DTU Technical Release Series TR-RWH 01

Partially Below Ground (PBG) tank for rainwater storage

Instructions for Manufacture

Prepared by Dai Rees

Development Technology Unit
School of Engineering
University of Warwick
Coventry CV4 7AL
Tel: +44 (0)1203 522339
Fax: +44 (0)1203 418922
dgr@eng.warwick.ac.uk
http://www.eng.warwick.ac.uk/DTU/

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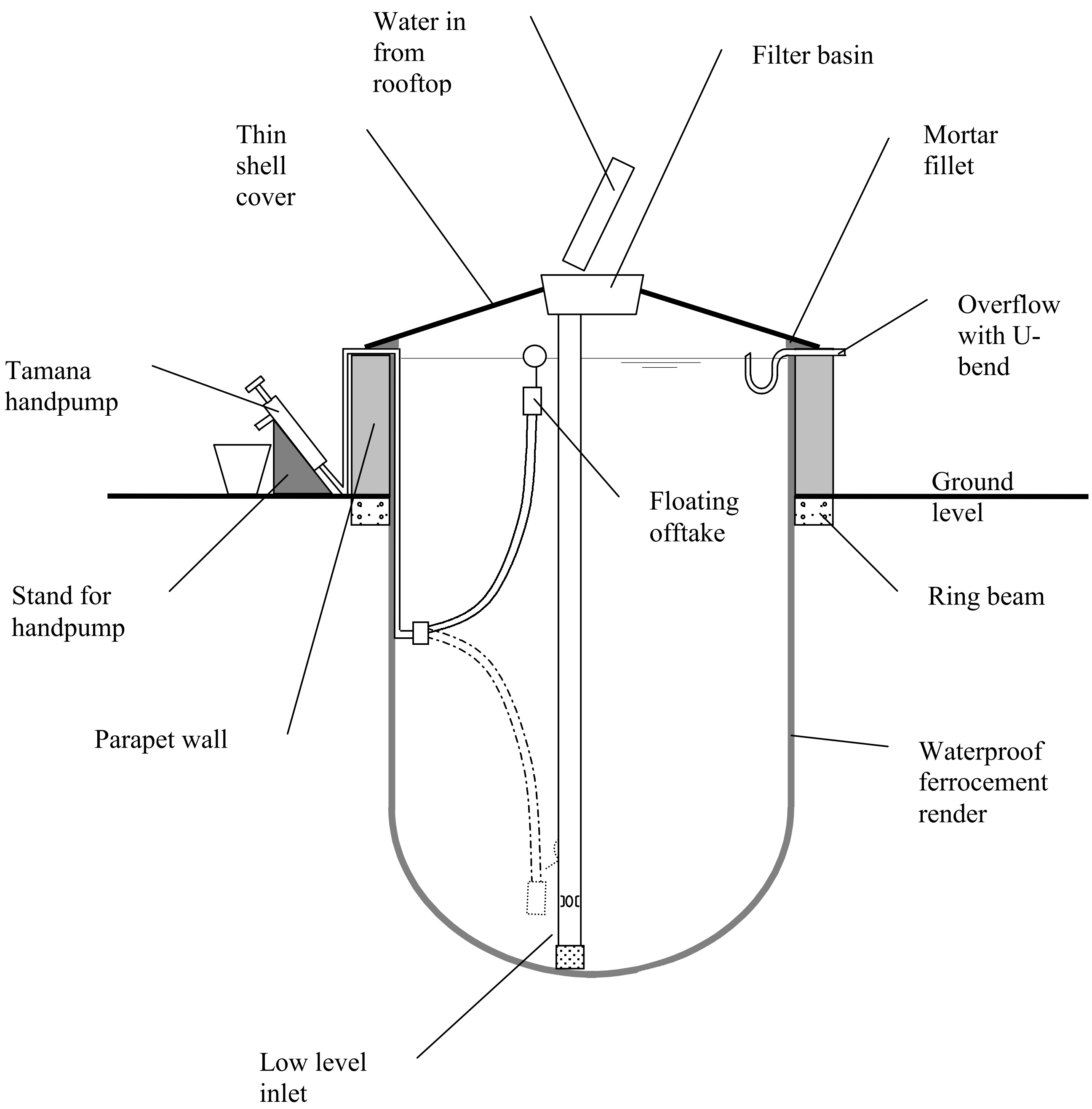
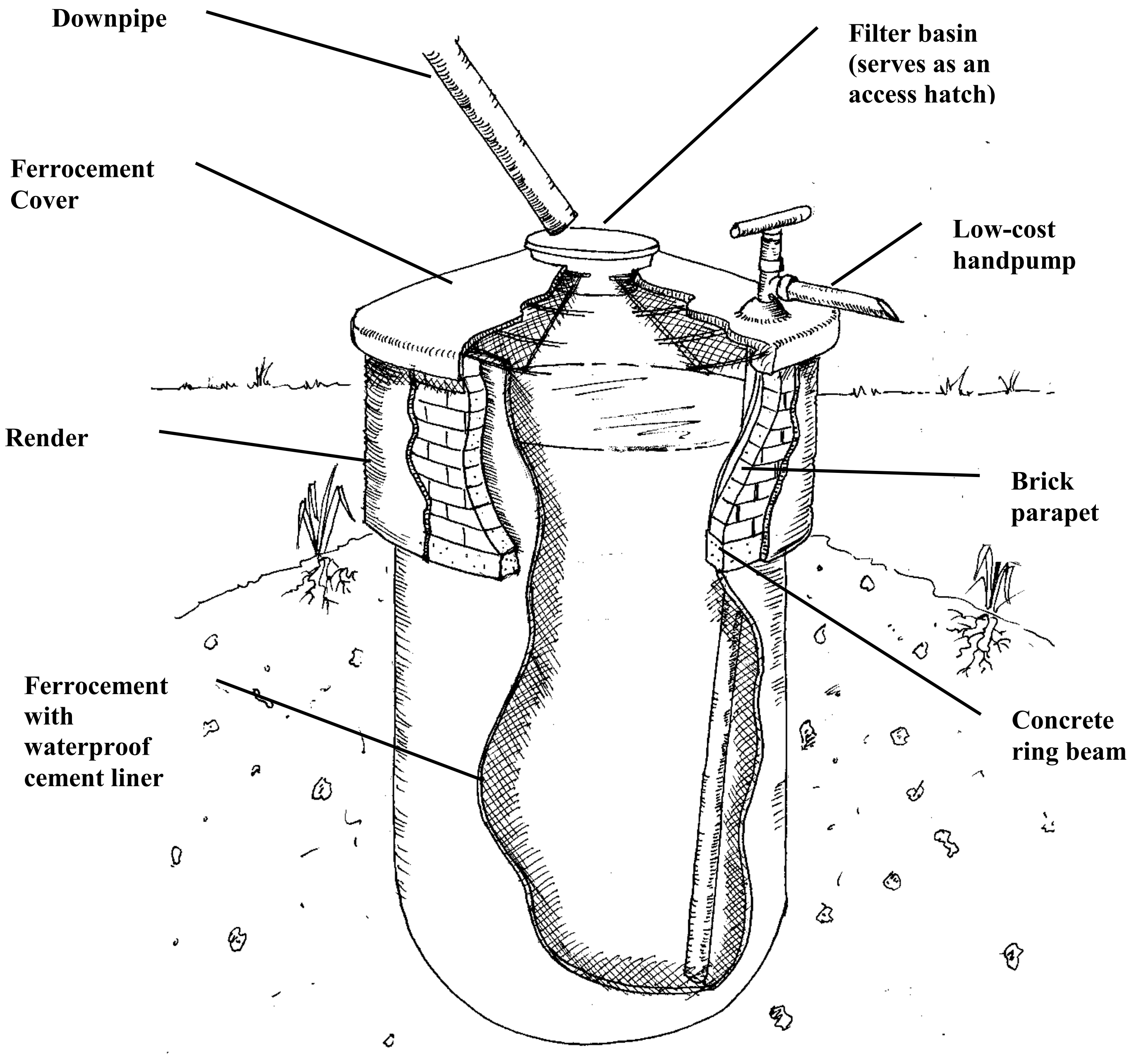


Figure 1- The Partially Below Ground (PBG) Tank



Partially below ground tank sketch

Introduction

Tanks for rainwater storage come in many shapes and sizes. The main distinction between tank types are size, shape, material and whether they are sited above or below ground.

Some of the relative merits and drawbacks of above and below ground tanks are listed in Table 1 below.

Table 1. Pros and Cons of Tanks and Cisterns		
	Tank	Cistern
Pros	• Above ground structure allows for easy inspection for cracks or leakage • Many existing designs to choose from • Can be easily purchased 'off-the-shelf' in most market centres • Can be manufactured from a wide variety of materials • Easy to construct for traditional materials • Water extraction can be by gravity in many cases • Can be raised above ground level to increase water pressure	• Generally cheaper due to lower material requirements • More difficult to empty by leaving tap on • Require little or no space above ground • Unobtrusive • Surrounding ground gives support allowing lower wall thickness and thus lower costs
Cons	• Require space • Generally more expensive • More easily damaged • Prone to attack from weather • Failure can be dangerous	• Water extraction is more problematic – often requiring a pump • Leaks or failures are more difficult to detect • Contamination of the tank from groundwater is more common • Tree roots can damage the structure • There is danger to children and small animals if tank is left uncovered • Flotation of the cistern may occur if groundwater level is high and cistern is empty heavy vehicles driving over a cistern can cause damage

The partially below ground (PBG) tank incorporates the merits of both above and below ground tanks in one simple, low-cost design. The PBG tank takes advantage of the support given by the soil, to do away with the need for a structural component below ground level. At the same time protection is given against contamination by surface runoff and damage by vehicles.

To date (November 2000), about 20 of these tanks have been built in SW Uganda using render linings, often without the chicken mesh. The reports from the field have been good, and feedback suggests that the tanks are easy to construct by masons with some training, at a reasonable cost. A training course for masons was held Kyera Farm, Mbarara, Uganda in June 2000 and 8 local masons were trained in the art of constructing the PBG tank. The instructions given here for manufacturing the tank were developed for this training course.

WARNING: The PBG tank is suitable for construction where the soil conditions are stable e.g. in the lateritic soils of East Africa. If there is any doubt about the stability of the soil, then seek further advice. Working in soils that are unstable can be very dangerous, even fatal.

Instructions are given in a step-by-step guide and these should be followed carefully, especially the tips relating to curing and quality of workmanship. It is worth bearing in mind, however, that materials availability varies from place to place, and so where a given material is not available, a substitute can usually be found and the necessary amendments made.

The instructions given below are for the construction of the PBG tank without the cover or handpump (although the cost of the cover is included in Table 2). **Instructions for the manufacture of the cover and the handpump are given is separate documents – TR-RWH 04 and TR-RWH 09 respectively.**

Neither is any detail given for sizing the tank in terms of demand and supply. This information can be found in many RWH texts or on the DTU Web Page at http://www.eng.warwick.ac.uk/DTU/rainwaterharvesting/index.html

Tools and materials required

Tools – the tools listed below are for the construction of the PBG tank without the cover or handpump.

- 2 shovels
- pick
- 2 buckets
- masons hammer
- wheelbarrow
- plastering tools (if plastic liner is not being used)
- bricklayers trowel
- spirit level
- handsaw for making wooden profile
- bucket on a rope for lifting out soil
- wooden mallet (can be home-made) for tamping walls

Materials

The following are the materials required for a 10.8 cubic metre, ferrocement lined tank.

Table 2 - Materials requirement for the 10.8 cubic metre ferrocement lined PBG tank

Item	Tank component									
	Ground leveling and ring excav'n	Ring beam	Excav-ation	Parapet wall	Parapet - external render	Internal render - first coat	Internal render-second coat	Cover	Placing cover	**Totals**
Cement (OPC) - kg		30		50	25	100	200	50	10	**465**
Sand - kg		60		300	125	300	600	150	50	**1585**
Aggregate (<50mm) kg		120								**120**
Bricks (angled) - no				300						**300**
Chicken wire (0.9m wide) - m							24			**24**
Staples - kg							1			**1**
Waterproof agent - kg							4			**4**
6mm rebar - m								20		**20**
8mm rebar - m								20		**20**
Coffee tray mesh - (0.9 wide) -m								4.8		**4.8**
Binding wire - kg								1		**1**
Basin for filter								1		**1**
Labour (skilled) - days		0.25	1	2		2	2.5	1	0.5	**9.25**
Labour (unskilled) - days	1	0.5	10	2		2	2.5	1	0.25	**19.25**

Table 3 - Costs for the PBG outlined in Table 2

	Number reqd	Unit cost (Ugandan Shillings)	Total cost (Ugandan Shillings)	Total £
Cement (OPC) - kg	465	300	139500	62.84
Sand - kg	1585	20	31700	14.28
Aggregate (<50mm) kg	120	25	3000	1.35
Bricks (angled) - no	300	52	15600	7.03
Chicken wire (0.9m wide) - m	24	1667	40008	18.02
Staples - kg	1	2500	2500	1.13
Waterproof agent - kg	4	4000	16000	7.21
6mm rebar - m	20	230	4600	2.07
8mm rebar - m	20	385	7700	3.47
Coffee tray mesh - (0.9 wide) - m	4.8	4350	20880	9.41
Binding wire - kg	1	2000	2000	0.90
Basin for filter	1	1000	1000	0.45
Labour (skilled) - days	9.25	5000	46250	20.83
Labour (unskilled) - days	19.25	3000	57750	26.01
		GRAND TOTAL	**388488**	**175.00**
		Total materials	284488	128.15
		Total labour	104000	46.85

Exchange rate as of July 2000 (£1.00 = USh2220)

Instructions for manufacture

1. Finding a suitable site
   1.1. The first step is to find a suitable site for the tank. Some pointers for what constitutes a good site are given below:
      - Close enough to the dwelling to avoid long lengths of guttering and downpipe (some suggest siting the tank mid way along the length of a building to reduce gutter size– this is fine if water from one side of the building only will be fed into the tank)
      - Reasonably flat where possible – otherwise the ground will have to be levelled before marking out
      - Away from areas where surface water will gather (i.e. depressions)
      - Away from trees – the roots of trees can be problematic
      - Away from areas where animals will wander – or else the tank should be fenced off
      - Not so close to the dwelling that the foundations of the dwelling are undermined
      - Somewhere convenient for extracting water e.g. close to the kitchen area

   1.2. The ground should be suitable for digging and for siting such a tank. There should be no large stones, bed rock or sheet rock close to the surface, and one should be sure that the groundwater table in the area is several meters below the bottom of the tank. This information can often be gleaned from locals who may have tried digging wells, sinking boreholes or digging garbage pits.

Figure 2 - Showing the cleared ground and the markings in place for the ring beam

2. Deciding what depth the tank will be
   2.1. As mentioned earlier, the sizing of the tank in terms of supply and demand is not given in this document. It is assumed that the sizing of the tank has been carried out correctly.

   2.2. The nominal diameter of the tank is given as 2m. All the sizes given in these instructions are for a tank of 2m nominal diameter. The actual internal diameter is slightly less than this.

2.3. The actual volume of the tank is dependant, therefore, upon the depth of the tank. Table 2 below shows the volume of the tank for a number of given depths (the depth is total depth from the top of the parapet wall, which is 1.0m high).

Table 4 - depths and volumes for PBG tank			
Volume (cubic metres)	Depth of cylindrical section to be dug	Add 1m for the parapet wall and 0.95m for the hemisphere	Total depth of tank (given from top of parapet to base of hemisphere)
8.0	0.55	1.95	2.5m
9.4	1.05	1.95	3.0m
10.8	**1.55**	**1.95**	**3.5m**
12.2	2.05	1.95	4.0m

3. Casting the ring beam
    3.1. Mark out two circles with inner and outer diameters of 1.9 and 2.2m respectively (i.e. radii of 0.95 and 1.10m respectively). This gives a ring beam of width 0.15m (150mm)
    3.2. Dig between the lines to a depth of 150mm keeping the trench neatly trimmed and clean. A machete can be used for trimming the walls of the trench to get a good, clean finish. When completed clean out any loose earth from the trench.

Figure 3 - Casting the ring beam

    3.3. Make a concrete mix of **1:2:4** (cement : sand : aggregate), using the quantities shown in Table 5. Be sure the concrete is well mixed and then place the mix into the trench being sure that any air voids are removed by 'vibrating' the concrete with a stick. Remember that wet concrete mixes will have lower final strength, so keep the mix workable but not too wet.

Table 5 - Quantity of material required for the ring beam	
	Approximate quantity required
Material	**Kg**
Aggregate (<50mm)	120
Sand (clean, graded)	60
Cement (Ordinary Portland)	30
Water (clean)	Enough to make the mix workable

3.4. The ring beam should be covered and cured for 7 days before any further work is carried out (keep the concrete wet during the curing period). Keep the beam covered with polythene during this time and wet the concrete at least twice a day.

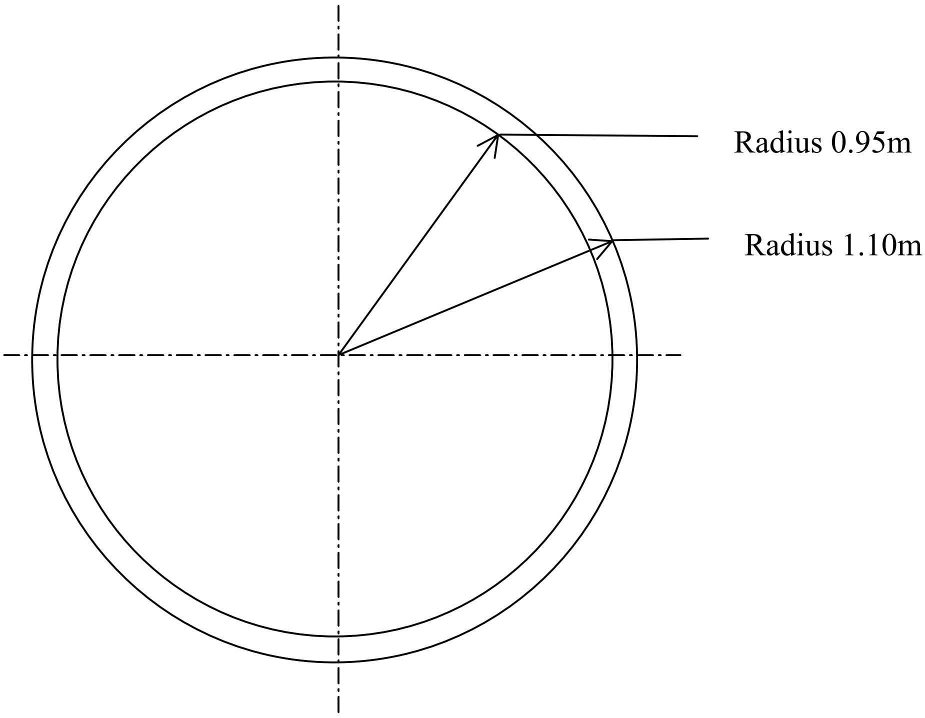


Figure 4 – Dimensions for marking for the ring beam

4. Excavating the hole
   4.1. When the beam has cured the hole can be dug. Use Table 4 to decide what depth of hole is required. The sides of the tank should be kept reasonably vertical. This can be checked occasionally using a plumb line or a masons spirit level.

   4.2. As a rough estimate of the time and manpower required to dig the hole, use the figure of 1 person-day per cubic metre of excavation.

   4.3. The bottom of the hole is shaped like a hemisphere or an inverted dome. This shape is easily dug with a shovel. A rod can be placed centrally in the ground and a piece of string used as a guide if there is any difficulty.

Figure 5 – Excavation of the tank

Figure 6 - Plumbing the walls to keep them vertical

5. Building the parapet wall
    5.1. The parapet wall is built to a height of 1.0m. It is recommended that bricks be cast and fired especially for the construction of the tank to the dimensions shown in Figures 7 and 8 below. Where this is not possible, it is recommended that a standard 100 x 75 x 225 fired house-brick is used, although other (larger) sizes can also be used.

Figure 7a – Showing the mould used for casting the bricks used for the parapet wall

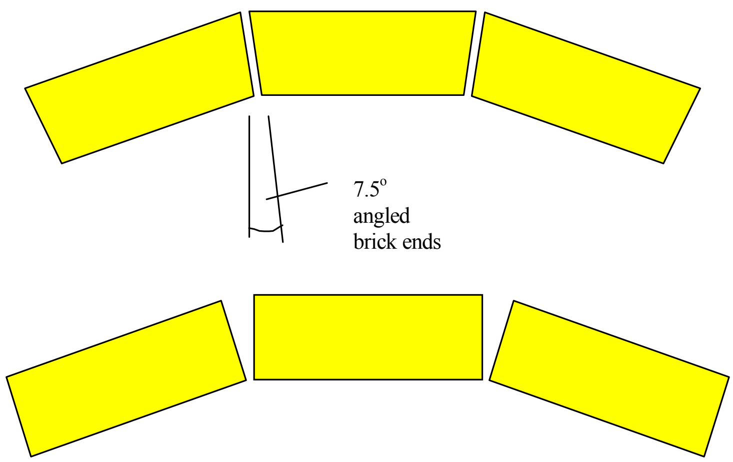
Figure 7b - The bricks with profiled ends

5.2. The number of bricks required depends on the actual brick size, but assuming the dimensions are as given above, then 24 bricks per course will be required. For a height of 1.0m this will be a total of 240 to 270 bricks (10 or 11 courses depending on thickness of mortar used). This represents 6m^2 of brickwork.

5.3. Bricks should be laid with a mortar mix of 1:6. When placing the final course of bricks two small gaps should be left, one for handpump pipe, which will be placed later, and the other for the overflow pipe. This should also be cast into the wall at this stage.

5.4. The overflow trap (see Figure 9) allows overflow water to escape from the tank while preventing mosquitoes from entering the tank. The U-trap is filled with water and so mosquitoes cannot pass. A mosquito mesh also prevents mosquitoes entering the overflow pipe. The trap is made from 50mm (or similar) plastic pipe. If the U-trap is not used then mosquito mesh should be fitted over the end of the overflow pipe. The tank owner should be advised to replace this if damaged or removed.

5.5. When complete, the parapet wall can be externally rendered. This is not essential but makes the tank look better.



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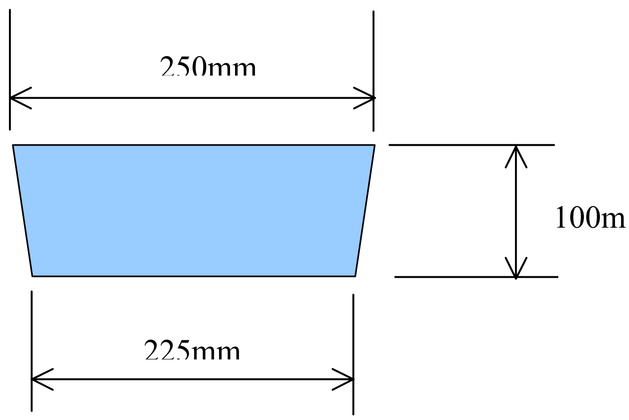

b/

Figure 8 - a/ where bricks are cast and fired specially for tank construction, they can be cast with a slight angle at each end. To minimise the amount of mortar used the bricks should be cast with an angle of 7.5° on each end of the brick b/ showing actual dimensions of brick cast for tank construction

5.6. Material requirement for wall

Table 6 – Quantity of material required for the parapet wall		
	Approximate quantity required	
	Wall	**Render**
Material	**kg**	
Sand (clean, graded)	300	25
Cement (Ordinary Portland)	50	125
Bricks	300	
Water (clean)	Enough to make the mortar workable	

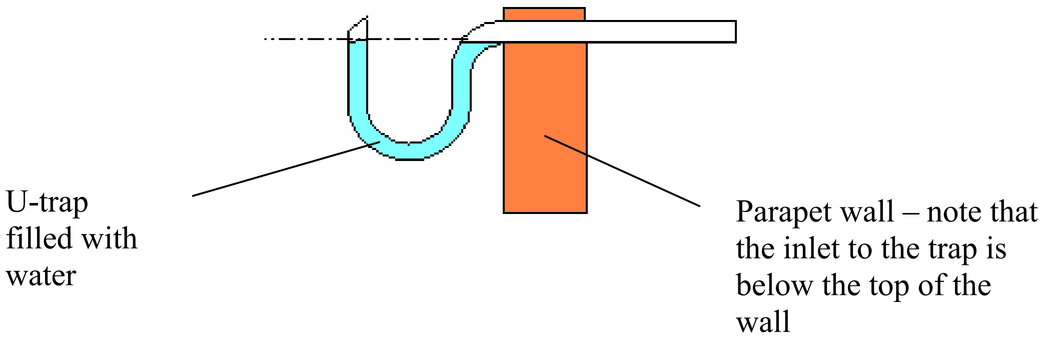

Figure 9 – The U-trap

5.7. Allow 2 skilled person-days and 2 unskilled person-days for building and rendering the parapet wall.

Figure 10 - showing the construction of the parapet wall

6. Lining and water-proofing the tank
    6.1. Any sharp stones or roots protruding from the wall should be removed. Where holes have appeared due to stones having been removed, these should be filled with clay soil and tamped hard and level with the surrounding surface.

    6.2. It is very important to achieve a waterproof lining for the tank. As mentioned earlier, one of the drawbacks of an underground tank is that it is difficult to detect leaks. We, therefore, need to be sure that the tank is well lined and will not leak under normal usage. Good workmanship here is essential.

6.3. Ferro-cement render. This technique is based on the well-known ferrocement technology that has been well documented (see Watt, 1978 and Gould and Nissen Peterson, 1999). The technique involves using a composite of cement render and galvanised chicken wire mesh. A water-proofing compound (readily available in most countries) is added to the cement render. The procedure for application is given here:

- A thin coat (~ 1cm) of 3:1 cement render is applied evenly to the wall of the tank. When the render has started to set (after about 30 minutes), score the render lightly to provide a key for the next layer.
- This first coat is allowed to cure for 2 days. The top of the tank should be covered with a plastic sheet during this time and the walls regularly and liberally sprinkled with water.

Figure 11 - showing the rendering in progress

- A layer of 1” chicken wire mesh is then applied to the render. This mesh is fixed to the render using galvanised fencing staples. Care should be taken to lay the mesh as flat as possible onto the render.
- When the chicken wire is in place the second coat of render can be applied. This is again a 1:3 mix, but includes a waterproofing agent, which is added during the mixing. Any proprietary waterproofing agent can be used and the manufacturer's instructions followed regarding the quantity to be added. The second coat of render should be applied in a similar fashion to the first – about 1cm in thickness (although it may be thicker in places to cover the chicken mesh). This second coat of render should be cured for 7 days as described above.
- The gap around the overflow pipe should be sealed using a waterproof mortar. This is done before the cover is fitted.

Scaffolding or ladders should be used when rendering the walls of the tank. See Figure 12

Material requirement for render:

Table 7 – Quantity of material required for the ferrocement lining (1:3 mix – approx. $21m^2$)	
	Approximate quantity required
Material	**kg**
Sand (clean, graded)	600
Cement (Ordinary Portland)	200
Water (clean)	Enough to make the mix workable
Waterproofing agent e.g. Leak Seal Waterproofing Compound @ 2%	As per manufacturers instructions
Chicken mesh (0.9m wide)	24m length
Staples	1 kg (fencing staples)

Figure 12 - Ladders and boards used to provide a working platform

7. Fitting the handpump
   7.1. More detail of the handpump is given in another DTU publication – TR-RWH 09 “Low-cost handpumps for water extraction from below-ground water tanks - Instructions for Manufacture”. The fitting and fixing procedures are dependant on the type of pump used.

8. Making and fitting the cover.
   8.1. The manufacture of the cover is discussed in a separate document TR-RWH 04 " Low-cost, thin-shell, ferrocement tank cover - Instruction for Manufacture". The cover is made independently of the tank and is fitted when complete.

Figure 13 - The tank with cover in place

8.2. The cover is easily lifted into place by 4 – 6 people. It weighs in the region of 200kg and the lifting height is 1m. Care should be taken when lifting the cover and proper safety precautions should be observed.

8.3. The cover will be mortared into place. A 2cm thick mortar is placed on top of the parapet wall and the cover is placed onto the mortar. The mortar is smoothed to seal the cover onto the wall. The mortar is also smoothed on the inside of the wall / cover joint to form a continuous waterproof lining.

9. The filter is part of the cover. When the cover is manufactured, a plastic basin is used to form the access opening. This basin is then left in place, filled with coarse gravel and covered with a fine cloth. The cloth filters out any coarse debris and should cleaned when dirty and replaced when damaged. It is easy to monitor the condition of the cloth as it is in clear view on top of the tank. The owner of the tank should be made aware of this.

Figure 14 - Showing two types of handpump (DTU and Tamana), filter basin and externally rendered parapet wall, on this demonstration tank at Kyera Farm, Mbarara, Uganda. The guttering has not yet been fitted.

10. Guttering and pipework

10.1. The guttering and downpipe are not specified. This is due to the wide variation in the styles available. This is left to the discretion of the installer.

10.2. In the general diagram in Figure 1, a low-level inlet is shown. This helps to prevent disturbance of the water and directs sediment to the bottom of the tank. The floating intake then takes water from just below the water's surface, where is cleanest. This arrangement is not essential but it is desirable, especially where the water is used for potable supply. The fitting of the low-level inlet again is left to the discretion of the installer. The floating intake is discussed in TR-RWH 09.

11. Maintenance. The maintenance of the tank is quite simple. The following steps should be followed:

- The tank should be cleaned annually - at the end of the dry season, the tank should be emptied and any debris in the bottom of the tank removed.
- The filter should monitored to make sure that it does not become blocked. If the cloth becomes damaged it should be replaced.
- The overflow should be covered with mosquito mesh at all times.
- The tank and associated guttering and pipework should be kept in good general repair. Any damage or faults should be rectified as soon as possible.
- The maintenance of the pump is discussed in TR-RWH 09.