

# Water from Roofs

**A handbook for technicians and builders on survey, design, construction and maintenance of roof catchments**



A discharged petrol tank used for roof catchment of rainwater in Somaliland.



A water tank being built of compressed soil blocks during a training course in Kenya.



Reusable formwork being assembled for a dome on a hemispherical tank built of ferro-cement with a storage volume of 90,000 litres during a training course in Namibia.

**Erik Nissen-Petersen  
for  
Danish International Development Assistance (Danida)  
2007**

## Technical handbooks in this series :

<u>Titles</u>	<u>Contents</u>
1 Water for Rural Communities	Lessons learnt from Kitui pilot projects
2 Water Supply by Rural Builders	Procedures for being rural contractors
3 Water Surveys and Designs	Survey, design and cost of water projects
4 Water from Rock Outcrops dams	Rock catchment tanks, masonry and earth
5 Water from Dry Riverbeds dams	Wells, subsurface dams, weirs and sand
6 Water from Roads	Rainwater harvesting from roads
7 Water from Small Dams	Ponds and small earth dams built manually
8 Water from Roofs use	Various types of roof catchments for domestic

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This handbook is one of a series of 8 publications on *Water in Arid Lands*, financed by the Danish International Development Assistance (Danida).

All the tanks described with designs, BQs and construction procedures can be viewed at Nyayo Primary School and Makaani Primary School where the tanks were constructed during two SIDA-funded training courses in 1997 and 1998. The two schools are situated 18 km and 24 km respective from Kibwezi on the road to Kitui. Other tanks can be viewed at 4 primary schools at Katangi, on the road between Machakos and Kitui.

To promote the simple technologies described in the handbooks, these can be read or downloaded free of charge from our website [www.waterforaridland.com](http://www.waterforaridland.com) .

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## **Disclaimer**

The designs and construction procedures described in this handbook are based on the author’s experiences and observations over 30 years. The tanks described herein, when properly constructed and maintained, have performed exceptionally well. However, local conditions vary widely, as does the quality of materials and workmanship, and while the author and Danida are keen to encourage the replication of described in this handbook, they cannot accept liability for the failure of a water harvesting system based on the designs and construction procedures described herein.

## **Foreword**

In Kenya today, there is an increasing demand for safe drinking water. Unfortunately, available water sources especially in arid and semi arid lands have saline water that is not suitable for human consumption. Under these circumstances, other water sources must be explored with a view to augmenting available water sources. One promising alternative water source is that of harvesting rainwater from roof catchments. This is a technology that is now widespread and in countries like India where there is a government policy on this which compels the housing industry to incorporate rainwater harvesting in the design of their housing units.

This handbook on water from roofs by Danida-Kenya has been produced at a time when Kenya through the newly restructured Ministry of Water and Irrigation is considering the need for a policy on incorporating rainwater harvesting when designing new housing units in urban, peri-urban and rural areas. This will have to fit into the current water resources management structure under the Water Resources Management Authority (WRMA) and associated Regional Water Services Boards whose mandate now includes that of designing and constructing water systems for rural water supply. Indeed water storage tanks for harvesting water from roof catchments are needed in all parts of Kenya where availability of fresh water supply is acute and hence a priority for affected communities. Besides the provision of water for domestic needs, water from roof catchments is a good water source for livestock.

Water from Roofs is a handbook that is expected to serve as a guide for technicians and water users who are contemplating to design and construct water storage tanks using concrete, burnt bricks, blocks and rubble stones and ferro-cement. It emphasizes on the need for standard designs and bills of quantities for various sizes of water tanks during the planning stage and also delves into structural considerations before construction. The handbook provides insights into construction procedures and graphic and photo illustrations of the different types and sizes of water tanks. The aspect of repairs of water containers and tanks is also discussed in this handbook. Graphic and photo illustrations of the water tanks make the information more comprehensive and easily understood by any reader. This information is required by local technicians for constructing water tanks.

This handbook contains some practical applications of different types and sizes of water tanks in terms of choice of tank on the basis of capacity, depth, diameter and cost of construction. Cost is revealed through bills of quantities. The main aim of this booklet is to encourage communities experiencing water shortages to have an understanding of what it would take to construct a water tank and the available options when choosing construction materials. It is envisaged that through rainwater harvesting in water storage tanks, domestic water supply would increase significantly and thus ensure that affected areas would be transformed from water scarcity to water security areas.

Eng. M. A. Mahboub  
Permanent Secretary,  
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## VOCABULARY AND ABBREVIATIONS

Ant-hill	=	Ventilation towers made of soil and saliva by ants
ASAL	=	Arid and Semi-Arid Lands
ASALCON	=	ASAL Consultants Ltd.
Bill of Quantities (BQ)	=	List of materials and labour, with costing
Catchment	=	Area draining rainwater run-off to a common point
Danida	=	Danish International Development Assistance
Draw-off pipe	=	Pipe draining water by gravity
Evaporation	=	Water lost as vapour from a water surface
EU	=	European Union
Gradient	=	Slope
Impervious	=	Not letting water through
Murram	=	A clayey and laterite soil with small stones
Seepage	=	Water seeping through a material
SIDA	=	Swedish International Development Assistance
Siphon	=	Pipe lifting water over a high point to a lower level
SODIS	=	SOLar DISinfection of water
Storage ratio	=	Volume of water in relation to volume of storage
Turbid	=	Unclear water carrying sediment
Topographical	=	Relating to the shape and height of the land
UNDP	=	United Nations Development Programme

## TECHNICAL TERMS

Acceleration	=	Force per unit Mass
Characteristic strength	=	Design strength multiplied by material partial factor of safety
Compressive strength	=	Ability of a material to be under compression without failure
Density of liquid	=	Mass per unit volume at a standard temperature and pressure. It is denoted $\rho$ (rho) and has units of $\text{kg/m}^3$ .
Design load	=	Actual load x factor of safety
Pressure	=	Force per unit area
Design strength	=	Characteristic strength divided by material partial factor of safety $\gamma_m$
Gravitational acceleration	=	Force of gravity which is $9.81 \text{ m/s}^2$
Hydrostatic pressure	=	Pressure exerted on walls of a cylindrical tank
Stress	=	Applied load per unit area of the cross-section of member
Shear force	=	Algebraic sum of all the forces acting on the side of a section
Specific weight	=	Weight of a unit volume of the substance. It is by $\gamma$ (gamma)
Specific gravity	=	Ratio of the specific weight of a substance compared to that of a standard substance at a standard temperature
Tensional strength	=	Ability of a material to be subjected to pull without failure
Fluid	=	A substance, including water and air, that is capable of flowing and conforms to the shape of containing vessels

## HYDROSTATIC PRESSURE

The hydrostatic pressure exerted on the walls of cylindrical water tanks is calculated using the formula of:  $P = \rho g h$

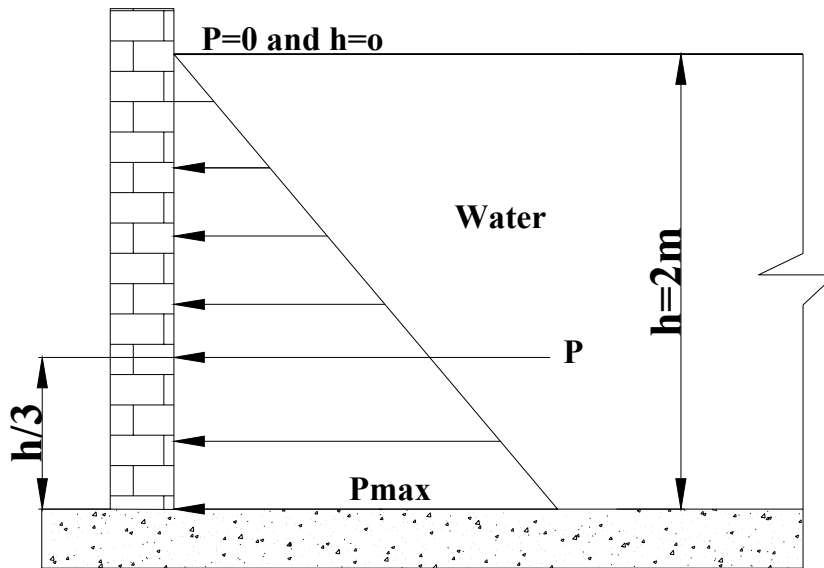
Where  $g$  = Gravitational acceleration ( $9.81\text{m/s}^2$ )

$\rho$  = Density of liquid ( $\text{Kg/m}^3$ )

$h$  = Height

$w$  is the specific weight =  $\rho g$

$P = wh$



Pressure diagram

## FORMULAS

$r$	=	radius
$d$	=	diameter
$h$	=	height
$\pi$	=	3.14 or $22/7$
$\pi d$	=	circumference of a circle
$\pi r^2$	=	area of a circle
$\pi r^2 h$	=	volume of a cylinder
$\pi d h$	=	area of a cylinder
$4/3(\pi r^3)$	=	volume of a sphere
$4\pi r^2$	=	area of a sphere
$2/3(\pi r^3)$	=	volume of a hemisphere
$2\pi r^2$	=	area of a hemisphere



## MEASUREMENTS AND CONVERSIONS

<b>Length</b>	1 metre = 3.28 feet	
	1 km = 0.62 miles	
<b>Area</b>	1 acre = 4,047 m <sup>2</sup>	= 0.4047 hectares (ha)
	1 ha = 10,000 m <sup>2</sup>	= 2.471 acres
	1 km <sup>2</sup> = 100 ha	= 247.1 acres
<b>Volume</b>	1 litre = 1.75 pints	= 0.22 Imp gallons (or 0.26 US galls)
	1 m <sup>3</sup> = 1,000 litres (l)	= 220 Imp gallons (or 260 US gallons)
	1 Imperial gallon	= 4.550 l
	1 US gallon	= 3.785 l
<b>Weight</b>	1 tonne	= 1,000 kg
	1 British ton	= 1,016 kg
	1 US ton	= 907 kg
<b>Volumes and weight of materials</b>		
	1 m <sup>3</sup> water	= 1,000 kg
	1 m <sup>3</sup> dry soil	= 1,230 to 2,000 kg
	1 m <sup>3</sup> compacted soil	= 2,180 kg, approximately
	1 m <sup>3</sup> loose gravel	= 1,745 kg, approximately
	1 m <sup>3</sup> stones	= 2,400 kg to 2,900 kg

### Exchange Rate Used in the Manual

Ksh = Kenya Shillings = USD 70 (November, 2006)

# Chapter 1. Water tanks

## 1.1 History of water tanks in Kenya

One of the oldest known water tanks in Kenya was built by the railway at Makindu River in 1907. It appears the tank was connected to a hydram pump that used the power of the flowing water in the river to push water into the tank from where it was used by steam locomotives.



It is interesting to note that the base of the tank is  $\frac{3}{5}$  of its height, which is the same ratio as for building rock catchment dams in neighbouring Kitui. This ratio eliminates the use of reinforcement in the walls. The square form of the tank, which has no cracks, is another interesting factor, because all other square and rectangular tanks known have leakages.

Large circular tanks were built at Simba near Makindu. Water was gravitated from Mount Kilimanjaro to the tanks for watering livestock in the ranching schemes of ALDEV in the 1950s.



The author built his first water tank of concrete blocks at his house at Kibwezi in 1976. Rainwater from the roof flows directly into the tank without gutters.



Another water tank was built of concrete blocks at a cattle dip in Kajiado in 1977.



The first tank built of ferro-cement in Eastern Africa was constructed at Kibwezi in 1978.



Although the early white settlers had built water tanks to harvest rainwater from their roofs, the technique was only replicated by installing corrugated galvanized iron sheet water tanks at a few schools in the 1970s.



The lack of interest might have been due to corrosion and improperly installed gutters.

13 large water tanks were constructed of concrete blocks for roof catchments as the only, and fully sufficient water source for 10 houses, 6 offices and a store at the Danida/MoA compound in Mutomo, Kitui, in 1982.



Several NGOs promoted water jars for roof catchment at schools in the 1980s. To reduce costs, the jars were built over a formwork made of sticks that also served as reinforcement.



After a few years, termites had eaten the sticks and parts of the walls fell off thereby leaving the jars in ruins.

The Diocese of Kitui made a cost-saving experiment using sisal fibres as reinforcement instead of chicken mesh and galvanized wire. The fibres in the pilot tank, seen in the photo to the right rotten away in a couple of years and the tank was abandoned.



## 1.2 History of tanks in Africa and Asia

In Ovamboland in Northern Namibia, many water jars made of asbestos were installed at schools for harvesting rainwater from asbestos roofs in the 1980s. Local health authorities claimed that there was no risk in drinking water collected and stored in asbestos.



In the Kalahari Desert, the government of Botswana has installed excellent water tanks for roof catchment and solar water heaters in their staff houses.



Students of the University of Gaborone in Botswana are studying rainwater harvesting from roofs using this testing unit.



In Thailand, the International Ferro-cement Information Centre has an impressive library and exhibition dealing especially with water storage in containers made of ferro-cement.



In the Delta Zone of Myanmar (Burma), every house has several ceramic jars for harvesting rainwater from roofs.

Water is channeled from the gutters to the jars by funnels attached to hosepipes that can be easily moved from a full jar to the next jar.



### 1.3 Simple roof catchments

The simplest means of storing rainwater is to place a jerrycan under a short length of gutter onto which a rope is tied. The rope guides rainwater into the jerrycan without wastage.

The green spots on top of the jerrycan are melted plastic that was used to seal holes in the jerrycan. The technique is explained in Chapter 2.



At a neighbouring house, the owner has enlarged his rainwater harvesting system by installing gutters along the whole side of the house and placing an oil drum underneath the lowest part of the gutter.

Corroded oil drums can be repaired cheaply as explained in Chapter 2.



This farmer, who lives at Simba next to the Nairobi-Mombasa highway, has made good use of an abandoned petrol tanker that had an accident nearby.

He simply hired a tractor to pull the tank to his house and repaired a few leakages in the tank with bitumen paste.



All the water tanks made of corrugated galvanized iron sheets, which were installed at private houses and schools for roof catchment, have been abandoned due to leakages caused by corrosion.

Chapter 2 explains how to repair such corroded tanks with chicken mesh and cement mixed with sand.



From the late 1970s to the mid 1980s, the Diocese of Machakos in Kenya, trained farmers to build their own water tank of concrete poured in a mould, while being reinforced with barbed wire.

The technique was so popular that about 7,000 tanks were constructed and financed by the farmers themselves.



#### 1.4 Jars

Several millions of this type of jar have been built of ferrocement by communities and individuals in Thailand.

The photo is from a training course on roof catchments for UNDP/Habitat in Myanmar (Burma).



A larger version of a water jar with a storage volume of 2,500 litres of water has been introduced during training courses in Kenya, Tanzania and Uganda.

As explained in Chapter 7, it can be constructed of only 5 bags of cement and some chicken mesh and galvanized wires.



### 1.5 Tanks built of bricks

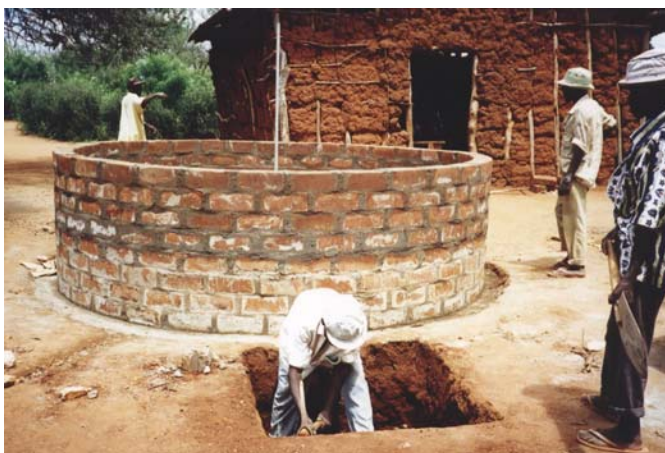
Water Tanks can be built fairly easy of burnt bricks that are reinforced with barbed wire wrapped tightly around the tank before plastering.

The construction technique for this tank and the other one built of blocks are described in Chapter 6.



A cheaper type of tank can be built of soil-compressed blocks having a content of 1 part of cement to about 20 parts of soil.

Please see Chapter 6 for details.



## 1.6 Tanks built of blocks

Water tanks can also be constructed of blocks cut out of coral or lava formations.

The photo shows a tank being built of concrete blocks during a training course at Arusha in Tanzania.

The cost of the concrete blocks can be reduced by half by inserting 50% rubble stones in the concrete when making the concrete blocks.



An experimental tank was built of rubble stones but it turned out to be too expensive in terms of skilled labour and high usage of cement.



## 1.7 Ferro-cement tanks

Ferro-cement tanks, such as this 11,000 litres tank, were popular in the 1980s and 1990s.

Unfortunately, many tanks were constructed by careless builders using poor sand and inadequate curing, which resulted in porous walls that gave way to seepage.



Another popular ferro-cement tank has 23,000 litre storage capacity as this one under construction in Myanmar.





A total of several thousands of these ferro-cement tanks having a storage capacity of 48,000 litres were built in half a dozen countries.

This tank is being properly cured under polythene sheeting for 3 weeks in Trans-Mara, Kenya.



### 1.8 Ground tanks

This 90,000 litres hemispherical ground tank was built of ferro-cement. A considerable number of similar tanks were constructed in Kenya, Uganda, Botswana, Namibia, Tanzania, Rwanda and Mozambique.

The photo shows the formwork being made ready for concreting of the dome. The staircase leads down to the water tap.



Hemispherical ground tanks can also be constructed of burnt bricks that are reinforced with chicken mesh nailed onto the interior of the tank.

Alternatively and at lower cost, hemispherical tanks can be built of a mixture of 1 part cement, 2 parts lime, 4 parts anthill soil and 6 parts river sand.



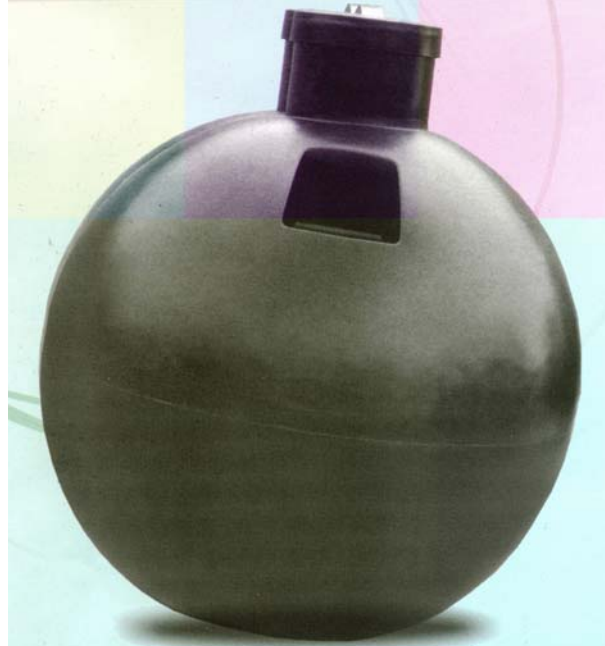
The designs, bills of quantities, costs and construction procedures for the hemispherical ground tank are described in another handbook of this series: *Water from Roads*.

## 1.9 Plastic tanks

Spherical ground tanks are manufactured of seamless polyethylene by several firms in Nairobi.

Spherical tanks are placed on a 2000 mm concrete slab in the bottom of a cylindrical excavation.

The space around the tank is back-filled with pea gravel or sand, while the tank is filled with water to the same level to avoid localized stress concentrations.



Cylindrical tanks are also made of two seamless layers of polyethene; the inner layer being white and the outer being black.

The tanks are UV stabilized and will not break down under harsh outdoor weather conditions.



## 1.10 Construction cost of water tanks

### Spherical plastic water tanks

Volume and construction material for tanks	Cost October 2006 Ksh	Cost per cu.m. Ksh
1 cu.m. of plastic	15,890	15,890
2 cu.m. of plastic	34,250	17,125
4 cu.m. of plastic	77,430	19,358

The cost of transporting the tanks, excavation, concrete slab and back-filling must be added to the costs listed above.

### Cylindrical plastic water tanks

Volume and construction material for tanks	Cost October 2006 Ksh	Cost per cu.m. Ksh
1 cu.m. of plastic	11,700	11,700
3 cu.m. of plastic	37,825	12,608
4 cu.m. of plastic	52,600	13,150
5 cu.m. of plastic	65,745	13,149
6 cu.m. of plastic	74,920	12,487
8 cu.m. of plastic	109,100	13,638
10 cu.m. of plastic	141,795	14,176
15 cu.m. of plastic	240,350	16,023
24 cu.m. of plastic	357,990	14,916

The above costs include 16% VAT. The cost of transporting the tanks and foundation must be added to the cost listed above.

### Water tanks described in this handbook

Volume and construction materials for tanks	Cost October 2006 Ksh	Cost per cu.m. Ksh
3 cu.m. built of ferro-cement	22,970	7,657
5 cu.m. built of concrete	41,690	8,338
10 cu.m. built of burnt bricks	68,145	6,815
11 cu.m. built of ferro-cement	53,193	4,836
12 cu.m. built of concrete blocks	66,768	5,564
15 cu.m. built of soil compr. blocks	56,850	3,790
23 cu.m. built of ferro-cement	77,976	3,390
46 cu.m. built of ferro-cement	109,266	2,375
90 cu.m. built of ferro-cement	163,280	1,814

## Chapter 2. Gutters

### 2.1 Gutters on rural buildings

Gutters are important for draining rainwater from roofs to storage tanks. Unfortunately, installation of gutters is often given low priority by cash-strapped rural households.

However, even temporary gutters are efficient and cost-effective and require little effort to put in place such as this one made of two strips of iron sheets laid in a few tree branches which are tied to the rafters of the house.

This owner is also satisfied with her small but efficient gutter arrangement that brings water right to her front door.



Here water is being collected from both sides of a double-pitched roof by means of hanging a gutter along the gable of the house.



Sadly, the builder was less inventive with the gutter seen in the left side of the photo because the gutter is too short and slopes away from the tank.



A simple arrangement to solve the problem with a tank situated on the wrong side of a single pitched roof in Ethiopia is shown in this photo.



Note the excellent slope of the gutter which is obtained by tying it to a splash-guard nailed onto the roofing sheets.

No matter how uneven or how long a roof is, gutters can be hung with the required gradient of 1 cm drop for every 100 cm length (1:100), when a splash-guard is nailed onto the roof.



To avoid the usual down-pipe with its two bends, which tends to get blocked thereby preventing water from entering the tank, it is much simpler and more efficient to let the gutter continue straight to the inlet as shown in this photo. It is also easier to clean the inlet mesh should it get blocked.



Primary schools and many houses in rural areas have uneven roofs without fascia boards, which made it very difficult to install gutters until the splash-guard was invented in 1986.

Splash-guards are strips of bent iron sheets nailed onto the roof. Gutters are suspended with a gradient from the splash-guard using galvanized wires. Splash-guards prevent rainwater from over-shooting the gutters.



## 2.2 Gutters in Myanmar

The Burmese people in the Delta Zone of Myanmar are very inventive with gutters of bamboo and plastic sheets.

Here a bamboo has been split and tied to a few sticks fastened with a good gradient to the rafters of the house.



This housewife has tied a plastic sheet onto three sticks to make a wide gutter that drains water into a jar.

When the jar is full of water, she diverts water from the gutter to another jar by means of a split bamboo that sits in the gaffe of a stick.



This house is equipped with another type of wide and removable gutter, which the owner re-attaches to the house when rains are expected.





Water from a gutter made of a split bamboo is delivered to the jars by a bucket and a hosepipe.



Water jars are covered with bamboo matts to keep out insects and dirt.



Hosepipes attached to funnels drain water from gutters to a series of jars.

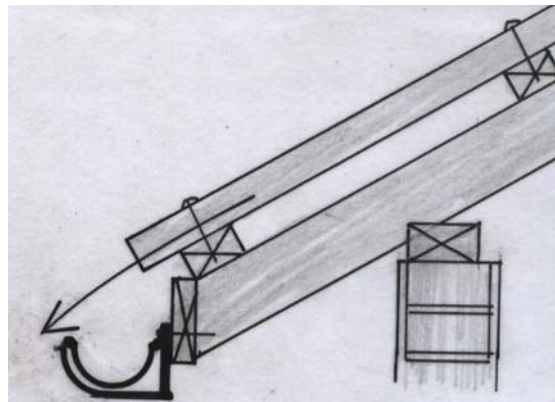
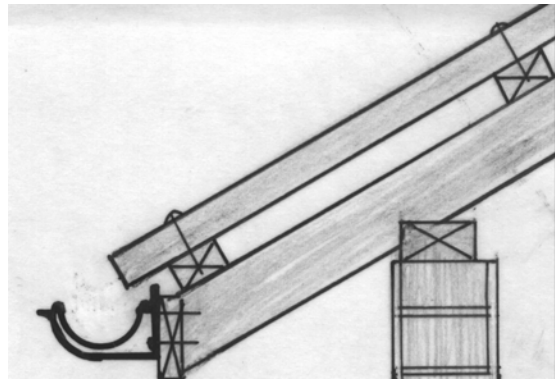
### 2.3 Semi-circular gutters

The best known gutter is the semi-circular one made either of galvanized iron sheet or PVC. The gutter is laid in gutter brackets that are nailed onto a fascia-board with a gradient thereby draining rainwater towards the water tank.

Since rural schools and houses are rarely equipped with fascia-boards, due to high cost and unsuitable rafters, many rural buildings remain without gutters and therefore without roof catchments for rainwater harvesting.

Where a semi-circular gutter is fixed too low onto a fascia-board, rainwater will be wasted by over-shooting the gutter.

In such cases the gutter cannot be raised closer to the roof because that will reduce or reverse its gradient towards the tank, thereby obstructing the flow of water.



### 2.4 Splash-guards

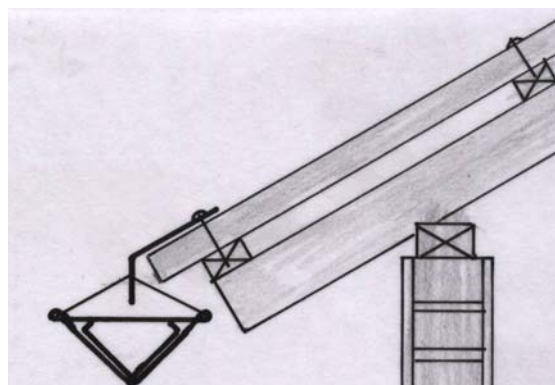
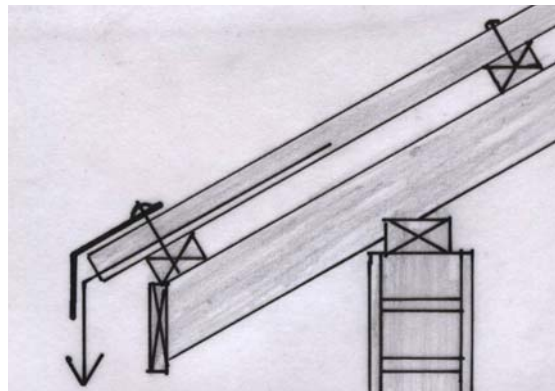
A solution to the problem was found at a Danida funded project in Kitui, Kenya.

A strip of galvanized iron sheet, called a splash-guard, was nailed onto the roof.

Rainwater running off the roof would hit the vertical lip of the splash-guard thereby diverting the water straight down into the gutter without causing any loss of water.

The next improvement was to suspend the gutter by galvanized wires from holes made in the splash-guard.

The wires can easily be adjusted to give the gutter the required gradient of 1:100 towards the water tank for uneven roofs as well as for roofs without fascia-boards.





## 2.5 Manufacturing gutters

Sheets of galvanized plain iron with gauge 26 or 28 and being 200 cm x 100 cm, are cut into three strips, each being 200 cm long and 33.3 cm wide.

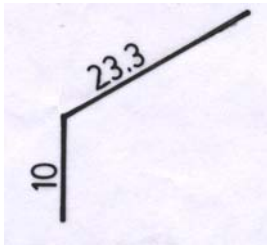
Mark the sheets with a thick wire, about 40 cm long and with each end having a sharp bend and a pointed end. The distance between the two bends must be 33.3 cm in order to make equal width of the cut sheets.



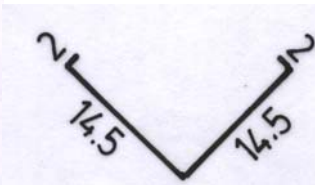
The metal strips are bent over a U-shaped piece of iron and hammered into shape with a piece of wood or a mallet.



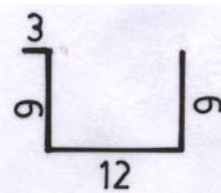
The shape of the metal strips depends on whether they shall be splash-guards, or gutters with one of the shapes shown below: namely the V-shaped gutter, the square gutter and the semi-circular gutter.



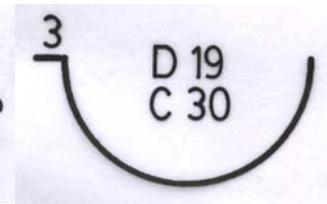
Splash-guard.



V-shaped gutter.



Square gutter.



Semi-circular gutter.



V-shaped gutter suspended from a splash-guard.



Square gutter fixed without splash-guard.

Gutters are fitted into hangers made of 3 mm galvanized wires that are bent over nails hammered into a piece of wood.



Gutters are fitted into the hangers which are tied to the splash-guard, with an equal sloping gradient towards the water tank whether the roof is even or uneven as seen in this photo.



## 2.6 Installing gutters

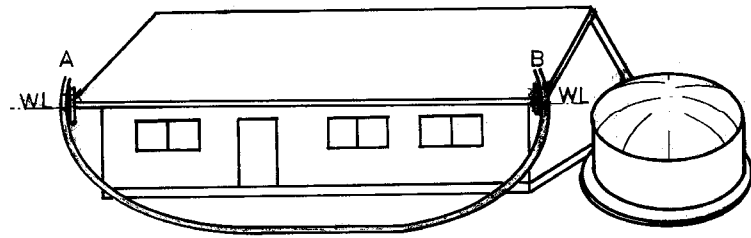
Gutters should be installed with a gradient of 10 cm depth for every 10 m length of a roof. This gradient 1:100 will make the rainwater running off the gutter with such high velocity that water will not be wasted due to overflow. Furthermore, the velocity will transport leaves and debris to the inlet sieve without any blockage of the gutter.

First the splash-guard is nailed onto the purlin at the edge of the roof. The vertical part of the splash-guard must be about 2 cm from the edge of the roofing sheets to allow water and dry leaves to pass down into the gutter.

The lower and vertical part of the splash-guard is nailed in a straight line of a string attached to the roof. The upper part of the splash-guard is nailed onto the uneven roof. The splash-guards overlap each other by 10 cm.



When the splash-guards are nailed onto the roof, a long transparent hosepipe is tied to each end of the splash-guard for the purpose of getting an exact horizontal line.



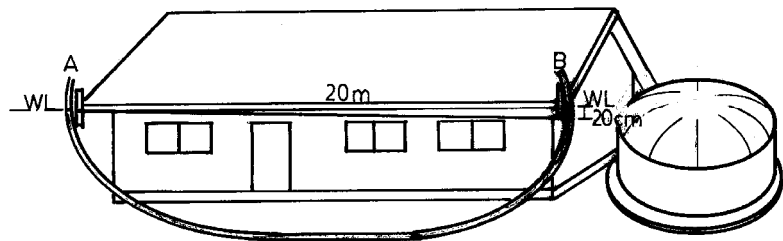
The hosepipe is then filled with water until it reaches the level of the splash-guard at that end of the roof being farthest away from the water tank.



The bottom of a gutter bracket is tied to the splash-guard at the level of the water in the hosepipe.

A second hanger is tied to the other end of the splash-guard. To obtain a gradient the second hanger is tied below the water level in the hosepipe.

If a roof is 20 m long, the hanger at the water tank must be 20 cm lower than the other hanger in order to get the desired gradient of 1:100.



A string is tied tightly between the bottom of the two hangers that are tied to each end of the splash-guard.



The first gutter can now be laid from the jar or tank to the first hanger.

If that distance is longer than the gutter, then lay two gutters and support them with two lengths of iron bars.



Bitumen paste can now be smeared to the inside of the gutter to make a water-tight joint with the next gutter.

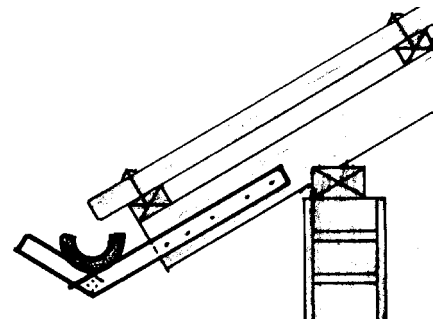
Two hangers are attached to the next gutter with one hanger at the middle and the other at the end.

The end of the gutter without a hanger is laid in the Bitumen smeared in the first gutter, while the hanger at the other end of the gutter is tied to the splash-guard, and so on until the whole length of gutter is installed.

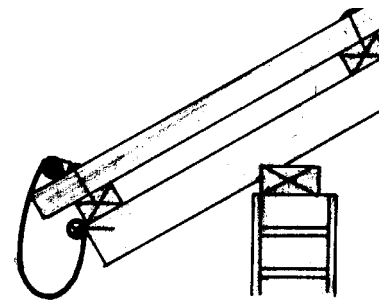


## 2.7 Other types of gutters

PVC pipes or Bamboo cut in half can be laid in timber or branches nailed onto the rafters.



One side of galvanized and corrugated iron sheets can be nailed to the rafters, while the sheets are held in position by galvanized wires tied to the roofing nails.



## Chapter 3. Water supply and demand

### 3.1 Viability of rainwater harvesting

Some people living in ASAL regions do not believe that rainwater harvesting is a viable water supply system because they say “it never rains here”. This is, of course, an understatement, because even in the Negev, Kalahari and Namibian deserts they receive about 100 mm of rainfall annually.

A rainfall of 100 mm annually was sufficient to cover all the water requirements for the Nabatean people who lived in the Negev Desert for about two thousands years. They used two main techniques for harvesting the sparse rainwater, which have been used widely ever since, namely:

- 1) Harvesting rainwater running off from hillsides by means of stone gutters, which is almost similar to harvesting water from roofs, except that rainwater running off roof catchments has no infiltration losses.
- 2) Harvesting floodwater run-off that has infiltrated sand and soil in riverbeds, by means of weirs and terraces. This technique is described in another two handbooks of this series: *Water from Dry Riverbeds* and under *Macro-irrigation* in *Water from Roads*.

### 3.2 Reliability of rainfall

Obtain seasonal rainfall data for, preferably, the last 10 years. Write a priority list with the highest seasonal rainfall at the top of the list as in this example:

Priority	Seasonal rainfall (mm)	Year	Reliability %
1	850	2000	10
2	790	1999	20
3	660	1998	30
4	560	1997	40
5	402	1996	50
6	309	1995	60
7	267	1994	70
<b>8</b>	<b>260</b>	<b>1993</b>	<b>80</b>
9	206	1992	90
10	203	1991	100

For example, if 80% reliability is required, it can be seen that this was obtained with a seasonal rainfall of 260 mm in 1993. This figure, 260 mm, should therefore be used as basis for calculating the run-off from a specific area. 10% should be deducted from the volume of water running off a roof to cover for losses on evaporation and splash-over as shown in the example below for a roof area of 50 sq.m.

$$50 \text{ sq.m roof} \times 260 \text{ mm rain} \text{ minus } 10\% \text{ loss} = \frac{50 \times 260 \times 10}{100} = \mathbf{1,300 \text{ litres loss}}$$

It is most economical to use a reliability of 80%, which means that water will not fill the tank completely with water in 2 years out of 10 years.

If 100% reliability is required the tank will be full of water every year but to achieve that the storage tank must be larger than for 80% reliability and that increases the construction costs.

### 3.3 Demand for domestic water

The minimum demand for domestic water for a homestead in ASAL can be estimated as:

Drinking water per person	=	2 litres daily
Cooking water per person	=	1 litre daily
<u>Bathing water per person</u>	=	<u>3 litres daily</u>
Minimum water demand per person	=	6 litres daily

The minimum demand for domestic water for 8 persons living in a homestead is:

6 litres x 8 persons = **48 litres of domestic water per day.**

Although rural families situated more than 5 km of walking to a water source use only 1 jerrycan of water daily, which is 20 litres per day, the figure of 50 litres per day is realistic because consumption of water increases when the effort of fetching it decreases.

The minimum demand for water for the above household, during the dry season, which in ASAL typically may last 30 weeks, is then: 30 weeks x 7 days x 48 litres = **10,080 litres.**

Although water tanks should always be water-tight and roofed, there will always be small losses of water due to contamination, evaporation and absorption amounting to about 10%.

The minimum required water storage capacity for the above homestead will therefore be: 10,080 litres + 10% loss = **11,088 litres.**

### 3.4 Supply capacity of roofs

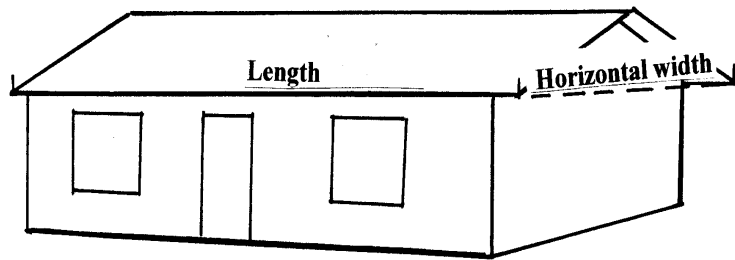
The next question is: *How much rainfall is required to supply 11,088 litres of water?*

The answer is: *That depends on the size of the roof and not on the rainfall.*

The horizontal area of a roof can be found by measuring the length and the horizontal width of either a square roof or a rectangular roof (in metres). Multiply the length with the width as shown in the following example:

Length 20.0 m x horizontal width 5.0 m = 100 square metres

A sketch showing the length and horizontal width of a double pitched roof.



The catchment area of a roof is found by multiplying the length with the horizontal width.

The rainfall for each month in a year should be known (in millimeters) in order to calculate the reliability of rainfall. This data may be difficult to obtain but perhaps a meteorological station or a government office might have some rainfall data that can be used.

It is easy to measure rainfalls using a rain gauge made of a cylindrical container, such as tin and a ruler as shown in the photo on the right.



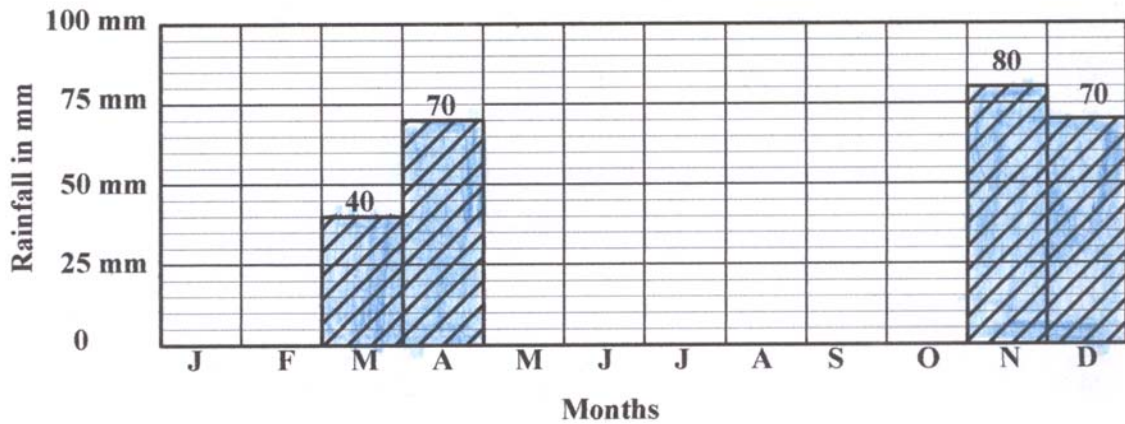
A rain gauge.

### 3.5 Required storage capacity

The following procedure explains step-by-step how to determine the minimum volume of a tank that can satisfy water demand throughout the dry season. Using the above example of 80% reliability with a 260 mm seasonal rainfall, the monthly rainfall would be as in the following example:

<u>Month</u>	<u>Monthly rainfall (mm)</u>
January	0
February	0
March	40
April	70
May	0
June	0
July	0
August	0
September	0
October	0
November	80
December	70
Total rainfall	260 mm

The data on the above monthly rainfall is converted into a graph by drawing it on millimeter graph paper as shown below.

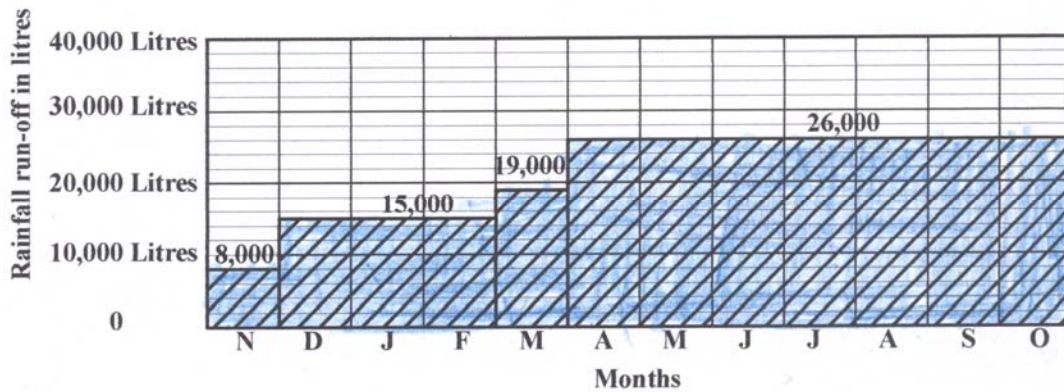


Monthly rainfalls for 12 months shown as a graph.

The required volume of a water tank that can store the cumulative rainfall of 260 mm, while drawing water from the tank over 12 months, can be found by drawing a graph as seen below.

Start with the rainfall from the first month after the longest dry period, which is 80 mm for November. 80 mm of rain falling on a 100 sq.m. roof without waste is  $80 \text{ mm} \times 100 \text{ sq.m.} = 8,000 \text{ litres}$ , which is marked on the graph. December had 70 mm of rain equal to 7,000 litres of water. Add these 7,000 litres to the 8,000 litres in November. The cumulative water is 15,000 litres, which is marked on the graph for December.

Since there is no rainfall for January and February, the cumulative volume of 15,000 litres is not increased. In March it rained 40 mm equal to 4,000 litres, which is added to the 15,000 litres, thereby increasing the volume to 19,000 litres. In April it rained 70 mm, equal to 7,000 litres, which is added to the 19,000 litres, giving a total of 26,000 litres of water which is the total cumulative volume of rainfall in that year.



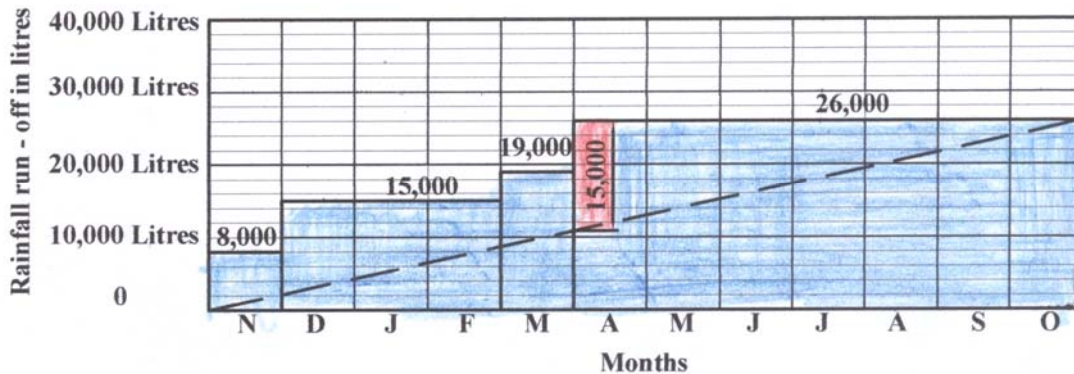
Graph showing the cumulative rainfall (in litres) for 12 months.



The volume of water that can be drawn daily from a tank having a volume of 26,000 litres of water is:

26,000 litres minus 5% storage loss / 12 months = 2,058 litres monthly = 66 litres daily = 3 jerrycans of water.

This cumulative consumption rate is drawn on the graph by a straight line from the lower left corner (1<sup>st</sup> November) to the upper right corner (31<sup>st</sup> October) as shown below.



Graph showing the monthly consumption rate of 2,058 litres = 66 litres daily.

The required storage volume of the water tank appears as the longest vertical distance from the line of consumption to the line of cumulative volume of water. This figure is marked by red and shows the water tank should have a storage volume of 15,000 litres.

### 3.6 Comparing demand with supply capacity

The above examples show that:

- 1) The minimum daily demand of domestic water for a homestead with 8 persons was 48 litres; this amounts to 11,025 litres of water in a dry season of 210 days, inclusive of the 5% storage loss, i.e.:  $50 \times 210 + 5\%$ .
- 2) 80% reliability of the annual rainfall would be 260 mm which is normal in Eastern Kenya.
- 3) When rainfall with this 80% reliability is collected from 100 sq.m. roof, it amounts to 26,000 litres, minus a storage loss of 5% = 24,700 litres. That requires a water tank with a capacity of 15,000 litres, which can deliver 66 litres of water daily throughout the year.
- 4) The difference between the estimated demand of 50 litres of water daily and the supply capacity of 66 litres daily is a daily surplus of 16 litres = equal to 32%.
- 5) The over-design of 32% can be corrected by reducing the roof area and the tank volume by 32% or, alternatively, be used for increased consumption.

## Chapter 4. Design considerations of water tanks

### 4.1 Choice of building materials for tanks

The most economical way of building water tanks is to use as much locally available material as available in that specific region. An additional advantage is that local builders are conversant with building with local materials.

It could be tempting to install a ready-made plastic tank from a supplier or manufacturer, if no reliable builders and local materials are available in the neighbourhood. It is, however, important to remember the cost of VAT, transporting the tank to the site and building a concrete foundation for the tank which must be added to the cost of purchasing. The choice of building materials can be decided by considering the following:

- 1) Where coarse river sand is expensive, tanks should be built of either burnt bricks or soil-compressed bricks (as in the photo) to reduce cost.
- 2) Where coarse sand is cheap, tanks should be built of ferro-cement if trained builders are available.
- 3) Where coarse river sand, pebbles, stones and hardcore (larger stones) are in plenty, it is most economical to use concrete in formwork (in situ) or concrete blocks.



- 4) The cost of making concrete blocks can be reduced by compacting rubble stones into the concrete in the steel mould. Such blocks, as seen in the photo are called rubble stone blocks.



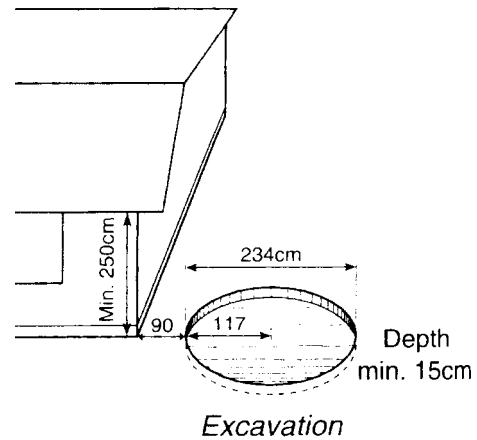
- 5) It is usually more economical to repair an old or abandoned tank than to replace it by constructing a new tank. As explained in another chapter, all types of cylindrical and spherical tanks can be repaired cheaper than building new ones. Repair of square and rectangular tanks are difficult and costly.

## 4.2 Foundations

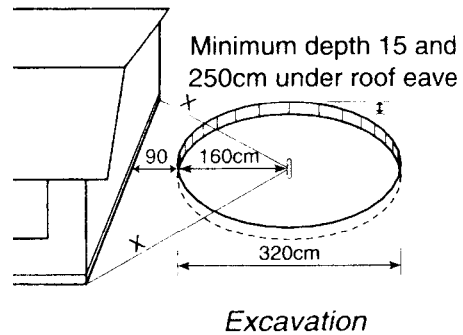
When the required storage volume of a water tank has been determined, the foundation for the water tank can be marked on the ground.

The walls of water tanks should be situated 90 cm from the wall of the house to allow the builders to work all around the tank. The bottom of the excavation must be 250 cm below the roof for the standard designs of 2 m high water tanks.

The sketch shows the excavation for a 5 cu.m. tank that will collect water from a single pitched roof or from one side of a double pitched roof.



This sketch shows the best location for a 10 cu.m. tank that shall collect water from both sides of a double pitched roof. The two distances marked x should be of equal length.



A 7 cm thick of concrete made of 1 part sand, 3 parts and 4 parts crushed stones (1:3:4) is compacted onto the dry soil in the excavated foundation for a tank.



The reinforcement of either BRC mesh or weld mesh is laid onto the 7 cm layer of concrete and another 7 cm thick layer of concrete is compacted onto the reinforcement.

The foundation for a water tank must be cast and completed within 1 day to obtain a strong foundation.



### 4.3 Extraction of water

Draw-off pipes for extracting water from tanks should always be concreted into the foundation of the tank.

A 90 cm long  $\frac{3}{4}$  inch G.I. pipe onto which an elbow and a nipple are screwed tightly is placed on the first layer of concrete in the foundation as seen in this photo.



Later on a small staircase with sufficient room for placing a jerrycan under the water tap shall be constructed.



The tap station should be covered with a lockable steel door to prevent misuse of the water in the tank.



A PVC pipe drains waste water from the floor of the tap station into a 2 m deep excavation that is filled up with rubble stones as shown in the photo.

Polythene sheets or empty cement bags are placed on top of the rubble stones before back-filling soil in the seepage pit.



## 4.4 Walls

Three types of walls for building water tanks are recommended:

### 1) Concrete in situ

Where river sand, pebbles and stones are cheap, the easiest tank to built is made of concrete compacted into formwork and reinforced with a spiral of barbed wire as explained in Chapter 5.



### 2) Bricks and block tanks

Where river sand is expensive, tanks should be built of either burnt bricks, compressed soil bricks, quarry blocks, concrete blocks or rubble stone blocks.

Walls for water tanks must be circular in order to distribute hydrostatic pressure equally.

To build an exact circle, a wire is tied to a vertical pipe erected exactly in the centre of the foundation and used as a guide.

Tanks built of bricks or blocks are reinforced with barbed wire, gauge 12.5, wrapped as a spiral tightly around the exterior tank walls. First 4 rounds are tied at the foundation followed by a spiral spaced 5 cm for the lower 100 cm of the tanks. Thereafter the spiral continues with a spacing of 10 cm on the upper 100 cm of the tanks as explained in Chapter 6.



### 3) Ferro-cement tanks

Where coarse river sand is cheap, tanks should be built of ferro-cement.

The reinforcement consists of a cylinder of BRC wire mesh that is tied onto the BRC wire mesh laid in the floor. Chicken mesh, 25 mm, is thereafter wrapped around the cylinder of BRC.

3 mm galvanized wire is then wrapped around the chicken mesh in a spiral spaced 5 cm on the lower 100 cm of the tank and 10 cm apart on the upper 100 cm.

The technique of ferro-cement requires careful builders who have learnt the skill. Designs, BQs, costs and construction procedures for 5 sizes of water tanks built of ferro-cement are presented in Chapter 7.

The point where leakage might occur in water tanks is usually the joint between the foundation and the wall. Leakage can be due to either a weak cement mixture, lack of proper curing or failure to remove dirt in the joint before applying mortar.

A proper joint is made by cleaning first the interior joint with plenty of water and compacting freshly made cement mortar 1:3 in the joint with a stick. Thereafter the mortar is rounded with a piece of bamboo or an empty beer bottle and coated with NIL.

When the mortar has set in the interior joint, the external joint is cleaned again with water. Mortar 1:3 is then compacted into the joint with a stick and is smoothed to an apron being about 10 cm high against the wall of the tank as in the photo.

The apron and the external side of the wall can be painted with a weather-proof paint made of 1 part cement to 10 parts of lime. Soil should be back-filled against the tank to avoid water stagnating near the tank.



## 4.5 Roofs

Water stored tanks without roofs in the arid and semi-arid (ASAL) parts of the tropics has an evaporation rate that may reach 3,000 mm annually, which is about 8 mm in a day. Therefore, if a tank is 200 cm high and full of water, evaporation alone will empty the tank in 250 days (2,000 mm / 8 mm).

Tanks should therefore be roofed air-tight for two reasons: a) to reduce evaporation losses, and b) to keep mosquitoes, lizards, frogs, mice, etc. out of the water for hygienic reasons. Water in the tank will breathe through the inlet where water flows into the tank and through the outlet for the overflow. The inlets and outlets must be covered with plastic mosquito mesh that is replaced before the next rainy season or at least once a year.

The easiest way to roof a water tank is to cover it with a slab of reinforced concrete as seen in the photo.

However, a reinforced concrete slab costs more than a dome constructed of ferro-cement.



Domes made of ferro-cement are cheaper than flat roofs made of reinforced concrete.

The photo shows templates erected on a column of PVC pipe into which steps made of GI pipes are inserted. The PVC pipe is then filled with concrete to make it firm.



The templates are covered with steel plates cut from old oil drums or damaged car bonnets. Polythene sheets and weld mesh are placed on the dome of steel plates and a 5 cm thick layer of mortar mixture 1:3 is compacted and smoothed onto the dome. After 3 weeks of curing the formwork is removed and used for other water tanks.



#### 4.7 Manholes and gutter inlets

Covers for manholes are made by filling a circular plastic basin with concrete into which a bent iron bar is inserted as a handle.

The basin with concrete is placed on the formwork near the center column while the roof or dome is concreted around it.



After a few days of curing, the cover can be lifted out of the basin and placed in the manhole where it fits so tightly that mosquitoes and lizards cannot enter the tank.

The inlet holes for the down-gutters are made by placing one or two empty tins on the formwork while concreting the roof as shown above.

After a few days the inlets are built over the inlet holes as seen in the photo. The inlet is covered with coffee and mosquito mesh to keep out insects.



Water from the down-gutter will shoot through the mesh, while debris will fall off the mesh by gravity.

#### 4.8 Center column

A center column should be placed in the center of a water tank for two purposes: a) to support the roof or dome, and b) to act as a ladder for easy access to the interior of the tank while it is being built and when it has to be cleaned in the years to come.





A center column is made by a 100 mm PVC pipe into which holes are burned with red hot ends of the 60 cm long 3/4" galvanized iron pipes that shall be inserted as steps.

The PVC pipe is then erected in the middle of the tank, while an iron rod is inserted into the PVC pipe before it is filled with concrete.



#### **4.9 Curing**

Especially ferro-cement walls and domes must be cured properly by being kept moist and under cover for 21 days. All other concrete and plaster works should also be cured during a similar period. It is a fact that if cement is not cured properly for the first 5 days it loses about 50% of its strength.

Many masons avoid the process of curing because they do not understand its importance. They find it is a complete waste of water and time to cure cement works. Only when they are deducted fines from their salary do they realize the importance of curing!



## Chapter 5. A tank built of concrete in situ

### 5.1 Introduction

Several thousands of this type of water tank with a storage volume of 5,000 litres of water have been built by farmers themselves in Machakos and Kitui since the late 1970s. The only assistance given to the farmers was to lent them a mould of corrugated iron sheets by the Diocese of Machakos. Each mould could be used for about 25 tanks before being worn out and replaced by the Diocese.

A mould consists of two circular iron sheets, 70 cm high and with a diameter of 180 cm and 200 cm respectively that are bolted together as seen below. A tank is built by using the mould in 3 stages, on top of each other.

Each stage consists of filling the mould with a concrete mixture of 1:3:4 in layers of 10 cm with each layer reinforced with a spiral of barbed wire. When the concrete has hardened in a couple of days, the mould is removed and assembled on top of the existing stage as explained on the following two pages.



A mould made of plan iron sheets gives a smooth wall on the internal and external sides.

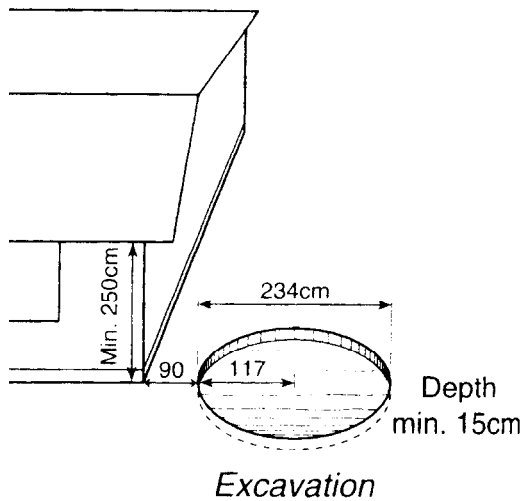


A cheaper mould can be made of corrugated galvanized iron sheets bent in a roller.



This type of mould gives the wall a corrugated surface on both sides.

## 5.2 Construction procedures for a 5 cu.m. tank of concrete in situ

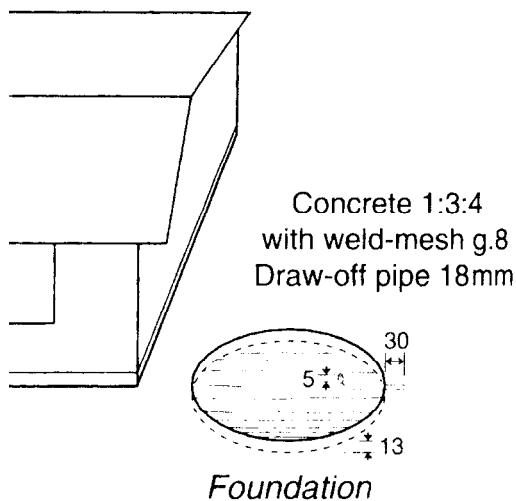


### Excavation

A circle with a radius of 117 cm is drawn on the ground 90 cm away from the corner of the wall of the house which will deliver the rainwater.

The depth of the excavation must be at least 250 cm below the edge of the roof, otherwise the gutter cannot get sufficient gradient towards the inlet of the tank.

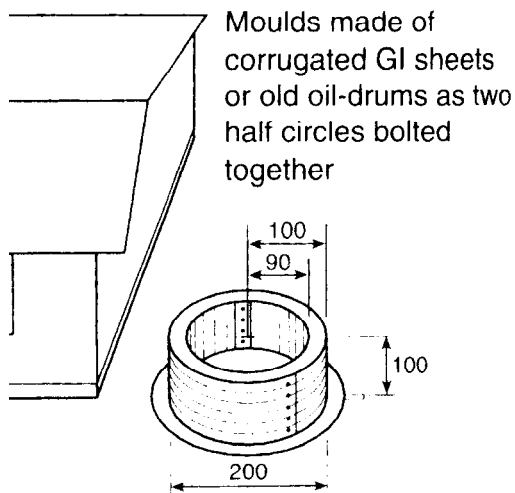
The tank should also have a depth of at least 15 cm into firm soil.



### Foundation

Two sheets of weld mesh, 8 ft. x 4 ft. are tied together and cut into a circle having a radius of 112 cm, which is 5 cm shorter than the radius of the excavation. A draw-off pipe is made of a 90 cm long 18 mm G.I. pipe onto which an elbow and a nipple are attached.

A 7 cm thick layer of concrete mixture 1:3:4 is compacted onto the dry soil in the excavation without watering the soil and without hardcore. The weld mesh and draw-off pipe is laid on the concrete and a 6 cm layer of concrete is compacted onto the foundation.

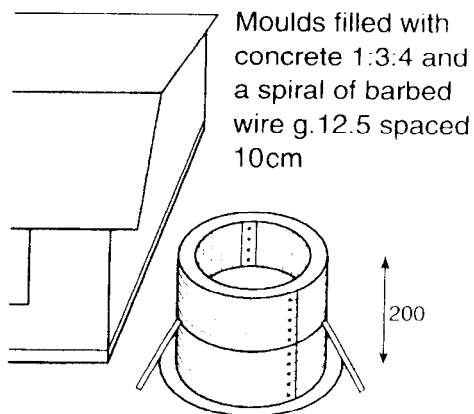


### Mould in first the stage

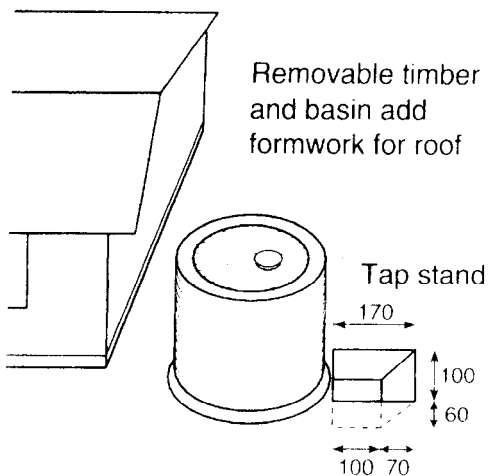
Place the two circular moulds on the foundation, 10 cm apart.

Mix concrete 1:3:4 and pour it into the mould in 10 cm high layers while a spiral of barbed wire is laid in the concrete as reinforcement.

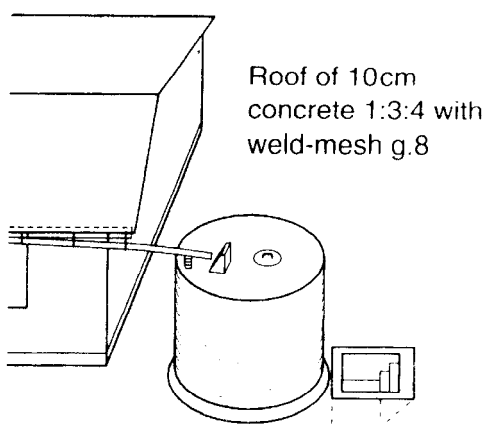
Knock the mould with a piece of timber when the mould is filled up with concrete in order to remove air bubbles from the concrete.



*Mould in second position*



*Formwork for roof*



### **Mould in the second and third stages**

After a further two days, remove the mould and place it on top of the concreted wall.

Then repeat the procedure of filling the mould with concrete and barbed wire in layers of 10 cm.

After another two days, remove the mould, place it on top of the concreted wall and fill it up with concrete and barbed wire.

### **Formwork for roof**

Remove the mould two days later and plaster the interior of the tank with 2 cm of mortar 1:3. Apply cement slurry (NIL) with a steel trowel onto the plaster.

Make a formwork of timber supported by props at the top of the tank. Tie two weld meshes together and cut them into a circle that is 5 cm shorter than the outer edge of the tank. Cut out a circular hole for the manhole.

Place the 18 mm G.I. overflow pipe on the formwork vertically over the draw-off pipe.

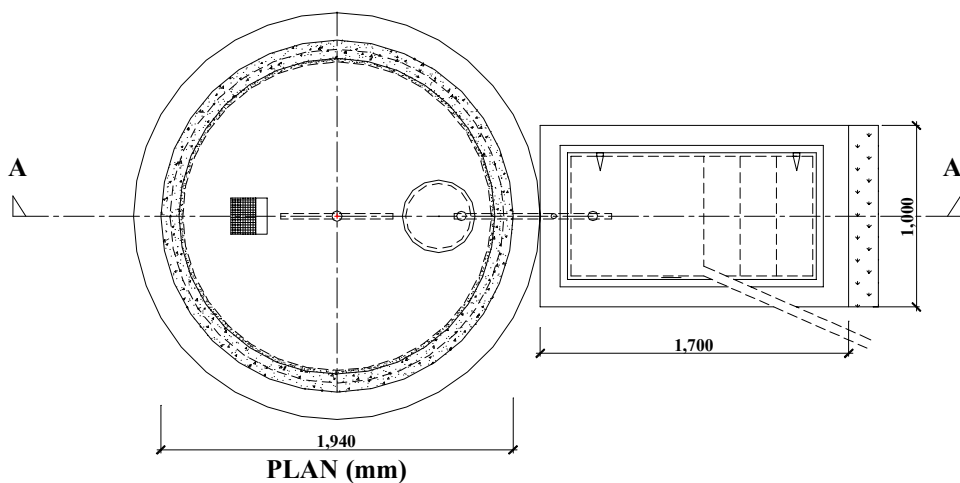
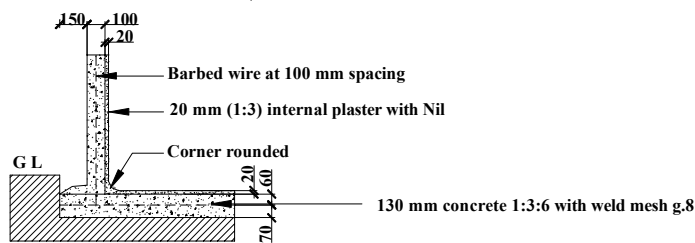
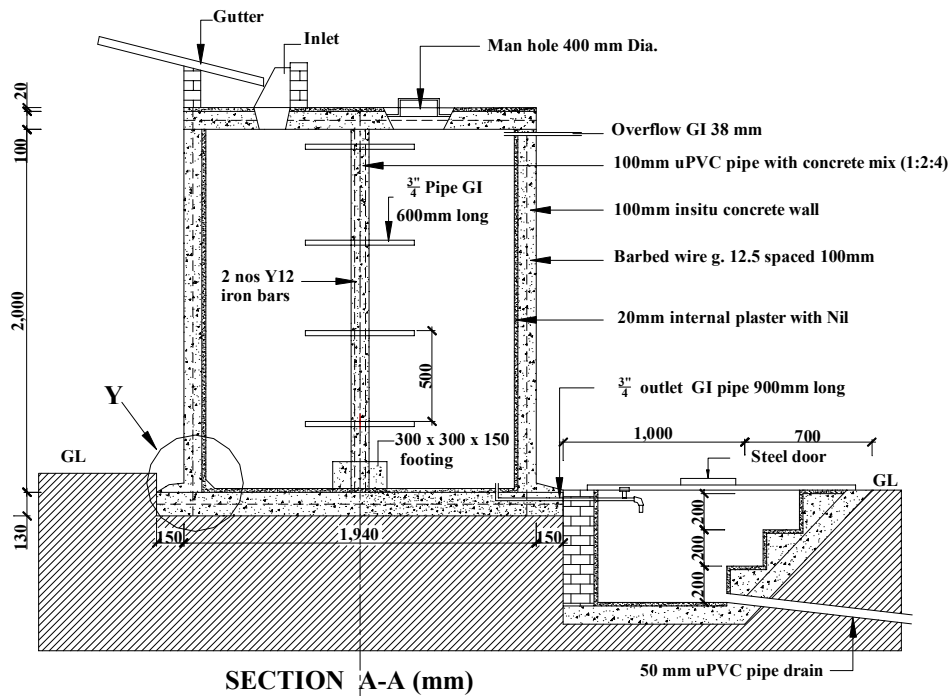
### **Roof and finish**

Compact a layer of 10 cm thick concrete onto the formwork with the weld mesh being in the middle and a plastic basin as a mould for the manhole cover.

Build the tap stand and install the gutter while the concreted roof is being cured.

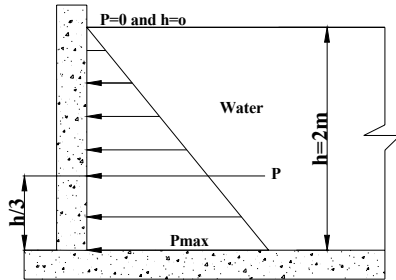
Remove the formwork after 7 days of curing and white-wash the external surface of the tank with 1 part cement to 10 parts of lime.

### 5.3 Standard design for a 5 cu.m. tank built of concrete in situ



## 5.4 Calculation on reinforcement of tank wall made in situ

Concrete 1:3:3 is compacted into a formwork and reinforced with spiral of barbed wire gauge 12.5 spaced 10 cm.



Pressure diagram of a tank wall built of concrete in situ

### Assumptions.

Wall thickness = 200mm

Concrete class = 20 with compressive strength of  $20 \text{ N/mm}^2$ , Nominal mix 1:2:4. Tensional strength of concrete is about 10% of compressive strength, which in this case is  $2 \text{ N/mm}^2$

### Analysis

Water density =  $1000 \text{ kg/m}^3$

Acceleration due to gravity -  $g = 9.8 \text{ N/s}^2$

Maximum water pressure =  $h \rho g$  where  $h$  = height,  $\rho$  = Density of water and  $g$  = acceleration due to gravity =  $2 \times 1000 \times 9.8 = 19.6 \text{ kN/m}^2$

Design load (pressure) = Actual load x factor of safety which is given as 1.6 in BS 8110.

Design load (pressure) is therefore  $19.6 \times 1.6 = 31.36 \text{ kN/m}^2$

Since the tank is cylindrical, the predominant stress on the walls is tensional. Maximum tensional stress at the bottom of the tank is given by  $\sigma_t = \frac{pd}{2t}$  where  $\sigma_t$  = tensional stress,  $p$  = design pressure,  $d$  = radius of tank and  $t$  = thickness of tank =

$$= 31.36 \times 2 / 2 \times 0.2 = 156.8 \text{ kN/m}^2 = \underline{0.157 \text{ N/mm}^2}$$

Characteristic tensional strength of concrete class 20 is  $2 \text{ N/mm}^2$

Design strength = Characteristic strength divided by material partial factor of safety  $\gamma_m$

For concrete,  $\gamma_m$  is given as 1.5 or greater for concrete in tension. (BS 8110)

Therefore, design strength =  $2 / 1.5 = \underline{1.33 \text{ N/mm}^2} = 1.33 \text{ N/mm}^2$  is greater than the tensional stress and therefore adequate

Shear acting at the bottom wall of the tank is given by:

$$\tau = \frac{pd}{(\pi d) t / 2} \text{ where } \tau \text{ is the shear stress} = 31.36 \times 2 / (\pi \times 2 \times .2/2) = 99.82 \text{ kN/m}^2 = 0.099 \text{ N/mm}^2 \text{ say } \underline{0.1 \text{ N/mm}^2}$$

Factored Shear strength of concrete is given by  $0.8 \times$  square root of its compressive strength  $f_{cu}$ , up to a maximum of  $5 \text{ N/mm}^2$ . (This shear strength has already been factored using  $\gamma_m = 1.25$ ) – (Bs 8110). Since the shear strength =  $0.8 \times$  square root of  $20 = 3.57 \text{ N/mm}^2$ . **Conclusion: The reinforcement is adequate.**

### 5.5 Bill of Quantities and cost for a 5 cu.m. tank of concrete in situ

Description	Unit	Quantity/ Days	Unit cost Ksh	Total cost Ksh
<b>Labour cost</b>				
Artisan	Artisans	1 x 8 days	400/day	3,200
Labourers	Labourers	2 x 8 days	200/day	<u>3,200</u>
<b>Cost of labour</b>				<b>6,400</b>
<b>Materials</b>				
Cement	50 kg bags	12	600	7,200
River sand	Tonnes	3	200	600
Crushed stones	Tonnes	3	600	1,800
Burnt bricks 4" x 6" x 10"	Units	50	5	250
Water	Oil-drums	8	100	800
Weld mesh 2.4 x 1.2 m	Sheets	4	370	1,480
Barbed wire 20 kg rolls, g 12.5	Kg	1	3,000	3,000
Chicken mesh, 3' x 90' x 1"	Rolls	2	3,000	6,000
Nails, 2"	Kg	5	100	500
Lime	25kg	1	400	400
uPVC, 2" sewage pipe	Lengths	1	400	400
G.I pipe, 1½"	Metres	0.5	420	210
G.I pipe, ¾"	Metres	0.9	200	180
G.I fittings, ¾" tap, elbow etc	Units	4	500	2,000
Galvanized coffee mesh	Sq.m.	1	200	200
Circular bolts	6 mm x 25 mm	6	20	120
Circular metal ring	Centimetres	200 x 20	Free	Free
Timber, 6" x 1"	Metres	30	75	2,250
Nails, 3"	Kg	5	80	<u>400</u>
<b>Cost of materials</b>				<b>27,790</b>
<b>Transport of materials</b>				
Hardware lorries	3 tonnes	1 load	3,000	3,000
Tractor trailer loads	3 tonnes	5 loads	900	<u>4,500</u>
<b>Cost of transport</b>				<b>7,500</b>
<b>Total cost of a 5 cu.m. tank built of concrete in situ</b>				<b>41,690</b>

## Chapter 6. Three tanks of bricks, blocks and rubble stones

### 6.1 Introduction

Almost all kind of bricks and blocks can be used for construction of water tanks provided they are reinforced sufficiently, plastered to be water proof and kept moist under shade (cured) for 3 weeks.



As mentioned earlier in this handbook, the cost of making concrete blocks can be reduced by compacting rubble stones in the concrete.

Especially, bricks made of soil in a hand operated press are cheap and suitable for construction of water tanks. The bricks are also friendly to the environment because very little water and no firewood are required for making the bricks.

The press seen in the photo was made by Udungu Society in Nairobi. They also provide a tray for testing soil samples and a manual with the ratio for mixing sandy soil with a little cement and clayey soil with a little lime.



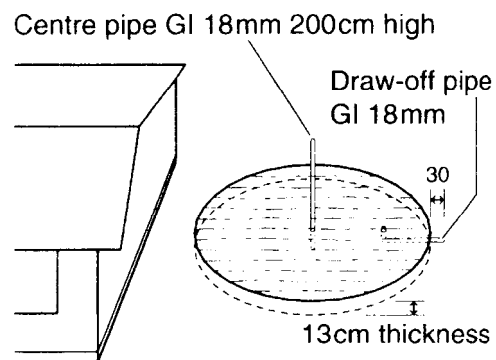
### 6.2 Construction procedures

#### Foundation and centre pipe

The excavation for a 10 cu.m. tank has a radius of 160 cm that is situated 90 cm from the wall of the house. The foundation is dug to a depth of 250 cm below the eave of the roof and at least 15 cm into solid soil.

The foundation is made of 13 cm thickness of concrete mixture 1:3:4 with a layer of weld mesh in the middle. Also a 90 cm draw-off pipe of 18 mm G.I. pipe is in the concrete.

A 200 cm G.I. pipe of 18 mm is concreted exactly in the centre of the upper layer of concrete in the foundation as a guide for the builder.



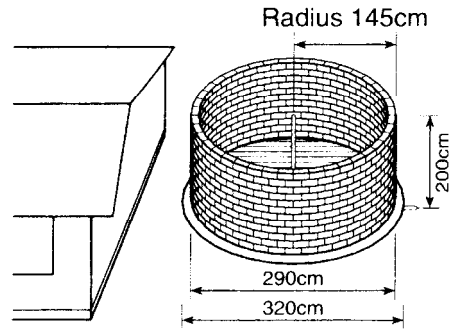
*Foundation, centre pipe and draw-off pipe*



### The wall of bricks or blocks

A 180 cm long wire is tied to the vertical centre post and its other end is bent so that it has a radius of 145 cm, which gives the exact position of the outer corners of the bricks or bends to be laid for the circular wall of the tank.

The thickness of the vertical joints between the bricks or blocks without cutting any of them is found by laying them out along the circle of the radius wire and spacing them without mortar.

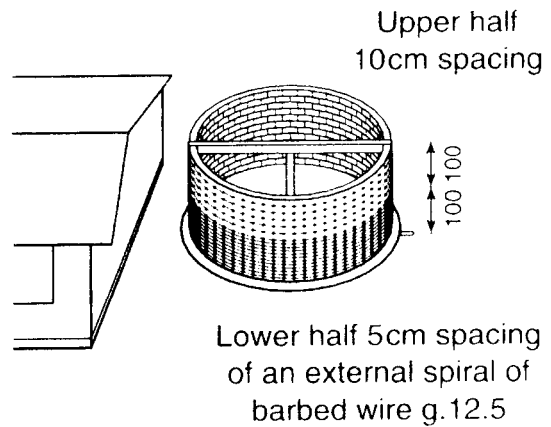


### Column and beam

When the wall is built to a height of 200 cm, a 100 mm PVC pipe is cut to a length of 185 cm.

The ends of 4 lengths of 18 mm G.I. pipes 60 cm long, are heated over fire and inserted into the PVC pipe at equal distances.

The PVC pipe is then placed around the centre pipe and filled with concrete.



### Plaster

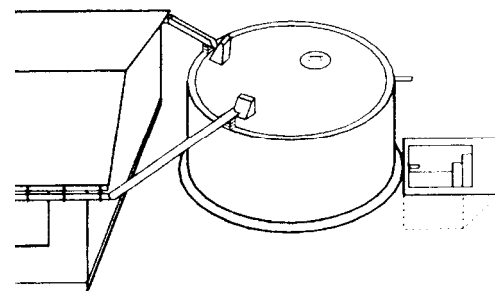
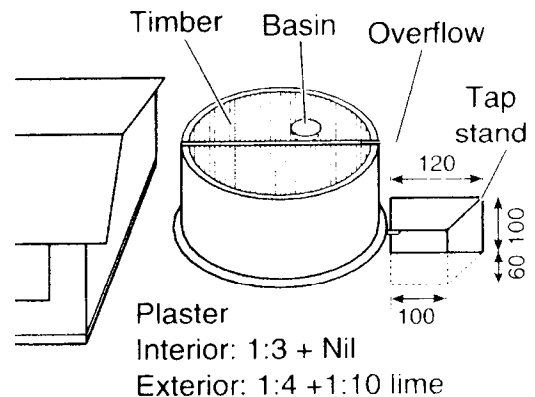
The outside of the tank is plastered with 2 cm of mortar 1:4. The interior wall and floor is plastered with 2 cm of 1:3 mortar onto which NIL is applied with a square steel trowel for water proofing.

### Roof and tap stand

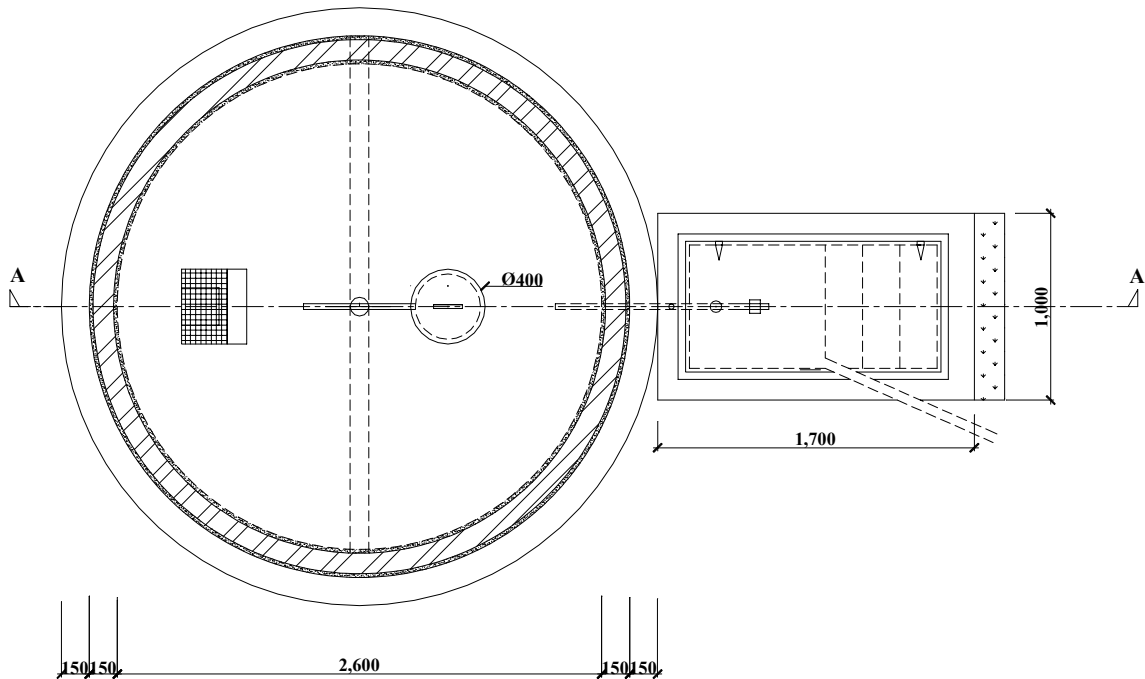
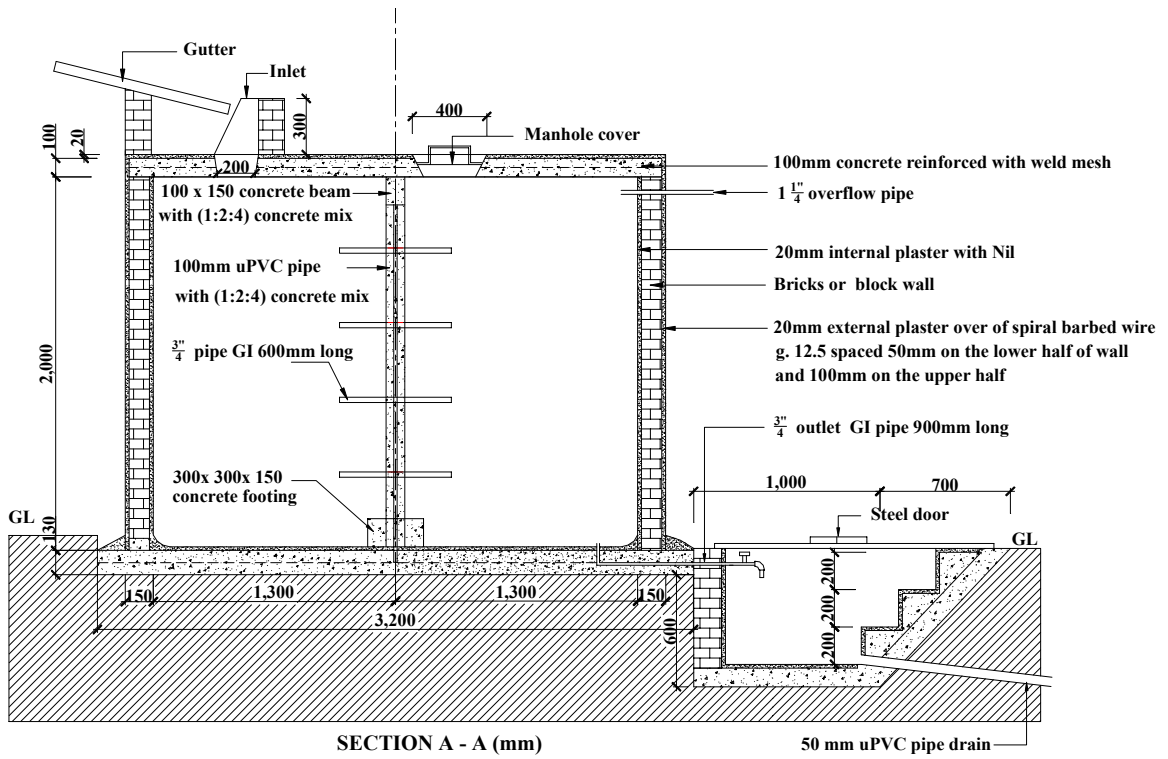
If a beam is required for a flat roof of reinforced concrete, it is made in formwork of timber being 10 cm wide and 15 cm deep and 4 lengths of twisted iron rods are laid into it.

The formwork for the roof consists of timbers supported by props. A basin, 2 tins and the overflow pipe are placed on the formwork for the roof.

The beam and the formwork are then covered with 10 cm of concrete 1:3:4. After 3 weeks of curing the formwork can be removed and used elsewhere.

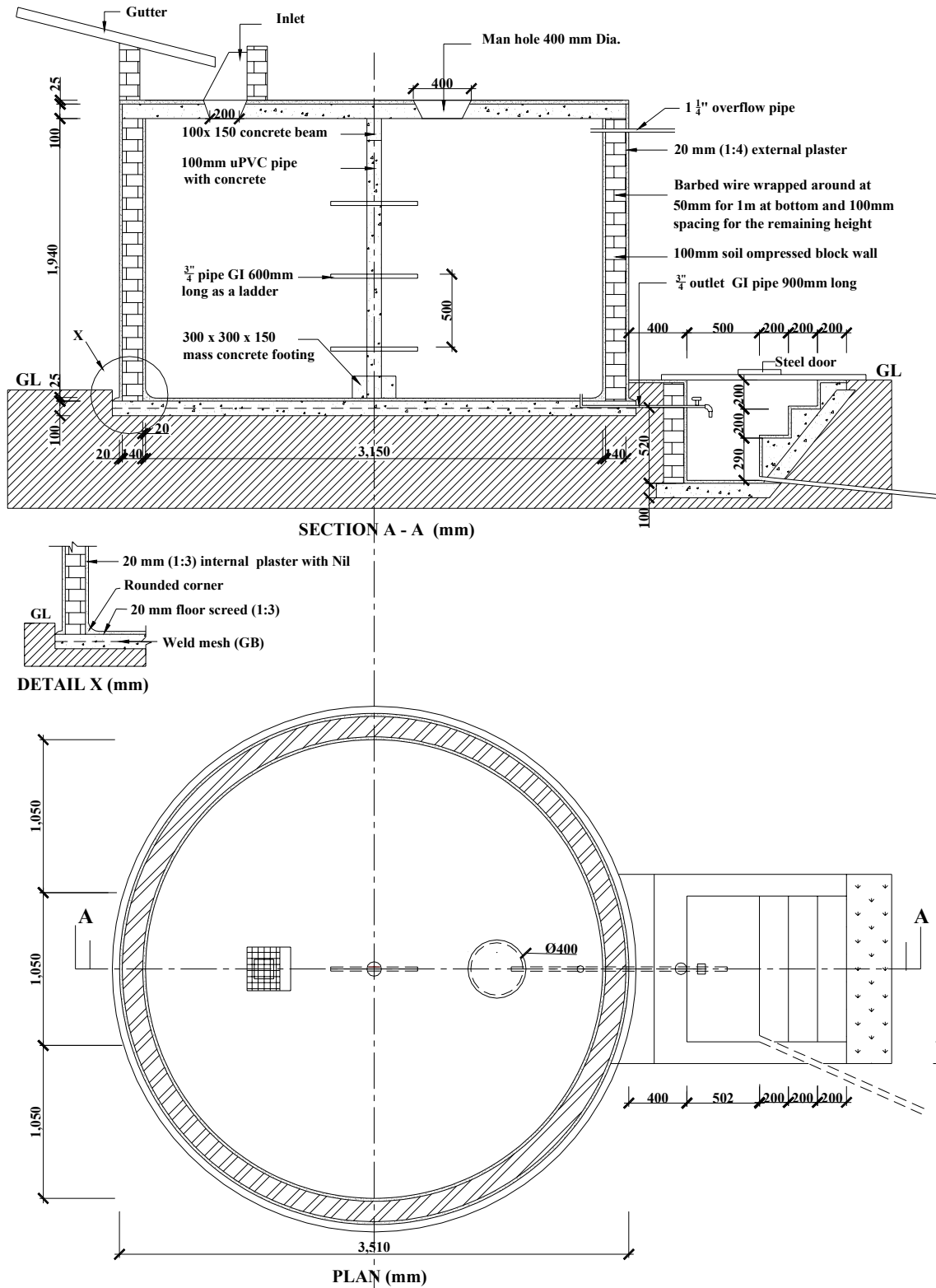


### 6.3 Standard design of a 10 cu.m. tank built of burnt bricks



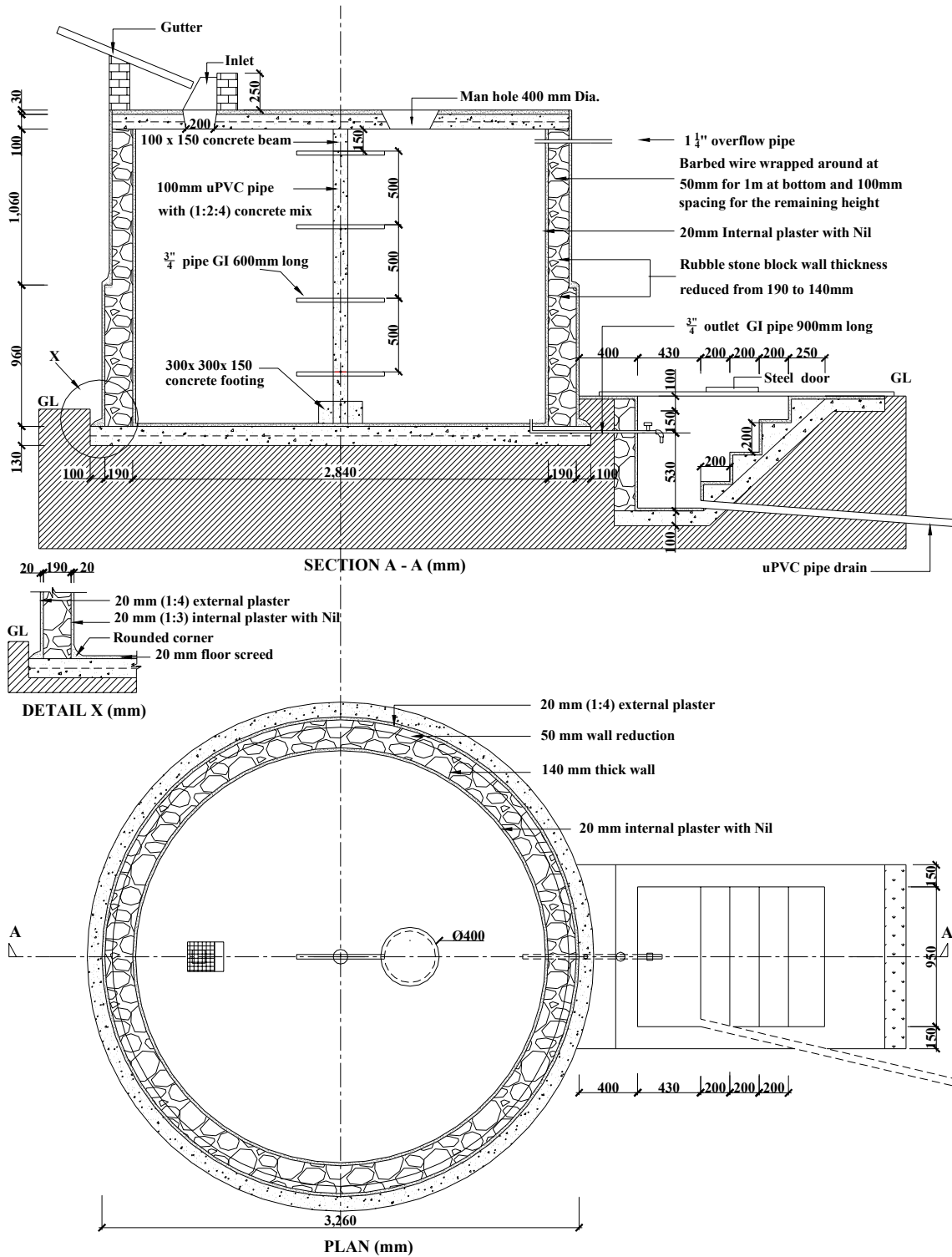
Bill of Quantities and costs of building the tank are listed on page 45.

## 6.4 Standard design of a 15 cu.m. tank built of soil compressed bricks



Bill of Quantities and costs of building the tank are listed on page 46.

## 6.5 Standard design of a 12 cu.m. tank built of rubble stones



Bill of Quantities and costs of building the tank are listed on page 47.

## 6.7 Bills of Quantities and cost of 3 types of tanks

### 6.7.1 Bill of quantities and cost of a 10 cu.m. tank built of burnt bricks

Description	Unit	Quantity	Unit cost (Ksh)	Total cost (Ksh)
<b>Labour cost</b>				
Artisan	Artisans	1 x 9 days	400/day	3,600
Labourers	Labourers	2 x 9 days	200/day	<u>3,600</u>
<b>Cost of labour</b>				<b>7,200</b>
<b>Materials</b>				
Cement	50 kg bags	21	600	12,600
River sand	Tonnes	4	200	800
Crushed stones	Tonnes	4	600	2,400
Hardcore	Tonnes	1	200	200
Burnt bricks 10" x 12" x 20"	Units	700	12	8,400
Water	Oil-drums	10	100	1,000
Weld mesh 2.4 x 1.2m, g.8	Sheets	9	370	3,330
Barbed wire 20 kg rolls, g 12.5	Kg	30	150	4,500
Twisted bars, Y12	Lengths	13	700	9,100
Lime	25 kg	4	400	1,600
uPVC, 2" sewage pipe	Lengths	3	300	900
uPVC, 4" sewage pipe	Lengths	2	400	800
G.I pipe, 1½"	Metres	0.5	420	210
G.I pipe, ¾"	Metres	4	200	800
G.I tap, ¾"	Units	1	500	500
G.I elbow, ¾"	Units	1	45	45
G.I socket, ¾"	Units	1	80	80
G.I nipple, ¾"	Units	1	90	90
Galvanized coffee mesh	Sq.m.	1	200	200
Timber, 6" x 1"	Metres	70	75	5,250
Nails, 3"	Kg	8	80	<u>640</u>
<b>Cost of materials</b>				<b>53,445</b>
<b>Transport of materials</b>				
Hardware lorries	3 tonnes	1 loads	3,000	3,000
Tractor trailer loads	3 tonnes	5 loads	900	<u>4,500</u>
<b>Cost of transport</b>				<b>7,500</b>
<b>Total cost of a 10 cu.m. tank built of burnt bricks</b>				<b>68,145</b>

### 6.7.2 Bill of quantities and cost of a 15 cu.m. tank of soil compressed blocks

Description	Unit	Quantity	Unit cost (Ksh)	Total cost (Ksh)
<b>Labour cost</b>				
Artisan	Artisans	2 x 10 days	400/day	8,000
Labourers	Labourers	4 x 10days	200/day	<u>8,000</u>
<b>Cost of labour</b>				<b>16,000</b>
<b>Materials</b>				
Cement	50 kg bags	25	600	15,000
Lime	25 kg bag	4	400	1,600
River sand	Tonnes	6	200	1,200
Crushed stones	Tonnes	4	600	2,400
Hardcore, 4" x 6"	Tonnes	1	200	200
Soil compressed blocks, 4" x 5" x 12"	Units	555	15	8,250
Water	Oil-drums	10	100	1,000
Weld mesh, 8' x 4' (feet) N° 8	Sheets	10	370	3,700
Barbed wire, g12.5, 20 kg	Rolls	2	3,000	6,000
Twisted bars, Y12	Metres	15	18	270
Binding wire g.8	Kg	1	150	150
uPVC, 4" sewage pipe	Metres	3	133⅓	400
G.I pipe, ¾"	Metres	3	200	600
G.I tap, elbow, socket, nipple ¾"	Tap unit	1	700	700
Galvanized coffee mesh	Sq.m.	1	200	200
Mosquito mesh	Sq.m.	0.5	100	50
Timber, 6" x 1"	Metres	90	75	6,750
Pole	Lengths	8	40	320
Nail 3"	Kg	4	80	<u>320</u>
<b>Cost of materials</b>				<b>49,110</b>
<b>Transport of materials</b>				
Hardware lorries	7 tonnes	1 loads	5,000	5,000
Tractor trailer loads	3 tonnes	8 loads	900	<u>7,200</u>
<b>Cost of transport</b>				<b>12,200</b>
<b>Total cost of a 15 cu.m. tank built of rubble stones</b>				<b>77,310</b>

### 6.7.3 Bill of quantities and cost of a 12 cu.m. tank built of rubble stones

Description	Unit	Quantity	Unit cost Ksh	Total cost Ksh
<b>Labour cost</b>				
Artisan	Artisans	1 x 12 days	400/day	4,800
Labourers	Labourers	2 x 12days	200/day	<u>4,800</u>
<b>Cost of labour</b>				<b>9,600</b>
<b>Materials</b>				
Cement	50 kg bags	25	600	15,000
River sand	Tonnes	5	200	1,000
Crushed stones	Tonnes	4	600	2,400
Hardcore, 4" x 6"	Tonnes	5	200	1,000
Rubble stones blocks, 5" x 8" x 15"	Units	260	20	5,200
Burnt bricks, 3" x 5" x 8",	Units	30	5	150
Water	Oil-drums	10	100	1,000
Weld mesh, 8' x 4' (feet) N <sup>o</sup> 8	Sheets	9	370	3,330
Barbed wire, g12.5, 20kg	Rolls	2	3,000	6,000
Twisted bars, Y12	Metres	14	60	840
Binding wire g.8	Kg	1	150	150
uPVC, 4" sewage pipe	Metres	3	133 $\frac{1}{3}$	400
G.I pipe, 1 $\frac{1}{2}$ "	Metres	0.9	420	378
G.I pipe, $\frac{3}{4}$ "	Metres	3	200	600
G.I tap, elbow, socket, nipple $\frac{3}{4}$ "	Tap - unit	1	700	700
Galvanized coffee mesh	Sq.m.	1	200	200
Mosquito mesh	M <sup>2</sup>	0.5	100	50
Timber, 6" x 1"	Metres	90	75	6,750
Pole	Units	8	40	320
Nail, 3"	Kg	5	80	400
<b>Cost of materials</b>				<b>45,868</b>
<b>Transport of materials</b>				
Hardware lorries	7 tonnes	1 loads	5,000	5,000
Tractor trailer loads	3 tonnes	7 loads	900	<u>6,300</u>
<b>Cost of transport</b>				<b>11,300</b>
<b>Total cost of a 12 cu.m. tank built of rubble stones</b>				<b>66,768</b>

## Chapter 7. A ferro-cement jar

### 7.1 Introduction

The term, *ferro-cement*, means “reinforced mortar” because crushed stones (ballast) and hardcore stones are not used in ferro-cement, except for foundations made of reinforced concrete.

Ferro-cement is much stronger and lighter than reinforced concrete and is therefore used for many purposes such as: water tanks, boats, balconies, vaults, beams and other thin-walled and self-supporting structures.

However, successful application of ferro-cement requires trained builders who will not cheat on reinforcement, mixing mortar and curing. Furthermore, mortar must be made from clean and coarse river sand, newly manufactured cement and clean water without trace of salt or other corroding agents.

### 7.2 Ferro-cement jars

Millions of water jars have been made of ferro-cement and are used for roof catchments in Thailand. A family starts with building one jar. Some time later they build a second jar and so on until they have a line of jars that can supply water throughout the year.

The photo shows an enlarged version of the Thai jar being built during a training course for UNDP in Myanmar.



Ferro-cement jars have been introduced in a dozen African countries but have not been widely accepted, despite the jars having been made larger to hold 3 cu.m. of water, as shown in the photo, in attempts to counter the most common complaint that the jars are too small.





### 7.3 Construction procedures

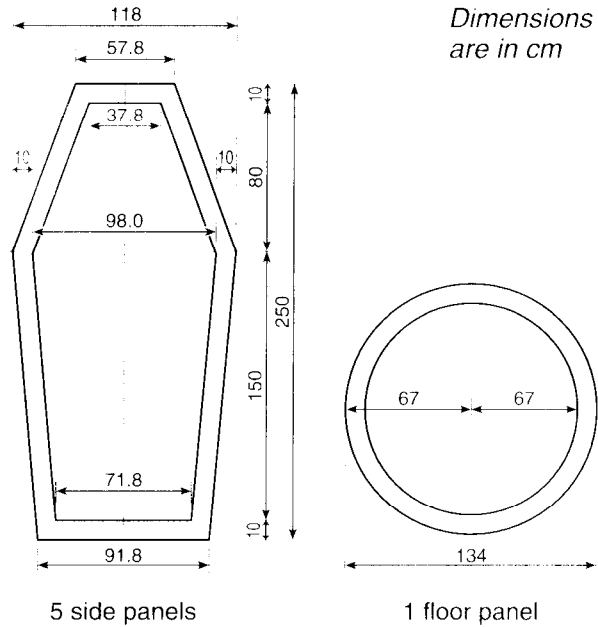
#### Mould

A mould is made of 15 m of canvas cloth 1.2 m wide that is cut into the shapes and sown together as shown in the sketch on the right.

To make a mould, start by drawing one side panel in full size on the canvas and cut it. Use this side panel to mark and cut the other 4 panels.

Then cut the floor panel and sew all 6 panels together with a strong string.

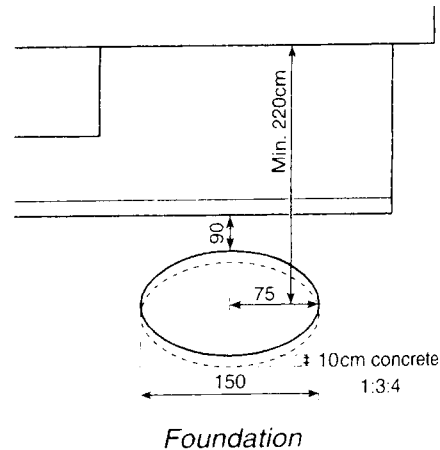
Make space for a string to be pulled and tied for the manhole at the top of the mould.



#### Foundation

The jar should be situated 90 cm from the wall of the house. The radius of the foundation should be 75 cm and the depth of the foundation should be at least 220 cm from the edge of the roof.

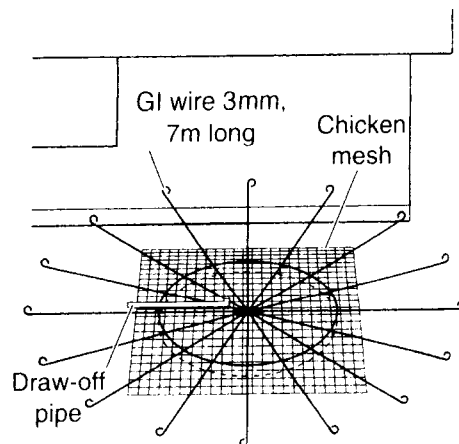
Fill the excavated foundation with 10 cm of concrete mixture of 1:3:4, compact and level it.



#### Reinforcement

Cut 8 lengths, each 7 m long, of 3 mm G.I. wire and bend the ends of the wires to avoid injuries. Tie the 8 wires together at the middle as spokes in a wheel. Make a ring of 3 mm G.I. wire with a diameter of 116 cm and tie it onto the 8 wires.

Cut two 140 cm long pieces of chicken mesh and tie them together. Place the chicken mesh and the G.I. wires on the foundation, together with a 90 cm long draw-off pipe of 18 mm G.I.



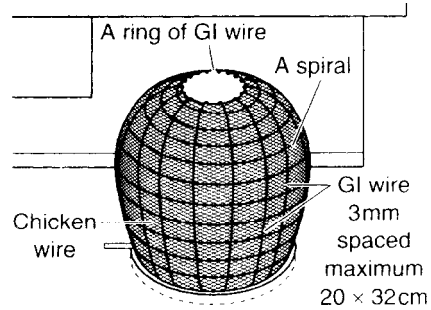
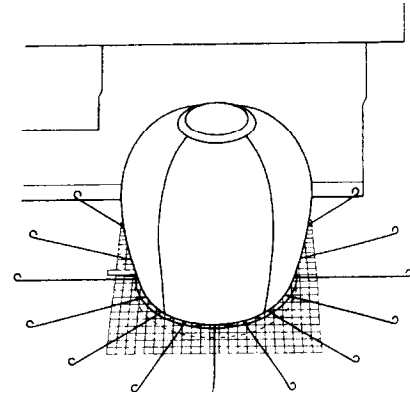
### Reinforcement of wall

Now place the empty mould on the foundation and fill the mould with saw dust, plane shavings, hay or sun-dried goat and cow manure.

The 16 wires sticking out from under the mould are now bent up against at the side of the mound and tied to a ring of G.I wire at the manhole.

The chicken mesh sticking out from under the mould is also bent up against the side of the mould and tied to the ring at the manhole.

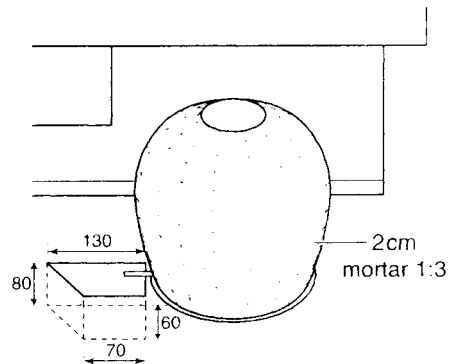
A long G.I. wire is tied onto the wire at the foundation and wrapped tightly around the mould as a spiral spaced at 20 cm apart.



*Reinforcement of wall*

### External plaster

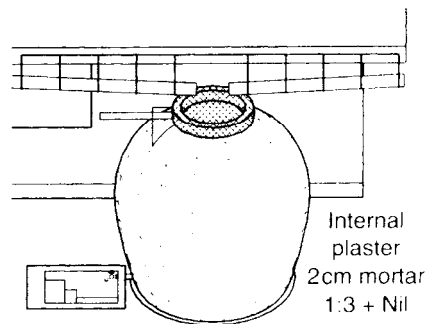
Mortar mixture of 1:3 is smeared onto the mould in a thin layer. After a couple of hours more mortar is plastered onto the mould until the plaster is 2 cm thick. The tap stand is built while the plaster is cured under shade.



*External plaster*

### Internal plaster

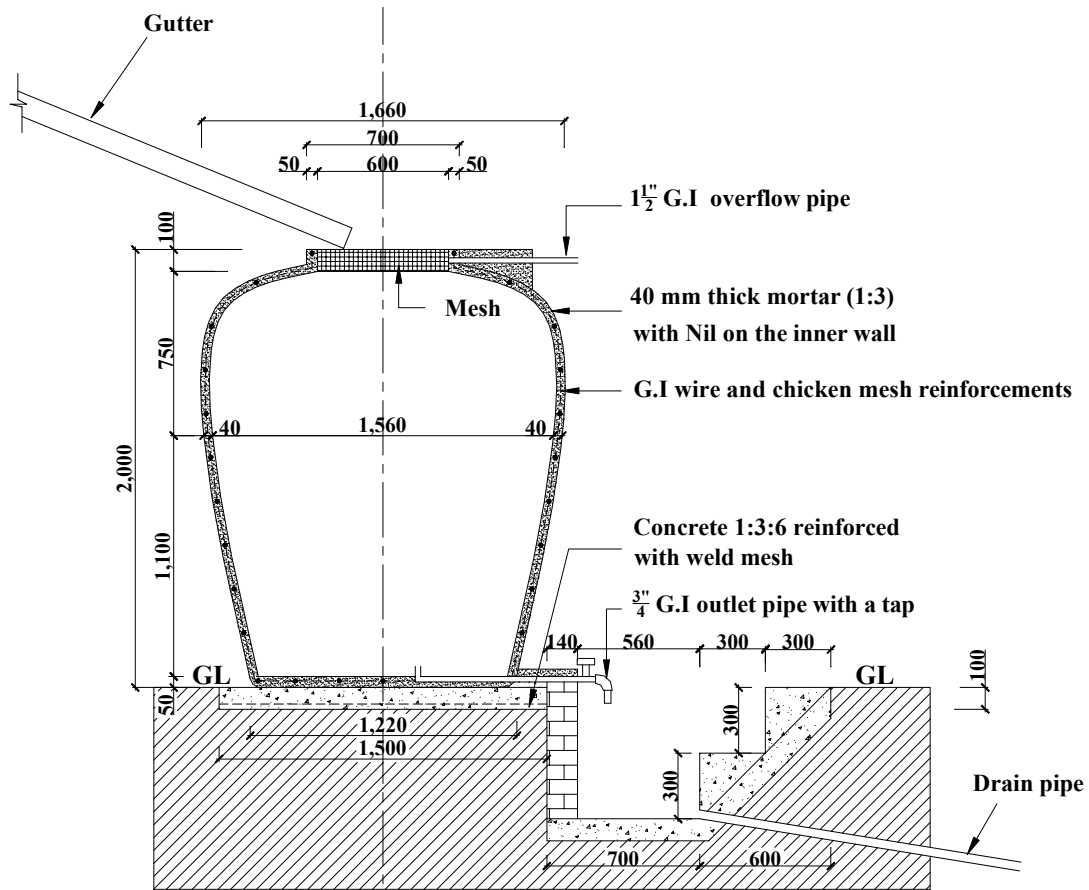
When the plaster has been cured for 3 days, the content of the mould and the mould itself are removed from inside the jar. Clean the jar and plaster mortar of 1:3 onto its sides and floor in thin layers until the plaster is 2 cm thick. On the same day, cement and water is mixed to NIL and smeared onto the inside of the jar.



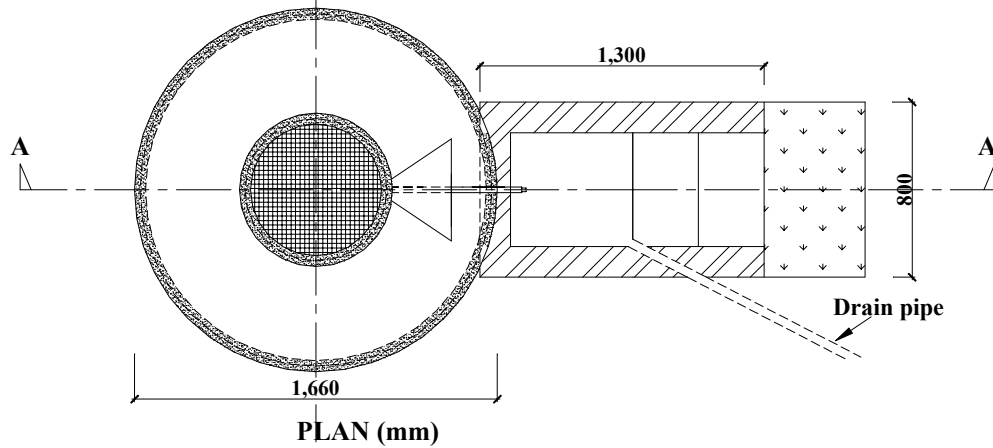
### Finish

Place two strips of iron sheets, 10 cm x 60 cm, on top of the jar as formwork for the manhole. Place a short length of pipe for an overflow and fill the formwork with mortar 1:3.

## 7.4 Standard design of a 3 cu.m. ferro-cement jar



SECTION A - A (mm)



PLAN (mm)

## 7.5 Bill of quantities and cost of a 3 cu.m. ferro-cement jar

Description	Unit	Quantity	Unit cost Ksh	Total cost Ksh
<b>Labour cost</b>				
Artisan	Artisans	1 x 5 days	400/day	2,000
Labourers	Labourers	1 x 5 days	200/day	<u>1,000</u>
<b>Cost of labour</b>				<b>3,000</b>
<b>Materials</b>				
Cement	50 kg bags	6	600	3,600
River sand	Tonnes	3	200	600
Crushed stones	Tonnes	1	600	600
Burnt bricks, 4" x 6" x 10"	Units	50	5	250
Hardcore 2" to 6"	Tonnes	1	200	200
Water	Oil-drums	3	100	300
Chicken mesh 25 mm 0.9 m	Metres	18	110	1,980
Galvanized ceiling nails	Kg	5	130	650
Lime	25 kg bags	2	400	800
uPVC, 2" sewage pipe	Lengths	1	400	400
G.I pipe, 1½"	Metres	0.5	420	210
G.I pipe, ¾"	Metres	0.9	200	180
G.I fitting, ¾" tap, elbow etc	Units	1	500	500
G.I wire, 3mm	Kg	5	150	750
Mosquito mesh	Plastic	0.5	100	50
Galvanized coffee mesh	Sq.m.	1	200	200
Canvas 1.2 m	Metres	15	200	<u>3,000</u>
<b>Cost of materials</b>				<b>14,270</b>
<b>Transport of materials</b>				
Hardware lorries	3 tonnes	1 loads	3,000	3,000
Tractor trailer loads	3 tonnes	3 loads	900	<u>2,700</u>
<b>Cost of transport</b>				<b>5,700</b>
<b>Total cost of a 3 cu.m. water jar</b>				<b>22,970</b>

## Chapter 8. Three ferro-cement tanks

### 8.1 Introduction

*Ferro-cement*, means “reinforced mortar” because crushed stones (ballast) and hardcore stones are not used in ferro-cement except for foundations.

Successful application of ferro-cement requires trained builders who will not cheat on reinforcement, mixing mortar and curing. Furthermore, mortar must be made from clean and coarse river sand, newly manufactured cement and clean water without a trace of salt.

The 3 ferro-cement tanks described below have the following storage volumes:

The tank shown in this photo is an 11 cu.m. ferro-cement water tank. This storage volume is sufficient for a family of 6 living in a small house in an area where the longest dry season lasts 2 months.



This is a 23 cu.m. ferro-cement water tank, which is adequate water storage for a family of 6 living in a house where the longest dry season lasts 4 months.

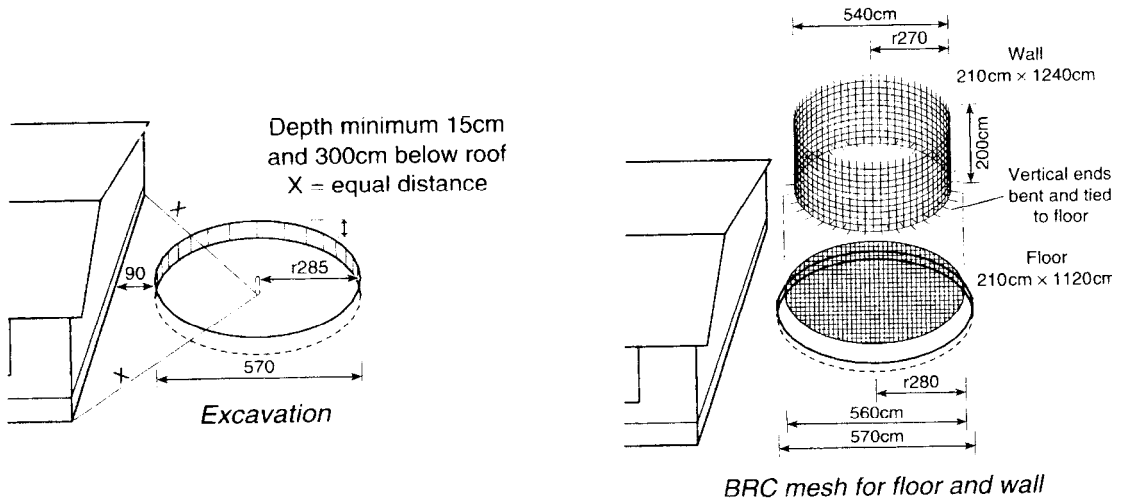


This ferro-cement tank has a storage volume of 46 cu.m., which is suitable for a family of 6 living in a house with a large roof area, and where the longest dry season lasts 6 months.



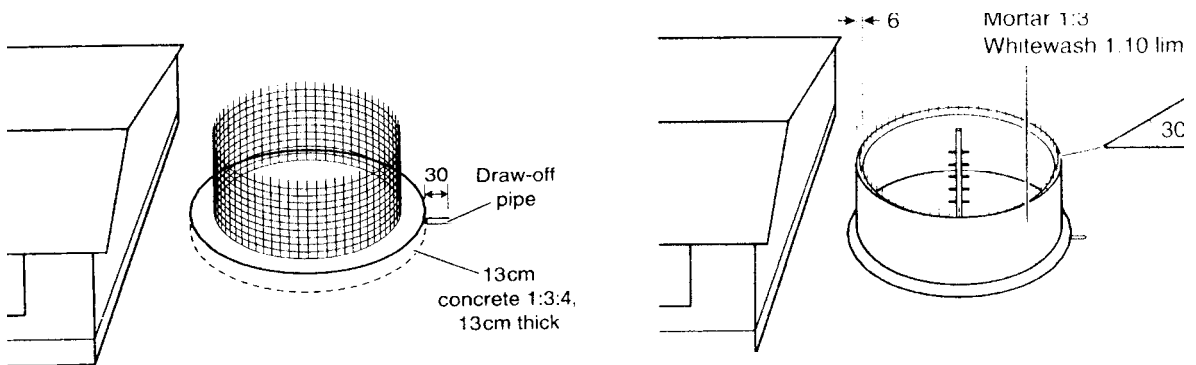
More than 2,000 of these 46 cu.m. tanks have been installed in schools in Kenya during the 1980s.

## 8.2 Graphic illustration of construction of a 46 cu.m. ferro-cement tank



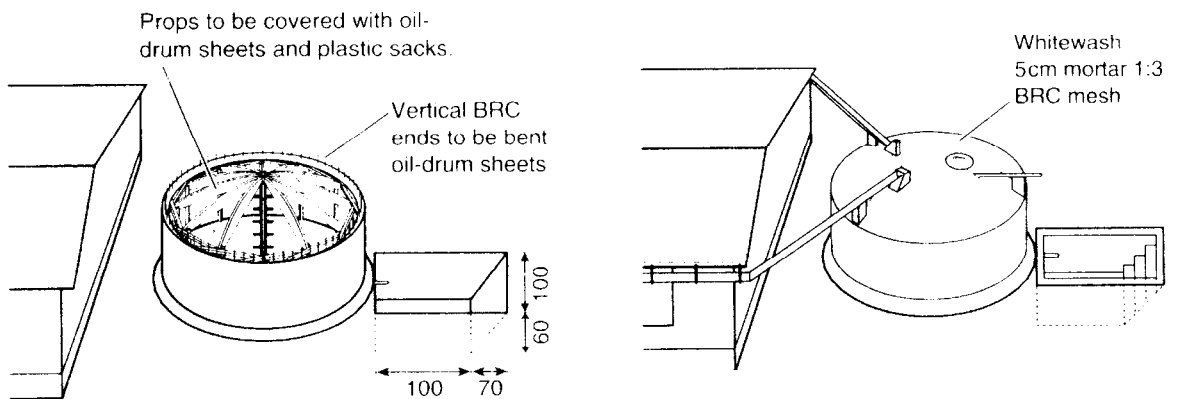
1) Excavation of foundation.

2) BRC mesh for floor and wall.



3) Concreting foundation.

4) Plastering wall.



5) Formwork for dome.

6) Completed tank.

### 8.3 Photo illustration of construction of 3 sizes of ferro-cement tanks

#### Measurements for the 3 tanks

Tank size Cu.m.	Radius of excavation for foundation	From eave of roof to foundation	Length of BRC for foundation	Length of BRC for wall	Length of BRC for dome	Bags of cement
11	156 cm	280 cm	604 cm	907 cm	312 cm	22
23	205 cm	290 cm	800 cm	1240 cm	410 cm	30
46	285 cm	300 cm	1120 cm	1740 cm	570 cm	50

A roll of BRC mesh No. 65 is rolled out on the ground and cut to the lengths shown above for reinforcement of the foundation, wall and dome for either the 11 cu.m, the 23 cu.m or the 46 cu.m. tank.



Joints of the BRC mesh for the foundation and the wall should consist of an overlap of 2 squares that are tied together with soft black binding wire.

BRC mesh for a foundation is cut and tied into a circular sheet with a radius shorter than the excavated foundations.



BRC mesh for a wall is tied together as a cylinder with the required overlap of 2 squares.

The cylinder of BRC mesh for a wall is tied to the BRC mesh for the foundation by bending the vertical irons in the wall to alternative sides and tying them with soft black binding wires as shown in the photo on the right.



7 cm of concrete mixture of 1:3:4 is laid in the excavation without hardcore stones and without watering the soil. The BRC mesh and the draw-off pipe are laid on the concrete. Another 7 cm layer of concrete

1:3:4 is compacted onto the mesh to give the concrete a thickness of 14 cm.

Chicken mesh is wrapped tightly around the BRC in the wall. A 3 mm G.I. wire is wrapped tightly around the chicken and BRC meshes in a spiral starting with 6 rounds at the bottom, which continues with a spacing of 5 cm for the lower 100 cm height of the tank and increases to 10 cm at the upper 100 cm of the wall.



Thereafter plastic sacks are cut open and hung onto the vertical ends of the BRC mesh at the top of the wall. The sacks are kept straight and taut against the mesh by a sisal twine wrapped tightly around the sacks at intervals of 4 cm starting from the top.



Mortar 1:3 can now be smeared onto the sacks from the inside of the tank. A two-legged ladder is used for access to and exit from the interior tank. The ladder shall be used for installing splash-guard and gutters.

The mortar is first smeared onto the mesh and plastic sacks in a thin layer all around the tank. A second and a third layer is applied all around until the wall has reached a thickness of 3 cm. A layer of NIL (cement mixed with water) is applied with a square steel trowel onto the plaster for water proofing on the same day. Hang sacks or polythene sheets on the inner wall for proper curing.



Next day, the sacks are removed and the external side of the wall is plastered without NIL to give the wall a final thickness of 6 cm. Hang the removed sacks on the outer wall for curing. Pour water behind the internal and external sacks three times daily.

A center column made of a PVC pipe filled with concrete and short pipes inserted for a ladder, is erected in the middle of the tank.





Templates made of timbers are tied onto the center column and on props along the inner wall.

Flattened iron sheets cut from discharged oil drums or bonnets or roofs from motor vehicles, are placed on the templates and supported by props to function as formwork for the dome.



Empty cement sacks or polythene sheets are placed on the formwork and covered with a layer of BRC mesh and chicken mesh.

The top of the wall is cut to an inward slope. The BRC mesh sticking up from the wall is bent over the dome and tied to the BRC mesh in the dome with binding wire.



A plastic basin, being a mould for the manhole, is placed near the center column on the formwork. Two empty tins being moulds for the inlets are also placed on the formwork.



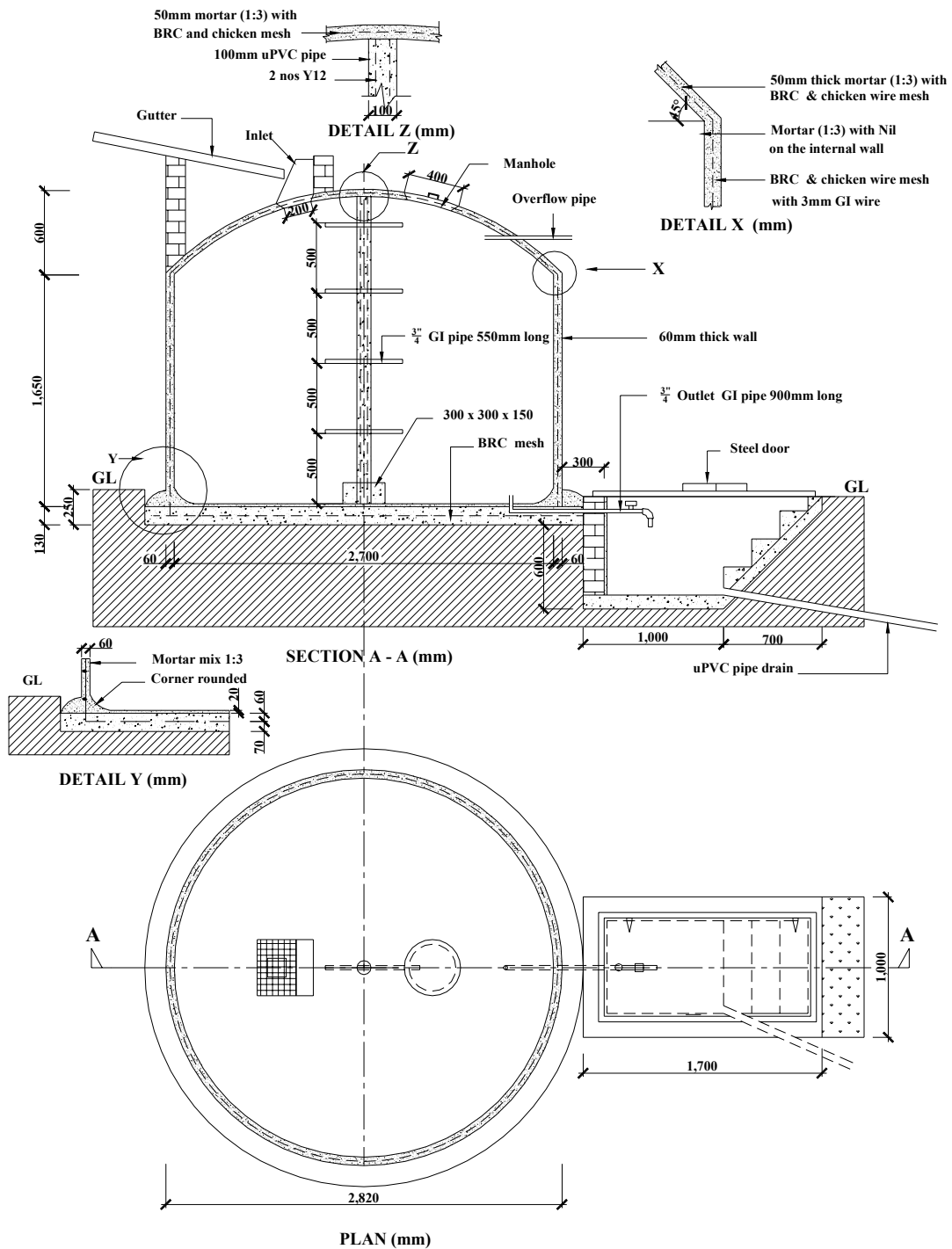
Mortar of mixture 1:3 is compacted onto the formwork in a 5 cm thick layer and smoothed. Polythene sheets are then laid on the dome and covered with soil for 3 weeks. This will facilitate proper curing without walking on the dome, because water from the mortar will condense on the underside of the polythene, thereby curing the dome without adding water.

While the dome is being cured for 3 weeks, the splash-guard, gutter and tap stand are installed.

After curing, the formwork of the dome is removed and the external wall of the tank is painted with a weatherproof mixture of 1 part cement to 10 parts lime.

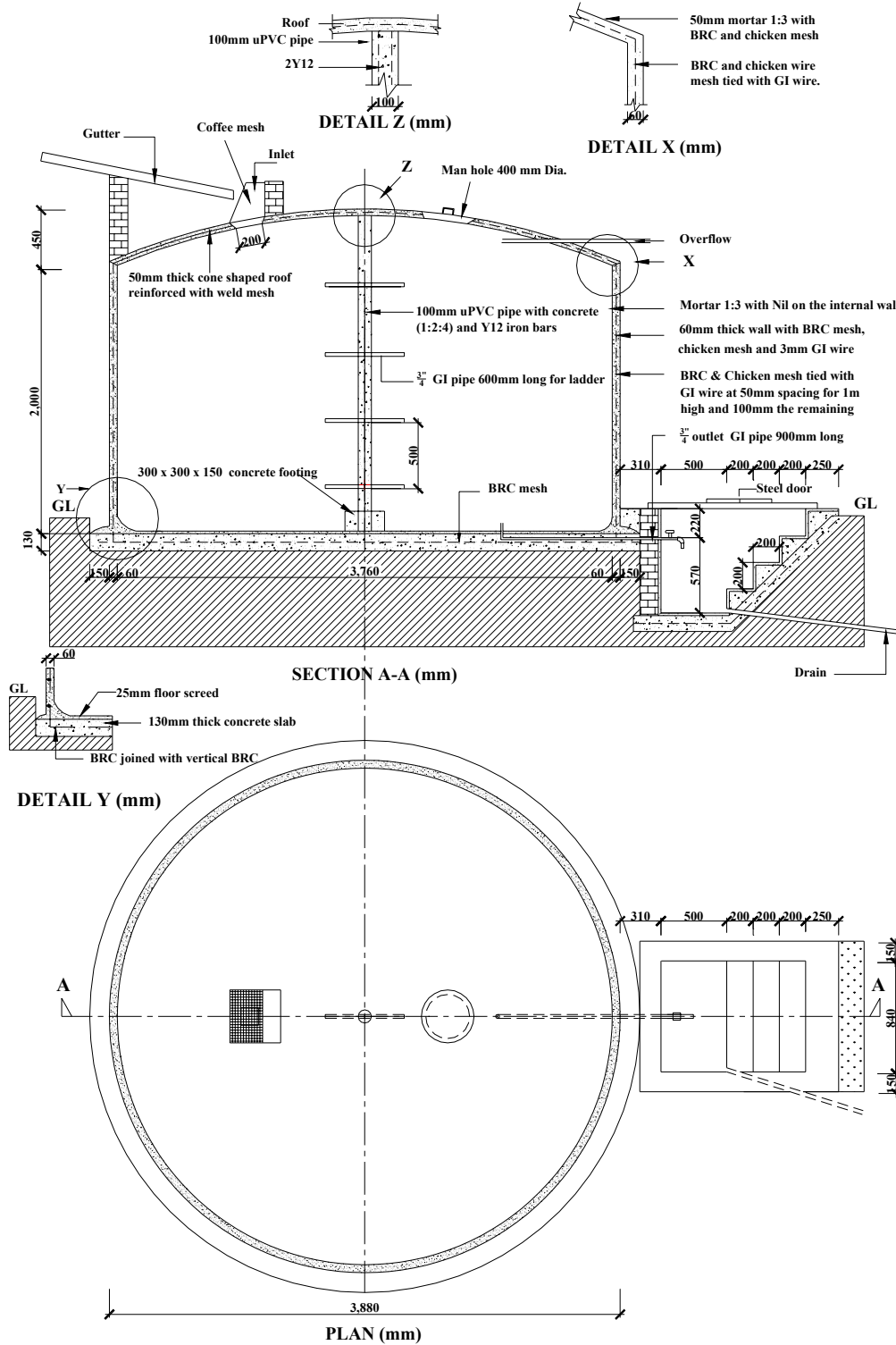


## 8.4 Standard design of an 11 cu.m. ferro-cement tank



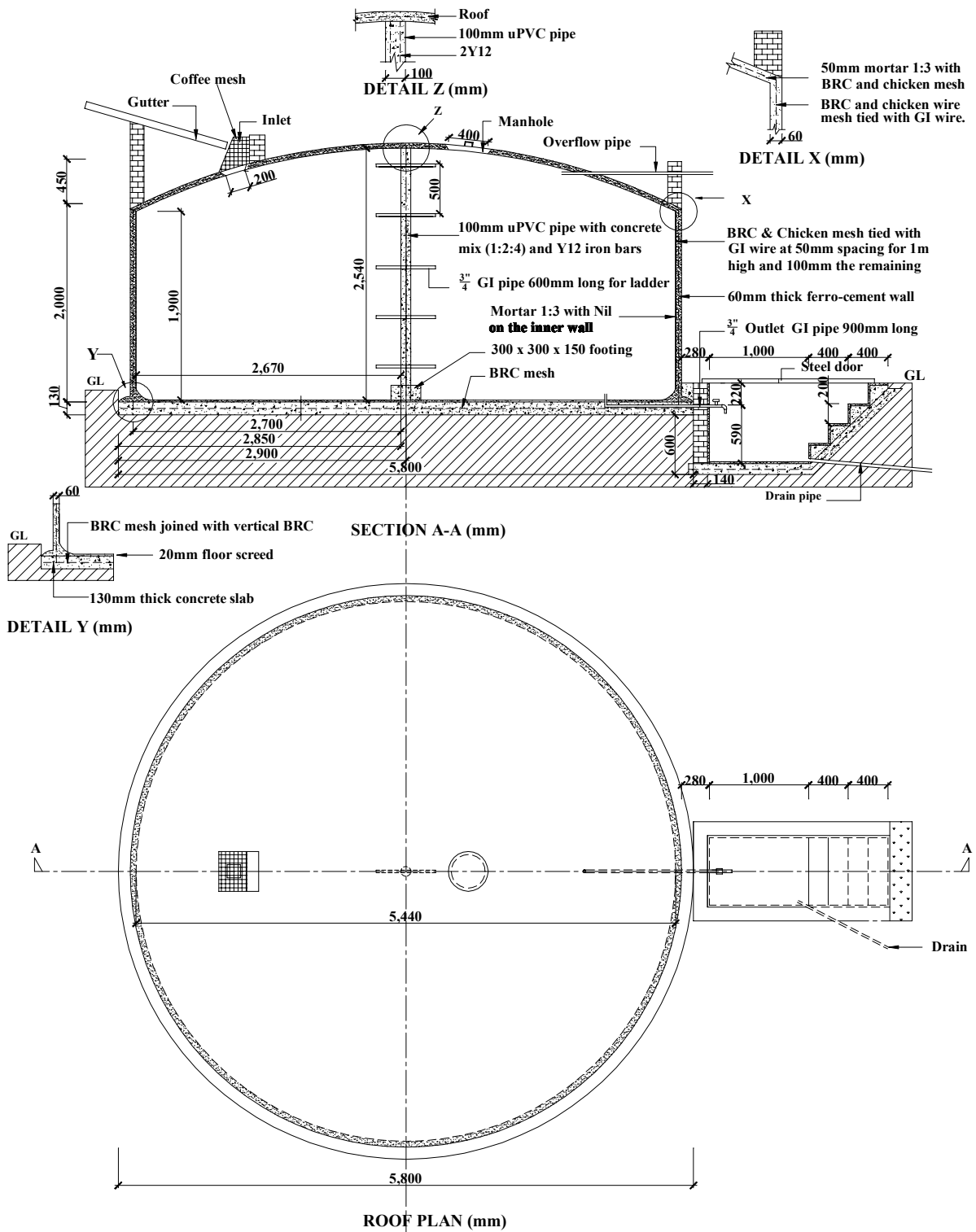
Bill of Quantities and cost of construction are listed on page 63.

## 8.5 Standard design of a 23 cu.m. ferro-cement tank



Bill of Quantities and cost of construction are listed on page 64.

## 8.6 Standard design of a 46 cu.m. ferro-cement tank



Bill of Quantities and cost of construction are listed on page 65.

### 8.8.1 Bill of quantities and cost of an 11 cu.m. ferro-cement tank

Description	Unit	Quantity	Unit cost Ksh	Total cost Ksh
<b>Labour cost</b>				
Artisan	Artisans	1 x 10 days	400/day	4,000
Labourers	Labourers	2 x 10days	200/day	<u>4,000</u>
<b>Cost of labour</b>				<b>8,000</b>
<b>Materials</b>				
Cement	50 kg bags	22	600	13,200
Lime	25 kg bag	1	400	400
River sand	Tonnes	5	200	1,000
Crushed stones	Tonnes	2	600	1,200
Hardcore	Tonnes	1	200	200
Burnt bricks 3" x 5" x 8"	Units	50	5	250
Water	Oil-drums	15	100	1,500
BRC mesh N <sup>o</sup> 65	Metres	23	260	5,980
Chicken mesh 25mm, 0.9	Metres	38	110	4,180
Twisted bars, Y12	Metres	3	60	180
uPVC, 2" sewage pipe	Metres	3	100	300
uPVC, 4" sewage pipe	Metres	3	133 $\frac{1}{3}$	400
G.I pipe, 1 $\frac{1}{2}$ "	Metres	0.9	420	378
G.I pipe, $\frac{3}{4}$ "	Metres	0.9	200	180
G.I tap, $\frac{3}{4}$ "	Units	1	500	500
G.I elbow, $\frac{3}{4}$ "	Units	1	45	45
G.I socket, $\frac{3}{4}$ "	Units	1	80	80
G.I nipple, $\frac{3}{4}$ "	Units	1	90	90
Galvanized coffee mesh	Sq.m.	1	200	200
Mosquito mesh	Sq.m.	0.5	100	50
Timber, 6" x 1"	Metres	12	75	900
Timber, 2" x 3"	Metres	16	75	1,200
Pole	Lengths	8	40	320
Sisal twine	Kg	2	70	140
Plastic bag	Number	20	30	600
Bolts 6 x 100mm	Number	8	40	320
Oil-drums, discharged	Number	7	Free	Free
Plastic basin	Number	1	100	<u>100</u>
<b>Cost of materials</b>				<b>33,893</b>
<b>Transport of materials</b>				
Hardware lorries	7 tonnes	1 loads	5,000	5,000
Tractor trailer loads	3 tonnes	7 loads	900	<u>6,300</u>
<b>Cost of transport</b>				<b>11,300</b>
<b>Total cost of an 11 cu.m. tank</b>				<b>53,193</b>

## 8.8.2 Bill of quantities and cost of a 23 cu.m. ferro-cement tank

Description	Unit	Quantity	Unit cost Ksh	Total cost Ksh
<b>Labour cost</b>				
Artisan	Artisans	2 x 10 days	400/day	8,000
Labourers	Labourers	3 x 10days	200/day	<u>6,000</u>
<b>Cost of labour</b>				<b>14,000</b>
<b>Materials</b>				
Cement	50 kg bags	30	600	18,000
Lime	25 kg bag	1	400	400
River sand	Tonnes	7	200	1,400
Crushed stones	Tonnes	3	600	1,800
Hardcore, 4" x 6"	Tonnes	1	200	200
Burnt bricks, 4" x 6" x 10"	Units	50	5	250
Water	Oil-drums	25	100	2,500
BRC mesh, N° 65	Sheets	33	260	8,580
Chicken mesh 25 mm, 0.9 m	Metres	50	110	5,500
Twisted bars, Y12	Metres	0.9	200	180
G.I wire, 3mm	Kg	20	150	3,000
G.I pipe, 1½"	Metres	1.3	420	546
G.I pipe, ¾"	Metres	0.9	200	180
G.I tap, elbow, socket, nipple ¾"	Tap-unit	1	700	700
uPVC, 4" sewage pipe	Metres	3	133	400
uPVC, 2" sewage pipe	Metres	3	100	300
Galvanized coffee mesh	Sq.m.	1	200	200
Mosquito mesh	Sq.m.	0.5	100	50
Timber, 6" x 1"	Metres	16	75	1,200
Timber 2" x 3"	Metres	30	75	2,250
Poles	Units	12	40	480
Nails	Kg	2	80	160
Bolt 6 x 120 mm	Units	8	50	400
Oil-drums, discharged	Units	10	Free	Free
Plastic bag	Units	30	30	900
Plastic basin	Units	1	100	100
Sisal twine	Kg	3	70	<u>210</u>
<b>Cost of materials</b>				<b>49,886</b>
<b>Transport of materials</b>				
Hardware lorries	7 tonnes	1 loads	5,000	5,000
Tractor trailer loads	3 tonnes	10 loads	900	<u>9,000</u>
<b>Cost of transport</b>				<b>14,000</b>
<b>Total cost of a 23 cu.m. tank built of ferro-cement</b>				<b>77,886</b>

### 8.8.3 Bill of quantities and cost of 46 cu.m. ferro-cement tank

Description	Unit	Quantity	Unit cost Ksh	Total cost Ksh
<b>Labour cost</b>				
Artisan	Artisans	2 x 14days	400/day	11,200
Labourers	Labourers	3 x 14days	200/day	<u>8,400</u>
<b>Cost of labour</b>				<b>19,600</b>
<b>Materials</b>				
Cement	50 kg bags	50	600	30,000
Lime	25 kg bags	2	400	800
River sand	Tonnes	10	200	2,000
Crushed stones	Tonnes	4	600	2,400
Hardcore, 4" x 6"	Tonnes	1	200	200
Burnt bricks, 4" x 6" x 10"	Units	50	5	250
Water	Oil-drums	35	100	3,500
BRC mesh, N° 65	Metres	33	260	8,580
Chicken mesh, 25 mm, 0.9 m	Metres	80	110	8,800
Twisted bars, Y12	Metres	3	60	180
G.I wire, 3 mm	Kg	25	150	3,750
G.I pipe, 1½"	Metres	1.8	420	756
G.I pipe, ¾"	Metres	3.4	200	680
G.I tap, elbow, socket, nipple ¾"	Tap - unit	1	700	700
uPVC, 4" sewage pipe	Metres	3	133⅓	400
uPVC, 2" sewage pipe	Metres	3	100	300
Galvanized coffee mesh	Sq.m.	1	200	200
Mosquito mesh	Sq.m.	0.5	100	50
Timber, 6" x 1"	Metres	36	75	2,700
Timber 2" x 3"	Metres	46	75	3,450
Poles	Units	12	40	480
Bolt 6 x 120 mm	Units	12	50	600
Oil-drums, discharged	Units	29	Free	Free
Plastic bag	Units	50	30	1,500
Plastic basin	Units	1	100	100
Sisal twine	Kg	5	70	350
Nails	Kg	3	80	<u>240</u>
<b>Cost of materials</b>				<b>72,966</b>
<b>Transport of materials</b>				
Hardware lorries	7 tonnes	1 loads	5,000	5,000
Tractor trailer loads	3 tonnes	12 loads	900	<u>10,800</u>
<b>Cost of transport</b>				<b>15,800</b>
<b>Total cost of a 46 cu.m. tank built of ferro-cement</b>				<b>108,366</b>

## Chapter 9. A ground tank made of ferro-cement

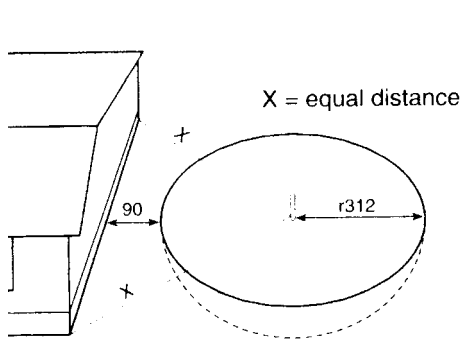
### 9.1 Introduction

Hundreds of these hemispherical ground tanks with a storage capacity of 90 cu.m. have been constructed successfully in several African countries over the last 20 years. The tank was developed as a replica of a soft boiled egg cut in half during a breakfast at Kibwezi in 1986. Only two technical constraints have been experienced with the tanks:

- 1) The tanks tend to crack if built larger than the recommended 90 cu.m. unless additional reinforcement is added to the wall.
- 2) The tanks also tend to crack if built in Black Cotton Soil due to expansion of the soil during rains and contraction during drought periods.

Another three versions of hemispherical ground tanks built of ferro-cement, burnt bricks and anthill soil are described in another handbook of this series *Water from Roads*.

### 9.2 Graphic illustration on construction of a ground tank



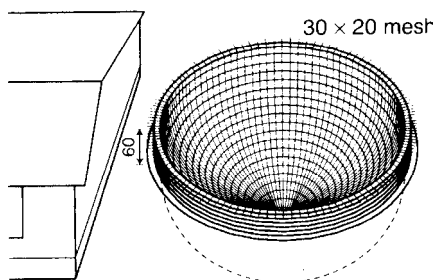
1) Marking the tank on the ground.

#### Internal reinforcement

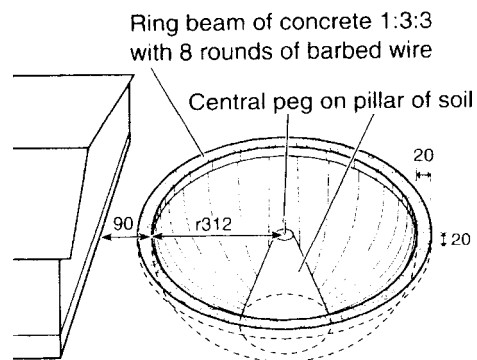
Mesh of barbed wire g. 12.5. and chicker mesh nailed on to 3cm of mortar 1:3 and covered with 3cm of mortar 1:3 + Nil

#### External reinforcement

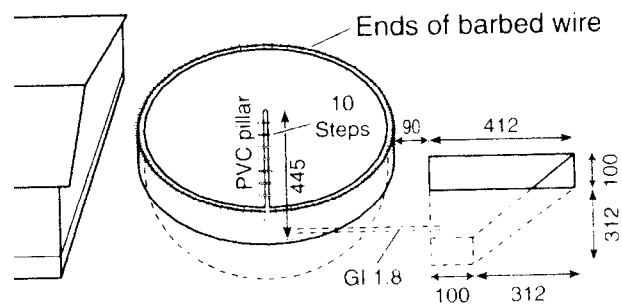
8 rounds of barbed wire g. 12.5



3) Reinforcement of tank.

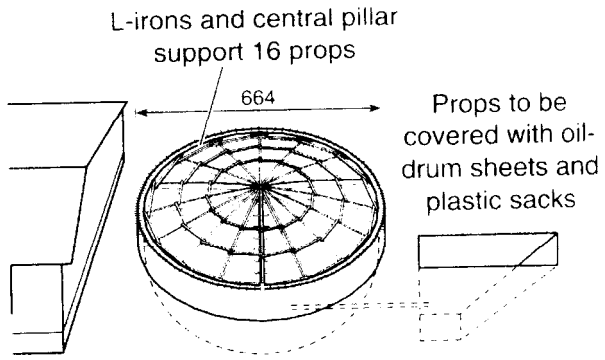


2) Excavating the tank and ring beam.

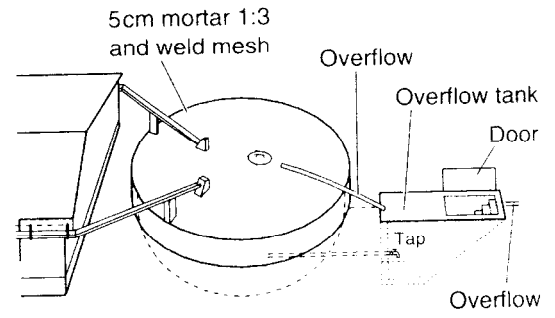


4) Upper wall, center column and stairs.

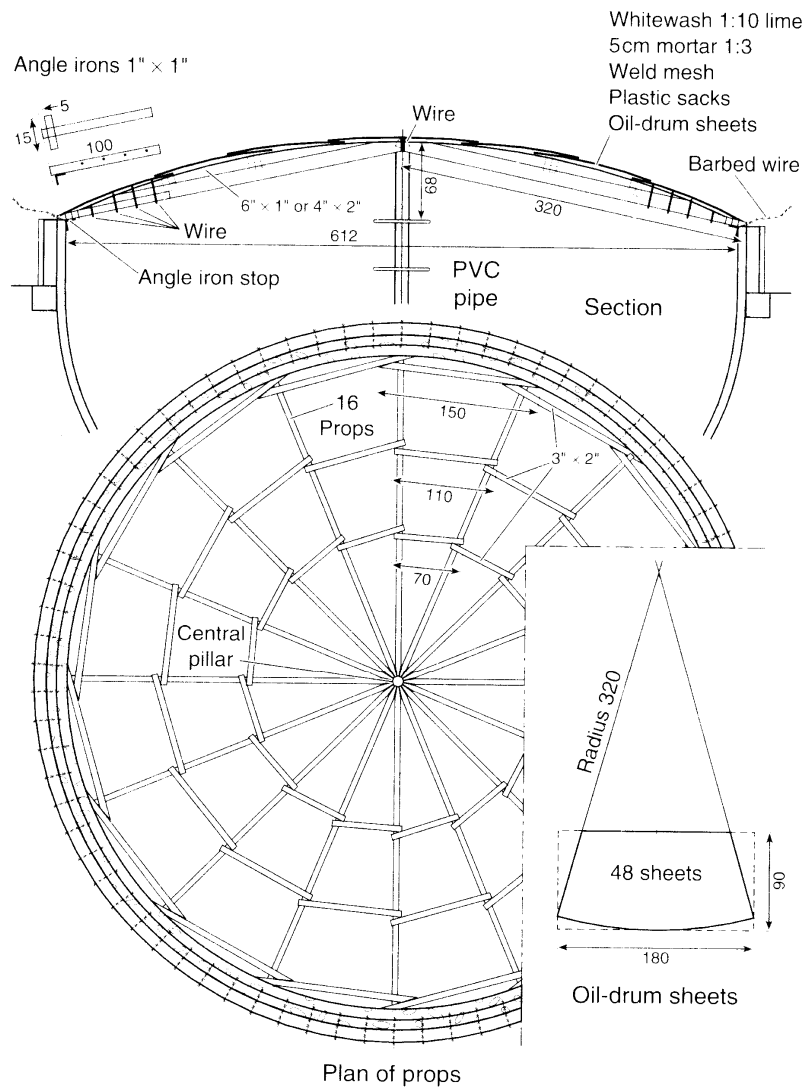




5) Formwork for dome.



6) Completed tank.



Dimensions are in cm

Design of formwork for a dome

## Photo illustration of a ground tank made of ferro-cement

### Excavation

The photo shows a completed ground tank. The water tap is situated in a lockable staircase to facilitate water to be drawn by gravity.

Two gutters are connected to the top of the tank where also the manhole is situated. The inlets for the gutters also function as overflow so that the tank can be filled completely with water without any dead storage.

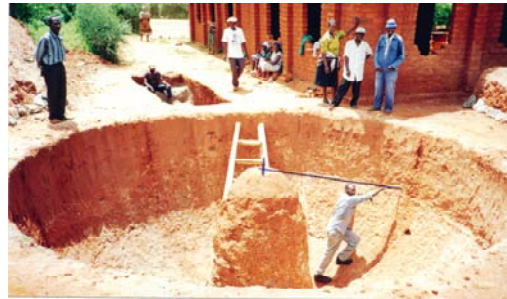
The circular outline for a tank having a radius of 312 cm is marked on the ground 90 cm from the building.

The staircase is also marked on the ground as a rectangular shape of 412 cm x 100 cm that is situated 90 cm from the tank.

The excavation for the tank is made in a hemispherical shape using a radius wire of 312 cm tied to a peg in the center of the tank with the other end showing the side of the wall. The peg and its soil pillar are the last to be removed.

A 20 cm x 20 cm seat for a ring beam is excavated at the rim of the hemispherical excavation, while the staircase is being excavated.

The ring beam is made of concrete 1:3:3 reinforced with 8 rounds of barbed wire gauge 12.5. The ring beam must be made level and kept moist under shade.



### Ring beam and tank

A 60 cm high wall of bricks or blocks is built onto the ring beam.

8 rounds of barbed wire, gauge 12.5, are wrapped tightly around the wall and spaced 10 cm apart. The wire is covered with 2 cm mortar of mixture 1:3.

In the staircase 10 cm of concrete 1:3:3 with weld mesh is compacted onto the floor and ramp. A wall of bricks or blocks is built onto the concrete.



The hemispherical soil excavation and the interior of the ring beam are plastered with a 3 cm thick layer of mortar 1:3.



Chicken mesh can now be nailed onto the plastered interior of the tank. Thereafter barbed wire gauge 12.5 is nailed onto the chicken mesh in a spiral starting from the center of the bottom with a spacing of 20 cm.

Lines of barbed wire are nailed across the tank from rim to rim with a spacing of 30 cm. The lines of wire must protrude 30 cm above the rim for reinforcement of the dome. The barbed wire and chicken mesh are covered with 3 cm of mortar 1:3 which is smoothed and coated with NIL. The wall must be kept moist and under shade until the dome is built.



## Dome

The outlines of the tank and ring beam are drawn on the ground. The outline of the dome is drawn with a radius of 700 cm as shown in the photo.



The timbers for the 16 templates consist of 6" x 1" nailed onto 4" x 2". One of these timbers is laid on the drawn outline and marked with a pencil. All the other 15 templates are marked and cut after the first one.



A centre column of a 4" PVC pipe filled with two iron rods and concrete 1:3 and short lengths of pipes for a ladder is erected in the middle of the tank. The templates rest on this centre column with their upper ends. Angle irons tied to the lower ends of the templates rest on the circular wall.



Discharged oil drums or car bonnets are cut into flat iron sheets which are laid onto the templates and their members as shown in the photo.

Polythene sheets or old cement sacks are placed on the formwork and covered with chicken mesh.



BRC mesh is cut into sheets and tied together over the chicken mesh.

The barbed wire sticking out of the circular wall is bent over the BRC mesh and tied.

Moulds for the manhole and inlets are placed on the dome. A 5 cm thick layer of mortar 1:3 is compacted onto the dome and smoothed to finish. The dome must be kept moist under shade and without anybody walking on it for 3 weeks.



### **Extraction of water**

The recommended method of extracting water from ground tanks is by gravity in order to achieve minimum maintenance.

In flat landscapes water can be extracted by gravity through a staircase as shown in this photo from Northern Namibia.



In hilly landscapes water can be gravitated through a pipe to a water tap situated at a lower point than the bottom of the tank as at this private homestead in Kitui, Kenya.



Water can also be lifted up from a ground tank with a small hand pump concreted into the top of the dome as seen in this photo from a church near Lake Victoria in Kenya.

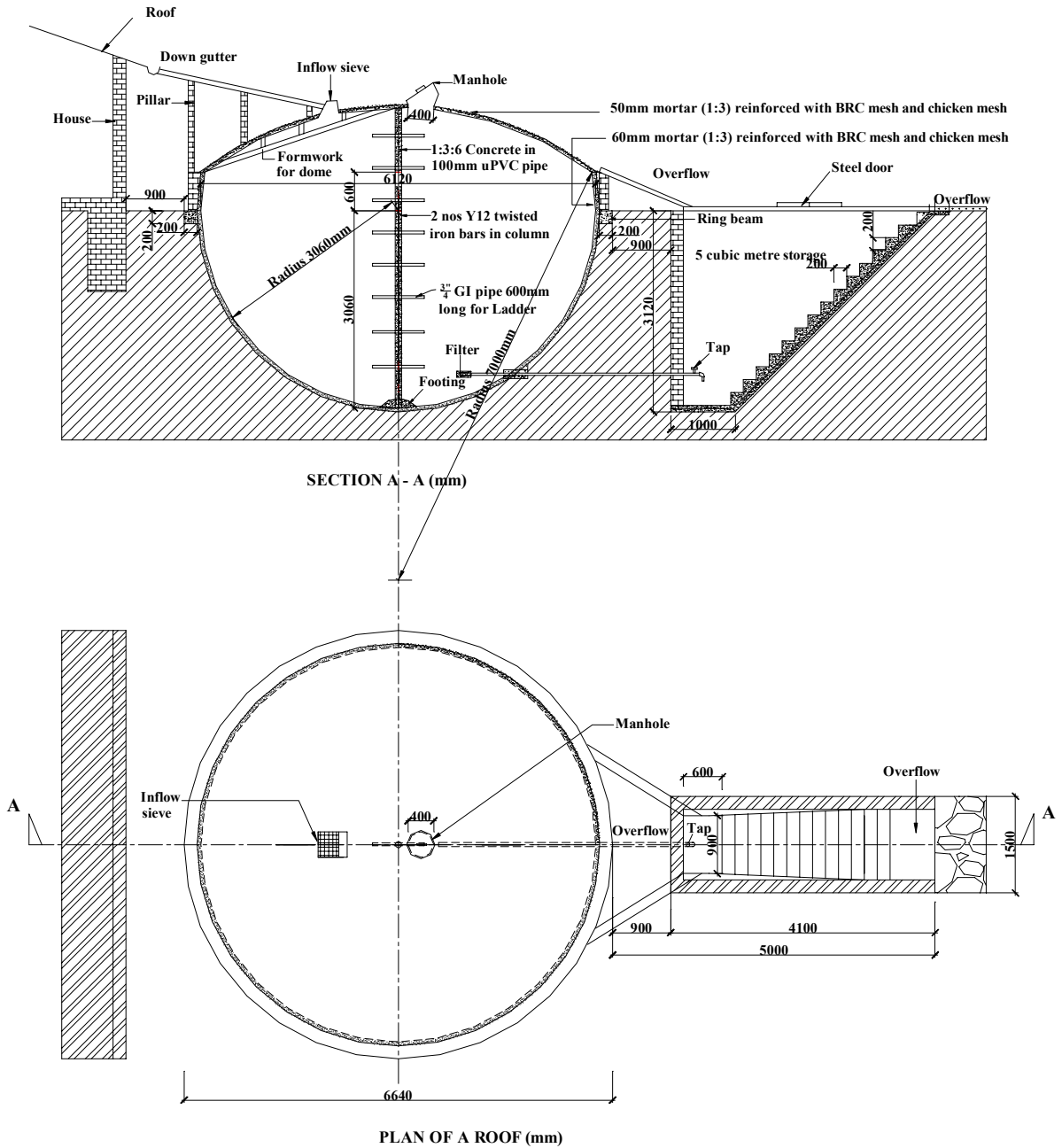


A Mark II hand pump with a delivery pipe at the edge of the tank is installed on top of this ground tank at Maseno Hospital in Kenya.

An overflow pipe, seen in the lower right corner of the photo, was also installed at this and at two other tanks at the hospital.



### 9.3 Standard design of a 90 cu.m. ground tank



Bill of Quantities and cost of building the tank are listed on the following page.

## 9.4 Bill of Quantities and cost of a 90 cu.m. ground tank

Description	Unit	Quantity	Unit cost Ksh	Total cost Ksh
<b>Labour cost</b>				
Artisan	Artisans	3 x 14 days	400/day	16,800
Labourers	Labourers	4 x 20days	200/day	<u>16,000</u>
<b>Cost of labour</b>				<b>32,800</b>
<b>Materials</b>				
Cement	50 kg bags	73	600	43,800
Lime	25 kg bags	2	400	800
River sand	Tonnes	17	200	3,400
Crushed stones	Tonnes	1	600	600
Burnt bricks, 4" x 6" x 10"	Units	1000	5	5,000
Water	Oil-drums	45	100	4,500
Weld mesh, 2.4 x 1.2 g.8	Sheets	25	370	9,250
Chicken mesh 25mm, 0.9m	Metres	100	110	11,000
Twisted bars, Y12	Metres	5	60	300
Barbed wire g12.5	Kg	100	150	15,000
G.I pipe, 1½"	Metres	4	420	1,680
G.I elbow, 1½"	Unit	1	80	80
G.I pipe, ¾"	Metres	9	200	1,800
G.I tap, elbow, socket, nipple, ¾"	Tap unit	1	700	700
uPVC, 4" sewage pipe	Metres	5	133⅓	670
Galvanized coffee mesh	Sq.m.	1	200	200
Mosquito mesh	Sq.m.	0.5	100	50
Timber, 6" x 1"	Metres	60	75	4,500
Timber, 2" x 3"	Metres	60	75	4,500
Poles	Units	12	40	480
Bolt 6 x 120mm	Units	12	50	600
Oil-drums, discharged	Units	48	Free	Free
Plastic bag	Units	50	30	1,500
Angle iron 25 x25mm	Units	16	120	1,920
Plastic basin	Units	1	100	100
Sisal twine	Kg	3	70	210
Nails 3"	Kg	3	80	<u>240</u>
<b>Cost of materials</b>				<b>112,880</b>
<b>Transport of materials</b>				
Hardware lorries	7 tonnes	1 loads	5,000	5,000
Tractor trailer loads	3 tonnes	14 loads	900	<u>12,600</u>
<b>Cost of transport</b>				<b>17,600</b>
<b>Total cost a 90 cu.m. ground tank built of ferro-cement</b>				<b>163,280</b>

## Chapter 10. Repair of water containers and tanks

### 10.1 Plastic jerrycans

Plastic jerrycans play a very important role in rural water supply because nearly all domestic water is transported from the water sources to the homesteads in jerrycans.

Many women must carry one full jerry can of 20 litres of water, which is equal to 20 kg, on their back every second day. In addition the women must also walk up to 10 km with the empty jerry can from the homestead to the water source which is usually in a riverbed.

They must also wait at the riverbed until it is their turn to fill their jerrycans with the water that seeps slowly into the waterholes they have scooped out of the sand.

They must walk 10 km up hill with the 20 kg jerry can because riverbeds are always in valleys. At home they must ration the 20 litres of water to be sufficient for 2 days consumption because no woman has the stamina to fetch

water from 10 km away every day, while also taking care of her children, livestock and homestead.

Where water has to be fetched from sources further away than 10 km a donkey has to be purchased. A donkey can carry 4 jerrycans of water for distances up to 30 km during a return trip taking 2 days.

In those dry areas the cost of a donkey is equal to the dowry for a wife. When the rain comes, the cost of a donkey decreases because water can be fetched nearby, while the cost

of dowry increases because now manual labour is needed in the fields.

Nowadays, some people prefer bicycles to donkeys for fetching water because bicycles are cheaper and more versatile than donkeys, although a bicycle can only carry a maximum of 3 jerrycans which is 60 kg of water.

Jerrycans are expensive for rural communities, therefore jerrycans have to be repaired when they leak or get worn out. Repairs are done on the spot by sealing the leaking places with melted plastic material.



A little girl carrying



A girl loading 80kg of



A woman transporting



Repair of a leaking



## 10.2 Oil drums



An oil drum used for roof catchment at a rural home.



Repaired oil drums.

Most rural homesteads can afford an oil drum to harvest rainwater from the roof. Unfortunately, the lower part of oil drums corrodes. The oil drums are then discarded as scrap metal. Most people don't know that rusty and leaking oil drums can easily be repaired for the cost of half a bag of cement.

The technique is simple. Mix a 1/8 of a bag of cement with coarse river sand in a ratio of 1 part of cement to 3 parts of river sand. Smear the mixture onto the inside of the oil drum in a 1 cm thick layer and let it dry for a day.

Next day apply a second coat of mortar 1:3 being 2 cm thick onto the interior of the drum and smoothen it. Within the same day, mix cement with water until it becomes a slurry called NIL and press it onto the interior plaster with a square steel trowel.

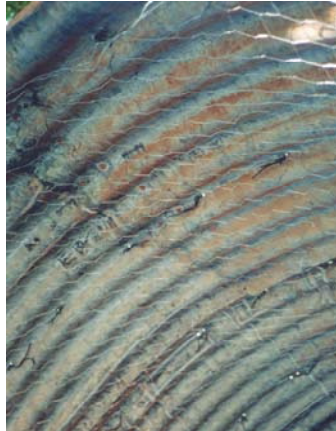
Keep the oil drum under shade and sprinkle the plaster with water 3 times daily for a week, then fill it up with water.

In fact, people who learn of this technique coat the interior of their new oil drums in the way described above because they say water drawn from drums coated with cement mortar has a nice sweet taste. In any case, the coat of cement mortar prevents any poisonous substance, which might have been in the drum, from contaminating the water.

### 10.3 Corrugated galvanized iron sheet tanks



A leaking water tank.



Chicken mesh tied to the interior of a tank.



A repaired tank.

Water tanks made of galvanized iron sheets were popular some three decades ago. Unfortunately, the bottom part of the tanks corroded and leaked after 5 to 10 years. They were then considered useless and discharged as scrap metal.

As with jerrycans and oil drums, such corroded and leaking water tanks can be repaired easily, and much cheaper than buying a new tank. The technique is as follows:

- 1) Small holes are punched in the wall for every 15 cm or so using a nail and a hammer.
- 2) Binding wire is cut in lengths of about 20 cm and bent in U's. One person puts the two ends of a U bent wire into two punched holes situated near each other.
- 3) A second person presses chicken mesh against the wall and uses the two ends of the U wire to tie to chicken mesh tightly against the wall. Thereafter chicken mesh is laid on the floor of tank.
- 4) Cement can now be mixed with clean river sand in a ratio of 1 part cement to 3 parts sand and some water. This mortar is then thrown onto the chicken mesh in a layer of about 1 cm thick.
- 5) The next day another coat of mortar is added until all binding wires and chicken mesh are covered with mortar. Within the same day, cement slurry (NIL) is pressed onto the moist plaster with a square steel trowel for water proofing. The outside of the tank can be painted with a weatherproof paint made of 1 part cement to 10 parts of lime mixed with water.

## 10.4 Leakage between wall and foundation

### Problem

Many tanks built of masonry leak water through the joint where the wall joins the foundation.

### Reason

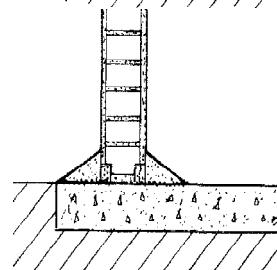
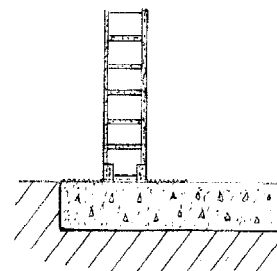
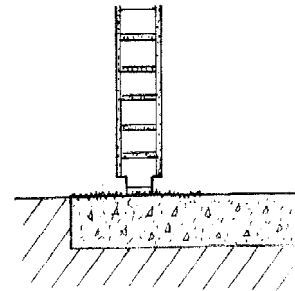
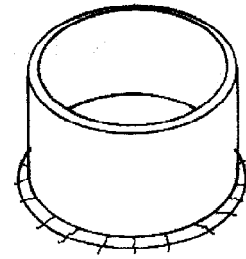
The reasons being either insufficient reinforcement, poor mixture of mortar or lack of cleanliness when the joint was made.

### Remedy

The joint can be made watertight by cleaning the joint, adding more reinforcement and making an apron on both sides of the joint.

### Procedure

- 1) Drain all water out of the tank and clean the floor and the foundation on the outer side of the tank.
- 2) Chisel a groove, about 3 cm x 3 cm, all around the joint on both the interior and external sides of the tank.
- 3) Roughen a 15 cm wide stretch of the foundation on both sides of the joint. Clean the joint and the roughened surface with plenty of water.
- 4) Wrap 5 rounds of barbed wire tightly around the tank in the external groove.
- 5) Compact mortar 1:3 into the external and internal grooves with a piece of timber.
- 6) Compact a 15 cm wide and 10 cm high apron over the external and internal grooves.



An internal apron can be made with a short length of bamboo



An external apron is made with a or an empty beer bottle.

## 10.5 Leakage through a cracked foundation

### Problem

Water leaks through cracks in the foundation.

### Reason

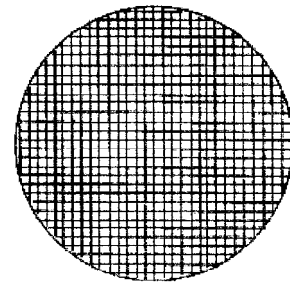
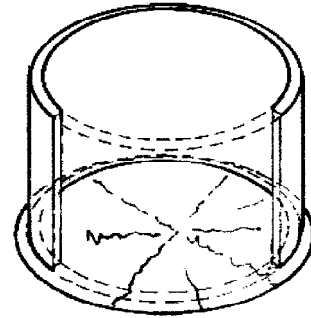
Soft soil under the foundation, insufficient reinforcement, poor mixture of concrete or improper curing.

### Remedy

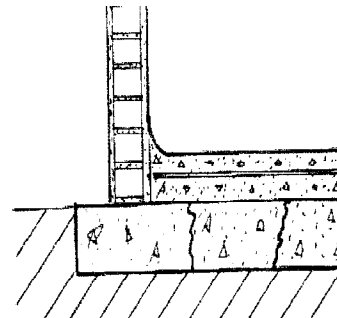
The leakage can be sealed by constructing a new foundation onto the old cracked foundation.

### Procedure

- 1) Drain all water out of the tank and clean the floor.
- 2) Fill all cracks with bitumen paste.
- 3) Cut sheets of weld mesh to fit the foundation. All overlaps must be at least 20 cm and tied together with binding wire for every 10 cm.
- 4) Mix concrete with 1 part cement to 3 parts river sand and 3 parts of crushed stones (1:3:3). Compact a 7 cm thick layer of concrete onto the old foundation.
- 5) Lay the weld mesh on the concrete in the tank.
- 6) Compact a second layer of 7 cm concrete onto the weld mesh in the tank.
- 7) Compact a 1 cm thick layer of mortar 1:3 onto the concrete. Smoothen the plaster and press a coat of NIL onto the plaster the same day.
- 8) The next day, compact a rounded apron into the joint between the new foundation and the wall.
- 9) Keep the foundation moist and under shade for 3 weeks. New foundation built upon



Weld mesh cut to fit



an old cracked foundation.

## 10.6 Leakage through walls without cracks

### Problem

Water leaks through the wall of a water tank, although the wall has no cracks.

### Reason

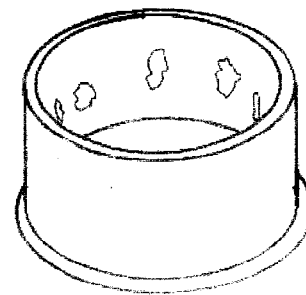
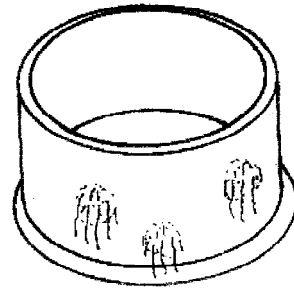
The wall is leaking due to porosity caused by either a mortar mixture with insufficient cement, insufficient curing or poor workmanship.

### Remedy

The wall can be sealed by replacing the porous parts with mortar 1:3 and with NIL. Should the wall still leak after that treatment, the interior of the tank should be coated with a water proofer.

### Procedure

- 1) Drain all water out of the tank and clean its interior.
- 2) Chisel away the porous parts of the interior wall.
- 3) Clean the chiseled parts with water and throw dry cement onto the watered parts of the wall.
- 4) Mix mortar of 1:3 and throw a thin layer of it onto the watered parts of the wall.
- 5) Next day, fill up the coated parts with mortar 1:3 and apply NIL with a square steel trowel. Keep the plastered parts moist under shade for 3 weeks, then fill the tank with water.
- 6) Should the tank still leak, its internal side has to be painted with a water proofer, such as swimming pool paint, non-toxic bitumen, oil paint or 1 part of cement with 10 parts of lime mixed with water.



A newly plastered tank must be

for 3 weeks as shown above.

## 10.7 Leakage through cracked walls

### Problem

Water leaks through cracks and fissures in the wall of a water tank.

### Reason

Vertical cracks are due to insufficient horizontal reinforcement and/or incorrect joining of bricks and blocks.

Horizontal cracks are due to incorrect joining between the horizontal courses between bricks and blocks.

### Remedy

Build a new tank on the outside of the cracked tank by wrapping reinforcement mesh or wire around the tank and plaster it.

### Procedure

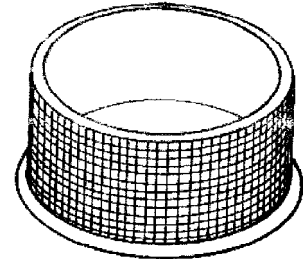
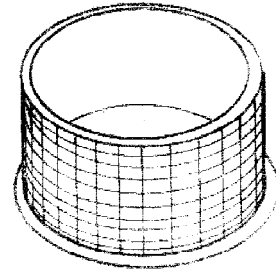
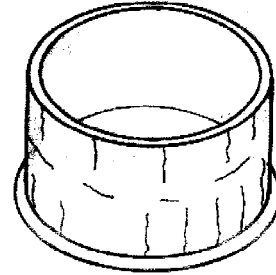
- 1) Drain all water out of the tank and clean it.
- 2) Chisel off any loose part on the external side of the tank wall.
- 3) Tie sheets of weld mesh together with binding wire and wrap them tightly around the tank and plaster the outside of the tank with 3 cm of plaster 1:3.

Alternatively, wrap chicken mesh tightly around the cracked tank after which a spiral of barbed wire, gauge 12.5 is wrapped tightly around the chicken mesh with a spacing of 5 cm at the lower half of the tank and 10 cm apart on the upper part of the tank. Thereafter plaster the outside of the tank with 3 cm

of plaster 1:3 and keep it moist under shade for 3 weeks.

Paint the tank with a weather proof paint made of 1 part cement to 10 parts of lime mixed with water.

Chicken mesh and barbed wire wrapped around a cracked tank



Weld mesh wrapped around a



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