 m^3 of concrete or 1 000 litres requires 1 000/0.60 = 1 680 litres of loose volume.

Loose volume (litres) = 40 x 1 (cement) + 40 x 2 (sand) + 40 x 3 (stone) = 240 litres,
Thus the yield (litres) = 0.6 x 240 = 144 litres,

Cement : 1000/144 = 6.94 = 7 bags
Sand : 7 x 40 x 2 = 560 litres = 0.56 m^3
Stones : 7 x 40 x 3 = 840 litres = 0.84 m^3

It can also be calculated as follows:

1 m^3 of concrete or 1 000 litres requires 1 000/0.60 = 1 680 litres of loose volume.

A mixture of 1:2:3 is equal to 6 units ⇒ 1 unit is equal to 1 680/6 = 280 litres.

Cement : 280 x 1 = 280 litres = 280/40 = 7 bags
Sand : 280 x 2 = 560 litres = 0.56 m^3
Stones : 280 x 3 = 840 litres = 0.84 m^3

Equation 1

$$c/w = \frac{\text{mass of cement (kg)}}{\text{mass of water (kg)}}$$

If the c/w ratio is too low, the concrete will not reach the required strength. If it is too high, cement is being wasted. Table 7 gives recommended c/w ratios and guidelines for concrete mixes by volume batching for a range of concrete grades. Table 8 describes the different concrete grades and what grade is used for what type of construction.

Table 7
Concrete mix proportions by volume batching for different concrete grades

Grade	Nominal stone size	Compac -tion	c/w ratio	Mix proportions per bag of cement			Materials per m^3 of concrete			Yield per bag
	(m)			Sand (m^3)	Stone (m^3)	Water (litres)	Cement (bags)	Sand (m^3)	Stone (m^3)	(litres)
Blinding	40	H	0.92	0.16	0.24	43.0	3.8	0.63	0.87	265
		V	0.90	0.17	0.28	41.0	3.4	0.59	0.94	295
	20	H	0.92	0.18	0.19	45.5	4.0	0.73	0.75	250
		V	0.90	0.19	0.22	41.0	3.7	0.67	0.81	270
7	40	H	1.03	0.13	0.21	37.0	4.2	0.61	0.88	240
		V	1.01	0.14	0.25	38.0	3.8	0.58	0.94	265
	20	H	1.03	0.15	0.17	36.5	4.4	0.71	0.75	225
		V	1.01	0.15	0.20	36.5	4.1	0.68	0.81	240
10	40	H	1.20	0.11	0.18	32.0	4.9	0.59	0.88	205
		V	1.18	0.11	0.22	32.0	4.5	0.56	0.94	220
	20	H	1.20	0.12	0.15	31.0	5.2	0.69	0.75	190
		V	1.18	0.12	0.17	32.0	4.8	0.65	0.81	205
15	40	H	1.45	0.09	0.15	26.5	5.9	0.55	0.88	170
		V	1.42	0.09	0.18	27.0	5.4	0.52	0.91	185
	20	H	1.45	0.09	0.12	26.5	6.2	0.65	0.75	160
		V	1.42	0.10	0.14	27.0	5.8	0.62	0.82	170
20	40	H	1.72	0.07	0.13	23.0	7.0	0.51	0.88	140
		V	1.67	0.07	0.15	23.0	6.3	0.49	0.95	160
	20	H	1.72	0.08	0.10	22.5	7.4	0.61	0.76	135
		V	1.67	0.08	0.12	23.0	6.8	0.58	0.82	145
	10	H	1.72	0.08	0.07	22.5	8.2	0.73	0.58	120
		V	1.67	0.09	0.08	23.0	7.7	0.74	0.62	130
25	40	H	1.85	0.06	0.12	21.5	7.6	0.50	0.89	130
		V	1.80	0.06	0.14	21.5	6.8	0.48	0.95	145
	20	H	1.85	0.07	0.10	21.0	8.0	0.59	0.76	125
		V	1.80	0.07	0.11	21.5	7.4	0.57	0.82	135
	10	H	1.85	0.07	0.07	21.0	8.9	0.71	0.58	110
		V	1.80	0.08	0.08	21.0	8.3	0.72	0.62	120
30	40	H	2.00	0.05	0.11	20.0	8.2	0.48	0.90	120
		V	1.94	0.05	0.13	20.5	7.4	0.46	0.95	135
	20	H	2.00	0.06	0.09	20.0	8.6	0.57	0.76	115
		V	1.91	0.06	0.10	20.0	8.0	0.55	0.82	125
	10	H	2.00	0.07	0.06	20.0	9.6	0.69	0.58	105
		V	1.94	0.07	0.07	20.0	8.9	0.69	0.62	110

H = compaction by hand (rodding and tamping).
V = compaction by vibration (internal pokers).

Table 8
Description of the various concrete grades

Grade	Description	Purpose
5	Blinding	Rough stooling
7	Mass concrete of roughest type	Large, lightly-loaded footing and foundation pads; making up over excavation in trenches; stooling; large, mass-gravity retaining walls
10	Mass concrete	Footings for one and two storey buildings; basements and foundation walls; small dams and weirs; piers. Abutments and wing walls for small bridges; retaining walls
15	Unreinforced concrete	Large foundations for non-vibrating machinery; dams and weirs; bridge piers abutments and wing walls. Floors in domestic buildings to receive light toppings with surface finishing
20	Standard structural-grade concrete	General reinforced concrete construction in buildings; small bridges, culverts and silos; machine foundations; unrendered walls above ground; single course domestic and office floors on the ground; base course of light-loaded floors on ground to receive toppings
25	High-grade structural concrete	Precast concrete fence posts and panels; machine foundations subject to vibration or shock; minimum for water-tight concrete and domestic driveways; light duty single course floors on ground (no trucking)
30	High Strength concrete	High stressed reinforced concrete members; precast structural units; concrete subject to severe vibration or shock loading; specially water-tight walls and tanks; concrete roads; all paved areas to carry fork-lift trucks or for other heavy industrial uses; single course industrial floors or base courses of floors to receive strong toppings

The material should be loaded in the following order:

- Stone and most of the water
- Cement
- Sand
- Water to make up to the required volume

Mixing should be long enough to get the proper mixture. Normally 1.5 to 2 minutes should be sufficient. As a guideline, the time required for one mix of concrete in a small mixer with a capacity of up to 500 litres is approximately:

- Filling : 3 minutes
- Mixing : 2 minutes
- Unloading : 3 minutes
- Extra : 2 minutes

Overloading the concrete mixer should be avoided. The mixer should be cleaned at the end of a shift. This should be done with a small quantity of stones and water, which should be mixed for a short while.

When mixing the components, the cement and the water react through a chemical process called hydration. Fine gels

Example 3

Concrete with a mix of 1:2:3 is to be mixed in a concrete mixer with a yield of 500 litres. The nominal stone diameter is 19 mm, the concrete grade should be 20. How much of each material should be batched per mix?

For such a mix Table 7 shows: c/w ratio = 1.67, cement = 6.8 bags, sand = 0.58 m^3 (580 litres) and stones = 0.82 m^3 (820 litres). The loose volume of 6.8 bags of cement = 6.8 x 40 litres = 272 litres. A c/w of 1.67 means that the volume of water required = 272/1.67 litres = 163 litres.

The total volume of loose material = 272 (cement) + 580 (sand) + 820 (stones) + 163 (water) = 1 835 litres. Only 60% of this is the yield of concrete, which means that the actual yield = 0.6 x 1 853 = 1 101 litres. The mixer has a yield of 500 litres. Therefore the ratio of the materials to be used per mix is 500 : 1 101 = 0.45.

Thus:	6.8 bags cement x 0.45	=	3.06 bags ≈ 3 bags
	0.58 m^3 x 0.45	=	0.26 m^3 sand
	0.82 m^3 x 0.45	=	0.37 m^3 stone
	163 litres x 0.45	=	73 litres of water.

Due to the fact that 7 bags instead of 6.8 bags would have to be used, the mix ratio in the earlier can still be used. The difference is very minor.

(hairs) start to grow around the cement particles and eventually the particles interlock and form a dense and rigid material. This material acts as a paste (glue) to hold the aggregates together, thus giving the concrete mixture its strength. The gels continue to grow as long as there is water. Thus, the mixture must not dry out too quickly.

Example 3 shows the calculations that should be done during the batching process.

4.1.5. Transporting, placing, compacting and curing concrete

Concrete should be transported as quickly as is possible so that the quality of the concrete is not affected, meaning that:

- It should not dry up
- It should not lose workability
- It should not be contaminated, for example by soil or dust
- It should not be diluted with water
- There should be no segregation, for example stones tend to settle to the bottom of the mix because they are the heaviest material in the mix

Concrete should be placed on clean surfaces. There should not be a delay in placing concrete, as it would harden before it is placed in the formwork.

Concrete should be properly compacted so as to remove all air that is trapped in the mix. Compaction can be done by hand or mechanically by vibration. The thin layer of concrete for lining canals is usually applied using shovels and screeding planks (straight edges), while the floats are used to finish the surface of the lining.

Newly placed concrete should not be allowed to dry out too soon as this will cause cracking, resulting in low strength and poor durability. Therefore, concrete should be kept wet for at least 2-4 weeks. Proper curing of concrete-lined canals is very important because the lining is thin and the concrete is exposed to hot weather. It is therefore recommended to cover the concrete with wet grain bags or other water-absorbing material as soon as the concrete has set. The grain bags should always be kept wet. A few days after placing the concrete, the grain bags can be removed and the canal stretch be filled with water, which should stay there for 2-4 weeks. The freeboard of the canal is normally not covered by water in this case. The latter should be watered 3-5 times per day, depending on the weather.

4.1.6. Steel reinforcement

Concrete is strong in compression, but weak in tension. It can withstand crushing forces, but breaks easily when a pulling force is applied or when there are one-sided forces working on the concrete. Steel reinforcement gives concrete the tensile strength it requires against external forces. Steel should be properly stored, ideally off the ground, especially in muddy areas. It should be kept clean. When used in a structure, it should be properly fixed in a position with plastic spacers or mortar blocks and tied together with soft wire.

The minimum concrete cover over the steel should be 40 mm. A diameter of 8-10 mm plain steel is normally sufficient for the works required in smallholder irrigation schemes. Steel requirements are normally given in units of mass. The mass per m^3 of steel is 7 850 kg. This can be used together with the diameter of the steel to calculate the length of steel to be ordered.

4.1.7. Mass concrete

Mass concrete is concrete mixed with large stones or boulders. It is often used in large, voluminous structures that do not require a high strength, such as the apron floor of a weir. Mass concrete is made by placing layers of concrete in the structure and throwing in the stones or boulders. This mixture should then be properly compacted, preferably by mechanical vibration, for example a poker, as a lot of strength is required to mix the large stones or boulders with the concrete.

Example 4

The length of steel, with a diameter of 8 mm, required for Nabusenga irrigation scheme is 4 000 metres. How many tons of steel should be ordered for the project?

The volume of 100 m of steel is equivalent to the cross-sectional area of the steel multiplied by the length, thus:

$\frac{1}{4} \times \pi \times d^2 \times \text{length} = \frac{1}{4} \times 3.14 \times (0.0008)^2 \times 100 = 0.005\ m^3$.

The weight of this length is: 0.005 x 7 850 = 39.25 kg.

4 000 metres of steel will therefore weigh: 4 000/100 x 39.25) = 1 570 kg = 1.57 tons.

4.2. Gabions and Reno mattresses

Gabion baskets and Reno mattresses are cages or baskets made from double-twisted, metallic-coated wire mesh, which is made like pignetting. Gabions are manufactured with a 8 x 10 mesh type, having a nominal mesh opening of 83 mm x 114 mm. Gabions come in different sizes. The most common sizes are 1 x 1 x 1 m, 1.5 x 1 x 1 m, 2 x 1 x 0.5 m, 2 x 1 x 1 m, or 4 x 1 x 1 m. Reno mattresses are manufactured with a 6 x 8 mesh type, having a nominal mesh opening of 64 mm x 83 mm. Their most common size is 4 x 2 x 0.23 m or 6 x 2 x 0.23 m. Sometimes the thickness can also be 0.17, 0.30 or 0.50 m instead of 0.23 m. The cages are filled with stones, well packed. The material used to fill the gabions must be 10-20 mm durable stone. Structures are quite easy to construct using gabions. The construction is labour intensive, but little skilled labour is required. The structures are permeable and flexible. Permeability is acceptable for weirs as long as the upstream side is sealed off. To avoid the loss of soil under the structure, a terram filter should be laid on the base soil, as shown in Figure 14. This filter allows water to infiltrate but does not allow sand and other particles through.

4.3. Bricks and cement or concrete blocks

Bricks and concrete or cement blocks can be used for small structures, and sometimes for lined canals in small-scale irrigation schemes. If suitable soils are available in a project area, farmers could mould and burn their own bricks for construction. Although brick-lining of canals is cheap compared to concrete lining, it takes much more time to accomplish. Brick lining also requires plastering on both sides of the walls to protect the bricks and to give a clean view of the structure.

The cement-stabilized soil block is mainly soil and water, with cement acting as the stabilizing agent. Sizes can be 290 x 240 x 90 mm or 240 x 140 x 90 mm. A desirable soil should consist of gravel, sand, silt and clay. An important factor that affects the strength of the finished block is the fines content of the soil, i.e. the silt and clay content. The desirable range of the fines content is from 20-30%.

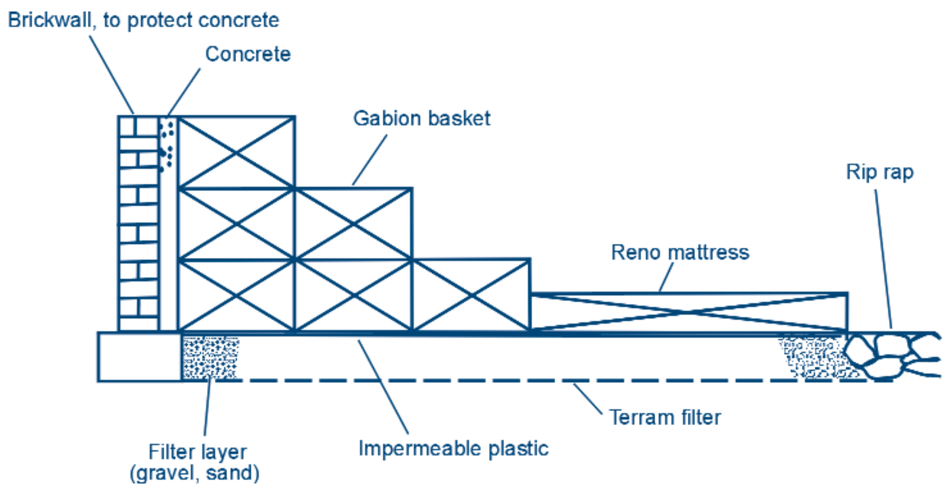
Concrete blocks could also be cast. The use of solid or hollow concrete blocks instead of the traditional bricks can be desirable for meeting the demands of good quality, speed of construction and overall economy. Blocks may be used in the following sizes: 400 x 300 x 200 mm, 400 x 200 x 200 mm, 400 x 100 x 200 mm. Such blocks can be cast at the site using a mix proportion of 1:3:6, with a gravel size of maximum 20 mm, or in the ratio of 1:4:8 or 1:5:10. A minimum water cement ratio should be used. The cement content should be about 150 to 200 kg/m^3 of concrete. The blocks should be compacted and cured properly. The curing is normally done for first 14 days by keeping them continuously moist followed by 14 days of air drying.

Construction usually involves the plastering of bricks/block in order to protect them and also give a good finish to the structure. Mortar mixes are given in Table 6.

4.4. Timber

Timber can be used to make small structures such as canal outlets. It is also often used as shuttering material, because it is easy to cut and join. Shutters form a mould which can shape concrete and support it until it dries. Hardwood should be used.

Figure 14
An example of a gabion basket structure



4.5. Pipes and fittings

4.5.1. Types of pipes and fittings

The most common pipes used in irrigation are asbestos cement (AC) pipes, unplasticized polyvinyl chloride (uPVC) pipes and polyethylene (PE) pipes. The types of pipes and their fittings are discussed in detail in Modules 7, 8 and 9. All pipes can be subjected to different levels of pressures, provided they are manufactured to withstand that pressure. As a result, each pipe and fitting must conform to the set standards. Generally, the materials need to be marked as follows in order to show that they are certified by a standards body where they were manufactured:

Pipes
- – The manufacturer's trade name or trade mark of product
- – The class of the pipe
- – The nominal size of the pipe
- – Batch identification

Fittings
- – The manufacturer's trade name or trade mark of product
- – The class of the fittings
- – The nominal size of the fitting, when relevant, of the branch limb
- – In the case of threaded adapter bushes, the size, shape and form of the thread

Adhesives
- – The manufacturer's trade name or trade mark of product
- – Suitable identification of the product
- – Date of manufacture
- – Words such as 'FLAMMABLE'
- – Batch identification

On-site inspection for compliance with specifications has to be carried out. The inspection can result in the acceptance or rejection of a given consignment by the engineer. The engineer therefore has to take samples after checking for compliance of markings. The samples can be used for adjudication in cases of dispute. Some guidelines for sampling are:

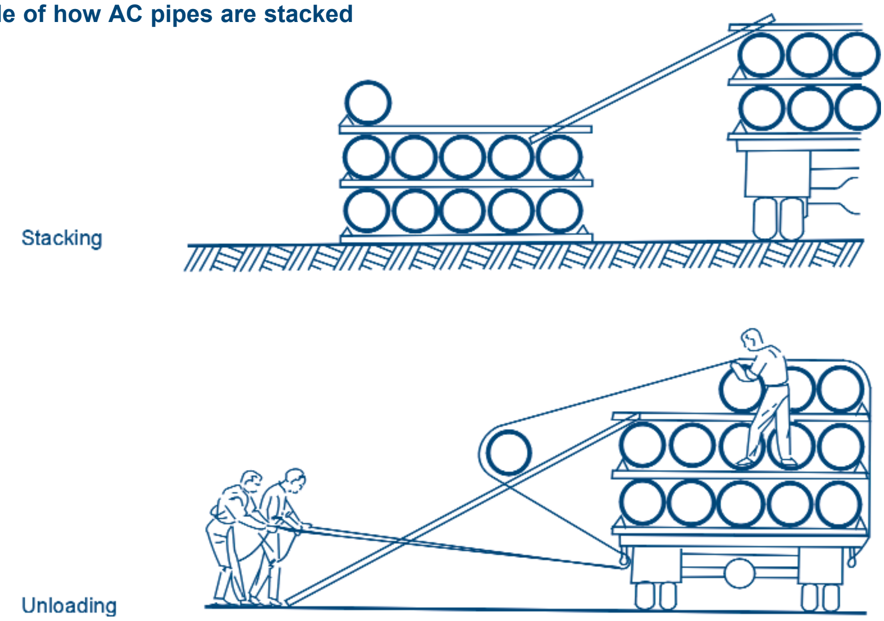
- ❖ *Pipes or fittings*: 4 to 16 pieces from a consignment of 100 to 10 000, in this instance checks are made on lengths of pipe or fittings with their rubber rings
- ❖ *Adhesives*: randomly take 1 container of adhesive from the consignment

4.5.2. Packing, transporting, storing and handling of pipes and fittings

Pipes and fittings should be packed to protect them against damage during transportation. Pipes should not come into contact with sharp objects, nor should they project beyond the body of the vehicle transporting them. Therefore they should be well secured along their full length. Rubber joint rings should not be contaminated with oil or grease.

Before uPVC pipes are transported to the site, they should be stored, not more than 1.5 m high (or about 7 pipe layers under cover in pipe racks) which provide support to the full length of the pipe. Different diameter pipes should not be stacked together. Once on site, the uPVC pipes should be stored on level ground that is free

Figure 15
An example of how AC pipes are stacked



of sharp objects. They should be stacked no more than 1 m high in a stack, formed by cross formation of pipes. Again, pipes of different sizes should not be stacked together.

AC pipes should be stacked in layers on top of 100 mm x 75 mm battens, both during transportation and storage on site (Figure 15). On site they can also be stacked using a close packing formation. When unloading AC pipes of diameter 100 mm to 400 mm, ropes and skids should be used to roll the pipe on the skid from the truck to the ground. The rope is used to hold the pipe as it rolls down.

Ideally for pipes from 450 mm to 600 mm, mechanical equipment should be used to lift and place them on the ground. In the absence of this, ropes and skids can still be used. When unloading AC pipes along the trench, an interval of 0.3 m between the pipes is ideal. Pipes less than 200 mm in diameter can be lowered into the trench by hand, larger diameter pipes should be lowered by mechanical means such as cranes, front-end loaders, etc.

Rubber jointing rings fittings and adhesives should be stored in their original packing in a cool dry place.

Chapter 5
Construction of canals

Whatever the construction method, it should be assured that the canal embankment is well compacted and stable. The embankment should be built up in layers, which should be well compacted, with the soil having the correct moisture content. After completing the construction of the embankment, the canal shape should be excavated, either manually or mechanically. Alternatively, the banks of the canals could be built around the canal section, using canal templates. If the canal is lined, it has to be assured that the thickness of the lining material is added to the canal section to be excavated.

If the canal sides are not too steep and water is available for curing, in-situ lining can be considered. Alternatively, pre-casted slabs can be made at a central place of the scheme, where there is access to water. The size of the slabs should be such that they are easy to handle and that they do not break when lifted. Shutters can be made of steel, timber and other materials.

5.1. Setting out canals

The first step in the construction of canals is the setting out of the canal alignment and elevations. This is done using survey instruments and pegs. For setting the canal levels, one method is to place steel pegs at intervals of 10 m at the elevations determined using the longitudinal section. The elevation of the top of the pegs should be lower than the design elevation of the canal by an amount equal to the thickness of the concrete floor. In the case of small canals this is 50 mm. Another method is to use the traveler, which is a vertical plank or stick with a cross-plank at a certain height (Figure 16).

In this method pegs, each with a cross-plank, are set out along the canal alignment. The height of the cross-planks is fixed in such a way that all of them are in line when the design levels have been obtained (Figure 17).

Figure 16
A traveler for setting out canals

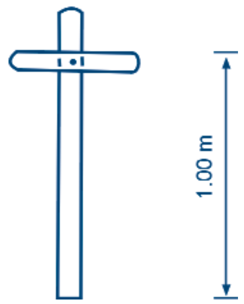
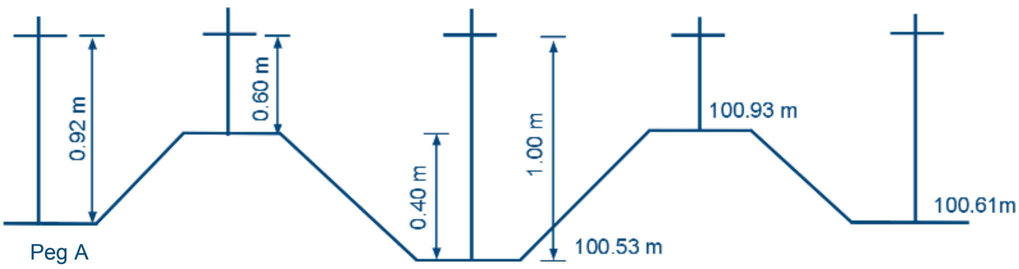


Figure 17
Setting out a canal using a traveler



Example 5

Considering a longitudinal section where the ground level at the chainage of 370 m is 100.61 m. The design bed or bottom level of the canal is 100.53 m and the bank level is 0.40 m higher, being 100.93 m. At the bank level the height of the traveler is 0.60 m. At what height above ground level should the traveler be put at A, where the ground level is 100.61 m?

The cross-plank of peg A (Figure 17) should be nailed at a height of 0.92 m above ground level because:

100.61 + traveler height = 100.93 + 0.60 ⇒ traveler height = 100.93 + 0.60 - 100.61 = 0.92 m.

Figure 18
Metal template for shaping canals (60° angle)

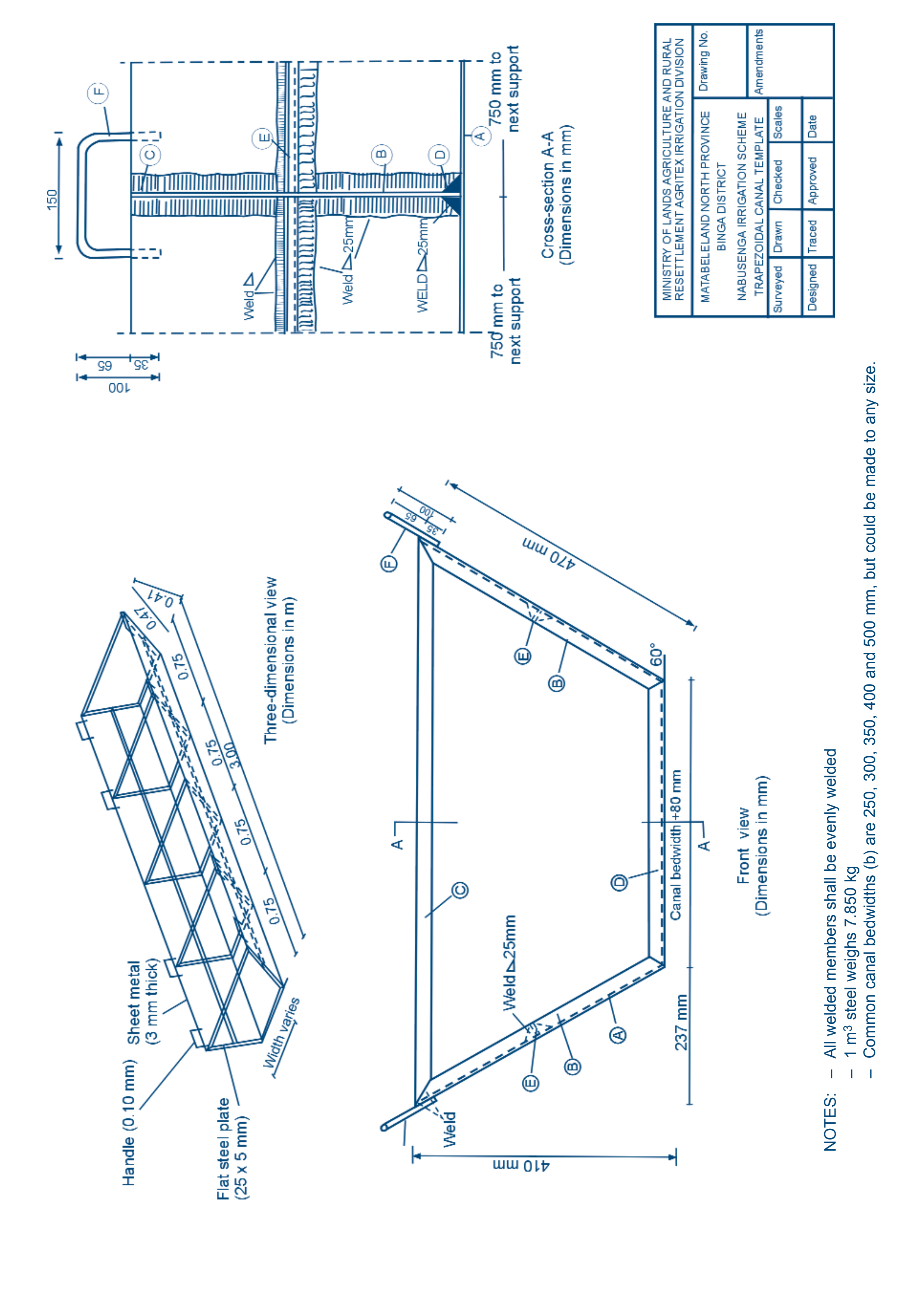
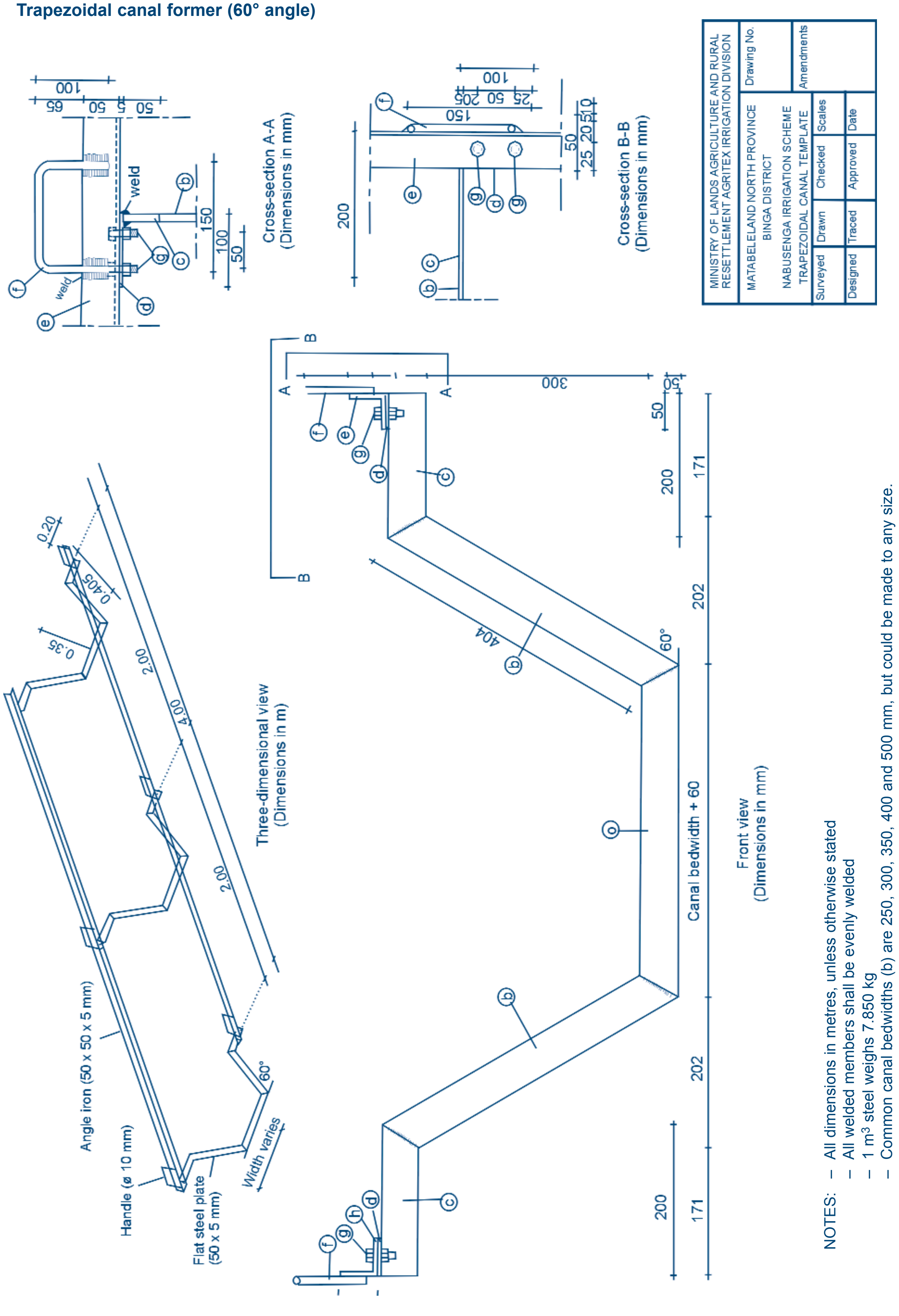


Figure 19

Trapezoidal canal former (60° angle)



5.2. Canal formation

After setting out the canal, the second step is to open and level the ground in a strip as wide as the bed or bottom width. The correct level can be checked with a wire or string in between two steel pegs.

The third step is to form the canal embankments. For this exercise templates are used (see Module 7). The templates can be made of sheet metal with a length of 3 m. The outside dimensions are 50 mm greater than the inside of the finished, lined canal. Once the template is aligned the soil is compacted around it in layers of 100 to 150 mm.

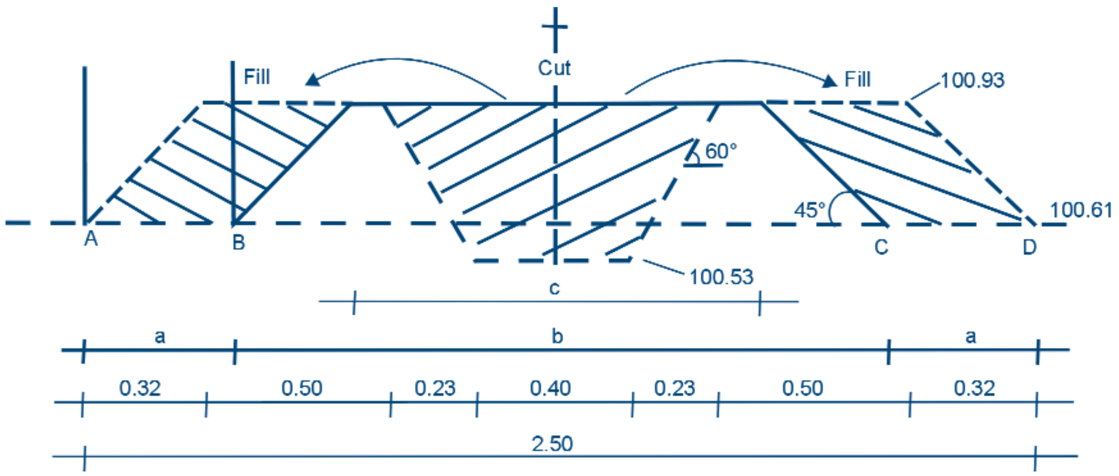
Mechanized canal formation is used in the construction of larger projects, or if labour costs are prohibitively high. It is used for soil transport, compaction and excavation.

Figures 18 and 19 show some of the equipment used in canal formation.

First of all, an embankment is made up to bank level. It is made from the soil excavated to form the canal section or soil is brought to the sides from elsewhere. The soil is piled on the embankment in such a way that it gives the final required canal bank and canal shape. Figure 20 shows the final cross-section (broken line) and the initial embankment with bed width b.

The fill is either collected from excavated drains, night storage reservoirs or from borrow pits outside the irrigation area. For large schemes, where machinery such as scrapers are used, a transport programme is made on which is indicated the most economic path for the cut to be used as fill (Figure 21). Such a transport programme is usually the basis on which contractors are paid.

Figure 20
Final cross-section and initial embankment of a canal



Example 6

The cut should be sufficient to fill 2 parallelograms, shown in Figure 20, each with base a. What are the cut and fit volumes?

As the canal cross-section is known, the cut cross-section can be calculated as follows:

$$\text{tg}60 = \frac{0.40}{x} \Rightarrow x = \frac{0.40}{1.73} = 0.23 \text{ m}$$

½ x (bottom width + top width) x canal depth = ½ x (0.40 + (0.40 + 0.23 + 0.23)) x 0.40 = ½ x 1.26 x 0.40 = 0.25 m^2

The fill cross-section is: 2 x a x 0.32 (area of a parallelogram is base x height).

The fill should equal the cut, thus: 2 x a x 0.32 = 0.25 m^2 ⇒ a = 0.39 m.

This results in an embankment bottom width b = 2.50 - 2 x 0.39 = 1.72 m.

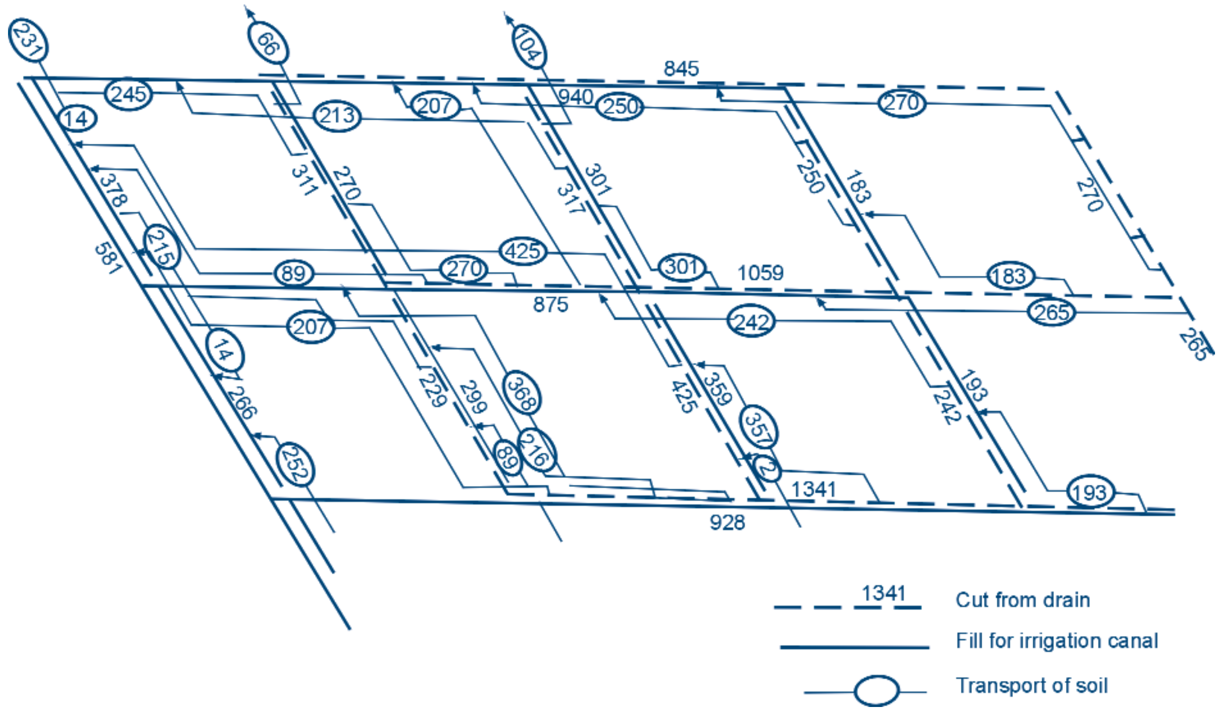
and in an embankment top width c = b - (2 x (100.93 - 100.61)) = 1.72 - 0.64 = 1.08 m

The fill of the original embankment is ½ x (b + c) x embankment height.

Thus, in the example: ½ x (1.72 + 1.08) x 0.32 = 0.45 m^3 per metre length.

Figure 21

The transport programmes for the cut and fill process during canal formation



To ease the construction of the canals, several points are indicated with pegs (points A-D in Figure 20). From the example it follows that points B and C have a distance of b/2 or 1.72/2 = 0.86 m to the centre line peg (see Example 6 for the calculation of b). The operator knows that the foot of the embankment should begin at point B and C and, when excavating, that the final bank foot commences at points A and D, which have also been indicated with pegs.

Care should be taken not only to construct the correct cross-section, but also the correct canal gradient (longitudinal profile). One should use a level instrument to check the canal bed elevation at about every 5 to 10 m (see Module 7 for more details).

6.3. Placing and curing concrete

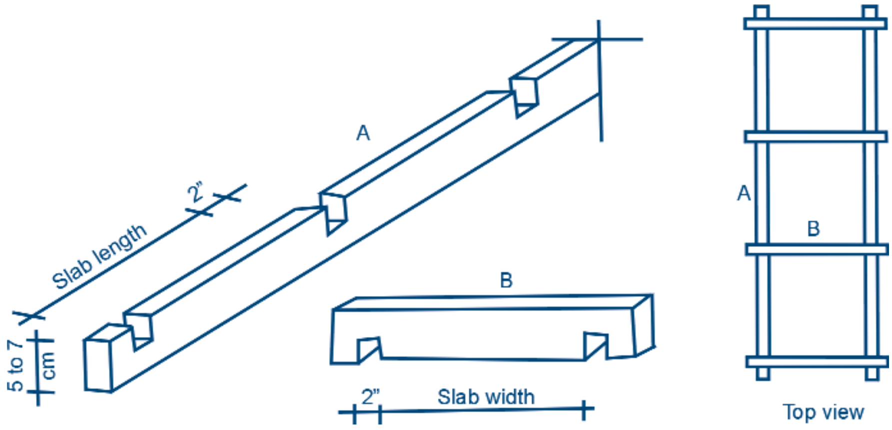
After aligning the canal and forming it, the next step is to place the concrete. To facilitate this, formers of 4 m length, also called screeding frames, with screeding edges 2 m apart are used. A builders line (which has notches in the middle) should be installed to centre the former and to keep the correct gradient. Concrete is placed in position with a straight edge, after which it is finished with a wooden float and steel trowel or steel float. Expansion joints are made at 2 m interval, related to the screeding edges. After curing, these joints should be filled up with bitumen seal.

Concrete canals should have shrinkage joints to allow for the expansion and contraction. The joints should be protected using bitumen materials to avoid leaking. The soil supporting the concrete lining should be well compacted to avoid soil settlement and thus cracking of the lining. Typical small canals can have joints at about 2 m intervals.

The concrete lining could be constructed in-situ or with pre-cast slabs. The thickness should be 50-70 mm for normal conditions. A simple shutter frame that can be used for construction of pre-cast slabs is shown in Figure 22.

Curing concrete or sand-cement mixtures is very important. It should be kept wet for 2-3 weeks, initially by spreading polyvinyl sheeting or grain bags that are kept wet continuously over the newly placed mixture, and after initial hardening by filling the canal section with water for about 2 weeks. To prevent pre-casted slabs drying out too quickly, they could be covered by grass.

Figure 22
Timber shutter frame for concrete slab casting



Chapter 6
Construction of pipelines

Construction of underground pipelines involves the initial setting out of the trench, the actual trenching, preparation of the trench bottom, bedding, pipe laying, pipe jointing, back-filling, placing thrust blocks and pressure testing.

6.1. Trenching, bedding and pipe laying

Reference points or benchmarks should be used in setting out the width and centre line of trenches. The width of the trench at the depth equivalent to the crown of the pipe should be at least 30 cm greater than the nominal diameter of the pipe. The part of the trench above the crown should be of a convenient width.

Trenching can be quite tedious if the ground is hard and larger diameter pipes are to be used. Trenches are dug using picks, mattocks and shovels, but if rock outcrops are encountered in the process, some blasting may be called for, depending on the severity of the situation. Local techniques can also be used to deal with rock outcrops, like heating and fast cooling to weaken the rocks and then hitting them with a hammer.

For AC pipes in areas where there is no road crossing the pipeline, the minimum recommended cover over the pipe should be at least 45 cm. For areas under roadways, it should be 60 cm for medium load and 90 cm for heavy load. This is to avoid the anticipated load damaging the pipe. For uPVC pipes, ASAE EP340.2 standards recommends a minimum cover of 75 cm and a maximum of 120 cm when traffic will be passing above the pipe. When no traffic will be passing, the same standard recommends at least 45 cm cover for 63 mm uPVC pipes, and at least 60 cm for larger pipes.

The bottom of the trench should be level or of a uniform slope, to accommodate the full length of the pipe. Where an uneven trench bottom is encountered, especially in rocky or hard ground, a 10 cm (or at least one third of nominal diameter) fine back-fill or bedding should be provided for during setting out, especially in the case of AC pipes. This layer has to be back-filled, using suitable bedding material such as free-draining coarse sand, gravel, loam or a soil of friable nature, and be leveled. In the case of fittings, such as the couplings of AC pipes, excavation in the back-fill should be made to accommodate the fitting such that the pipe remains level.

6.2. Pipe jointing

When pipes have to be joined, they have to be clean of dirt. All the solvent cleaners, adhesives and lubricants used in joining pipes should be those recommended by the manufacturer of the pipe or fitting. It has to be remembered that solvent cleaners and adhesives are highly volatile.

For uPVC piping less than 200 mm in diameter, an injection-mould adhesive type of fitting or an integral rubber ring should be used. For sizes larger than 250 mm diameter, a rubber ring end socket should be used. For AC pipes of 200 mm diameter, pipes can be jointed, via the coupling, by hand. Larger diameter pipes should be mechanically jointed. In both cases, a lubricant should be applied up to the witness groove and the alignment of the pipe up to the coupling should be well done. Both uPVC and AC pipes can be cut if shorter pipes are needed. If jointing is not done immediately, the pipes have to be temporarily closed in order to avoid the entrance of animals or dirt. It also is important to ensure that the temporary closures are opened on re-commencement of pipe laying. Valves and outlets should be closed every day.

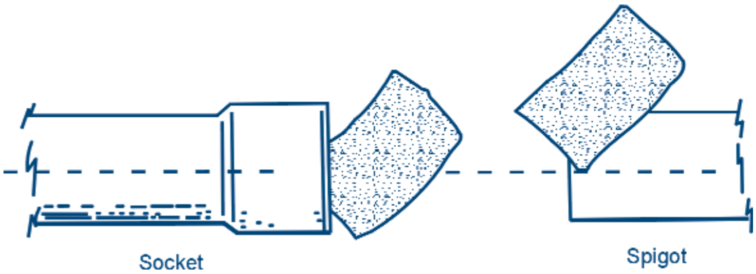
Figure 23 shows a pamphlet used by Agritex in Zimbabwe to explain how uPVC pipe jointing should be done.

6.3. Back-filling

After checking that the levels of all joints are correctly set out, side filling can then be done in layers that are 75 mm thick, using fine material for the fill. The layers have to be tamped by hand, ensuring that the joints are left exposed. Tamping should be done simultaneously on both sides of the pipe, in order to avoid misalignment. This should continue up to a height of two thirds of the pipe diameter, or up to 10 cm above the crown when the material is spread over the whole length of the pipeline except the joints. Beyond that, the rest of the back-filling can be done in layers of 15-30 cm. The trenches should be over-filled to allow for settlement. The space between the joints is back-filled after the pipeline has been pressurized and the joints inspected to ensure that there are no leaks (see below). It is necessary to ensure that all pipes are back-filled once they are installed, in order to prevent them from floating due to rainwater or groundwater.

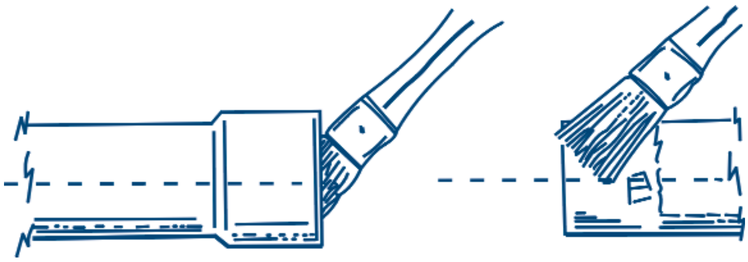
Figure 23
uPVC pipe jointing technique

1. Clean both ends to be joined of any loose dirt, earth or grit and remove oil, grease or paint. Lightly sand paper inside of socket and outside of spigot.



2. Apply light priming coat of solvent cement to inside of socket of spigot and allow it to dry.

3. Apply second coat, sparingly, to inside of socket and more liberally to outside of spigot. *With too much cement in the socket, a pool of this liquid will form which can result in failures at this point.*



4. While cement is still wet insert spigot into socket – push right home in a straight movement.

5. Hold the completed joint for approximately 30 seconds to allow the initial grab to occur, then leave as undisturbed as possible for 24 hours when pressure can be turned on.

Note: Prodorite Solvent Cement is highly volatile and to reduce evaporation to a minimum STORE IN A COOL PLACE and replace lid immediately after use.

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6.4. Thrust blocks

Thrust blocks transfer the load from a fitting or branch to a wide load-bearing area, thereby minimizing the chances of the fitting moving. They are required:

- When the pipeline changes direction
- At the end of a pipeline
- When there is a branch such as a tee

6.5. Pressure testing and flushing of the system

The purpose of testing pipelines is to ensure that the pipe joints are water-tight and that the permanent concrete thrust blocks are capable of resisting the load. Normally, at least 7 days should be allowed after constructing the last thrust block before the system is tested. By this time, the last thrust block should be able to withstand the load. When pressure testing, the pressure should not exceed one and half times the maximum working pressure. It is also important that the valves and all other outlets be opened and closed slowly.

The flushing is intended to remove all the dirt that inevitably gets into the system during pipe laying and it should be done for a couple of hours with the flush valves at the end of the lateral lines open. The flushing process should be stopped once clean water starts coming out of the valves.

Chapter 7
Land levelling

Proper land clearance and levelling are important for efficient irrigation, especially in surface irrigation schemes. It involves bush clearance and moving soil in order to have level fields for basin irrigation or uniform sloping fields for furrow or border strip irrigation.

Bush clearance in small schemes can be done manually by using axes, picks and shovels for cutting trees and bushes and uprooting trunks. For large areas, or if no manual labour is available, equipment such as bulldozers and heavy tractors are used.

7.1. Initial land levelling

Initial land levelling is usually done using bulldozers, scrapers, graders and land planes. Bulldozers are used to move soil over short distances, while scrapers are used to carry soil over longer distances. This machinery is not very accurate and elevation differences of up to 100 mm might still remain. The final, accurate land levelling is done with graders and tractor-towed land planes in particular, which usually achieve accuracy to within 25 mm of the desired levels. Settlement of fill will always occur and therefore the land levelling often has to be repeated after the end of the first year of cultivation. Fine levelling using a land plane is recommended after every ploughing.

A detailed topographic survey, preferably grid, is needed to calculate the most economic land levelling requirements. Based on the spot heights of the grid points and the required gradient of the land, the cut and fill can be calculated. The total volume of cut should preferably exceed the total volume of fill by 10-50%, depending on the total volume to be moved and the compressibility of the soil.

The three most widely used methods for calculating the amounts of soil cuts and fills are:

- Profile method
- Contour method
- Plane or centroid method

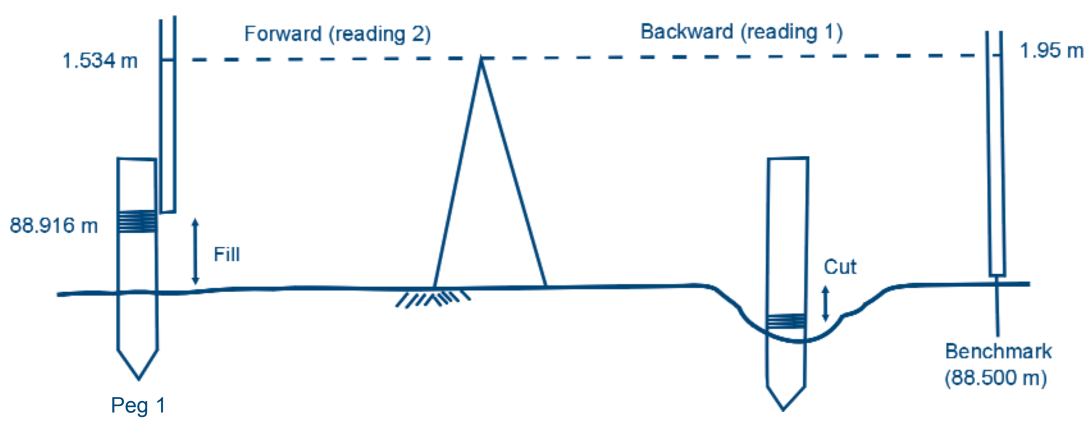
These methods are described in detail in Module 7.

7.2. Pegging final levels

The depths of fill or cut required are indicated in the field with pegs. Usually, the pegs of the grid survey are used. Painted lines on the pegs indicate the depth of cut or fill as shown in Figure 24. These painted lines are placed at the correct elevations with a level instrument. Starting from a benchmark with known elevation, the bottom of the staff should be placed at the correct elevations as obtained from the land levelling calculations.

In Figure 24 the benchmark elevation is 88.500 m and the elevation after land levelling for peg 1 should be 88.916 m. The backward reading to the benchmark is 1.950 m. Thus the height of point of collimation (HPC) is 88.500 m + 1.950 m = 90.450 m (see Module 2). As the paint should be at elevation 88.916 m, the staff should be placed such that the staff reading is 90.450 m - 88.916 m = 1.534 m.

Figure 24
Indication of cut and fill in the field



The machine operator cuts or fills the land to the required level, taking into account the most economic route from cut to fill. As already indicated in the beginning of this chapter, scrapers should preferably be used to move large volumes of soil over longer distances. Although this could be achieved with a grader, it would be a time-consuming and thus very expensive process.

It is important to make a final check to make sure that the desired levels have been reached before the pegs are removed.

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