Low-cost, thin-shell, ferrocement tank cover

Instructions for manufacture

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/

November 2000

Introduction
The thin-shell ferrocement tank cover is designed in such a way that it can be manufactured without the use of a mould or shuttering. It can also be manufactured remote from the tank to which it is to be fitted and moved into place once complete. The aim is to reduce the cost of the tank (cover) by eliminating costly shuttering or moulds and by reducing the quantity of material used to manufacture the cover. It also means that the cover can be removed at a later date for maintenance, refurbishment or cleaning, should this be a necessity. The cover can be manufactured by two persons (one skilled and one unskilled) in a single day (with some time required after that for curing) using tools required for the construction of a simple cylindrical ferrocement tank.

The design is based on a frame known as a reciprocal frame, that has spokes that, when loaded, put little radial loading onto the structure on which it sits. The frame is covered with a wire mesh that is then rendered with a sand cement mix.

Details of the construction process are given here for a 2.0m diameter cover that has an inspection chamber opening of approximately 0.5m. The cover pitch is 25^{o}. Strength tests have proved acceptable up to this diameter. No guarantee is given for greater diameters. The spoke angles have to be recalculated for different diameters – this is one disadvantage of the cover design.

Benefits of the thin-shell ferrocement tank
- low cost – reduced use of materials
- no shuttering or mould required
- strong and lightweight – the tank cover is designed to be strong (through good quality control) and light at the same time
- good quality control can be achieved through easy working environment
- can be manufactured by two people in a single day (one skilled and one unskilled)
- no clambering on top of tanks required during construction
- can be cured easily – in the shade and at ground level
- can be batch produced at one site

Tools and materials required

Tools
- hacksaw
- pliers
- tin snips
- masons trowel (small)
- masons trowel (large)
- plasterers float
- shovel
- buckets (2)
- wheel barrow (optional)
- vice (handy if available)
- workbench (again, handy if available)

Table 1 – Materials required for cover	
Item	**Quantity**
Cement (OPC) – kg	50
Sand – kg	150
6mm rebar – m	20
8mm rebar – m	20
Coffee tray mesh* - (0.9 wide) -m	4.8
Binding wire – kg	1
Basin for filter	1
Labour (skilled) – days	1
Labour (unskilled) – days	1

* or chicken mesh (twice the quantity required)
Other – plastic sheet 4 x 4m – (reusable)

Table 2 – Costs of materials (based on manufacture of cover in Uganda, July 2000)				
	Number req'd	Cost per unit Ush	Total cost Ush	Total £
Cement (OPC) – kg	50	300	15000	6.76
Sand – kg	150	20	3000	1.35
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	1	5000	5000	2.25
Labour (unskilled) – days	1	3000	3000	1.35
		GRAND TOTAL	62180	28.01
		Total materials	54180	24.41
		Total labour	8000	3.60

Instructions for Manufacture

Stage 1 – making the frame

- Choose a location with plenty of space to work. The procedure requires bending long lengths of reinforcing steel and so a clear working area is essential. Also a ground space of 2m diameter will be needed where no other activity will be carried out for a week (while the cover is cured). Preferably choose a covered area, so that curing can take place out of the sun and/or rain.

- The first step is to set up a jig for bending the reinforcing bar. The jig is made up of two steel pegs or nails about 5cms long, set about 5cm apart. The steel is placed in the jig and bent as shown in Figure 1. The jig needs to be fixed so that it cannot move when the steel is bent. A workbench is ideal where the pegs can be put into the vice. Alternatively the pegs can be driven into a heavy piece of timber and this arrangement can be used effectively. Steel re-bar (8mm) can be used to form the pegs, but slightly heavier steel is better.

Tip:
When bending the re-bar it does not bend exactly where it makes contact with the jig peg. The bending takes place a cm or two on the pulling side. This has to be allowed for when bending. The bending radius can be quite large because of the thickness of the steel. This doesn't present any real problems here.

- The next step is to bend the 8mm reinforcing steel into hoops. Four hoops, diameter 0.55m, 1.0m, 1.5m and 2.0m are required. To make the procedure easy, a peg can be knocked into the ground and used as a centre around which the four circles can be drawn using string and a marker (also mark the positions of the 8 spokes at 45^{o} intervals for later use). The steel can then be bent gently in the jig to match the circles. The hoops ends are tied with two or three pieces of tie wire. For this the steel is cut slightly oversize to allow for tying. The cutting lengths are given in Table 3. Where the cover is to be fitted to an existing tank the outer hoop should be bent to fit the mean radius of the top of the tank wall and any irregularities in the shape should be taken into consideration.

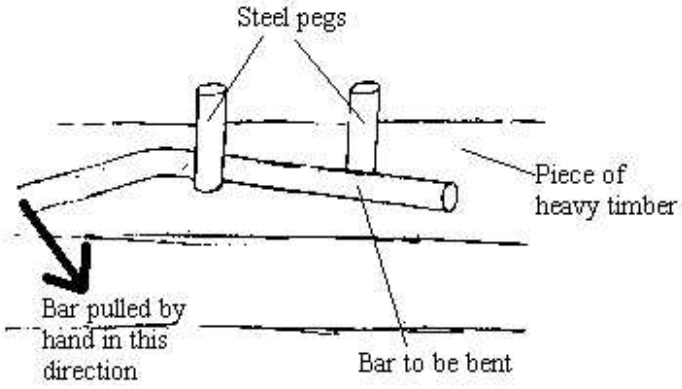

Figure 1 – Jig for bending steel reinforcing bar

Figure 2 – Workbench fitted with bending jig – the angles for the spokes are marked on the jig to make the process quicker and easier

Figure 3 – Marking out the hoop diameters before bending

Figure 4 – Tying the hoops using tie wire and a nail

Figure 5 – One of the spokes

Table 3 – Cutting list for steel hoops (8mm steel)	
Diameter	Steel cutting length (add 0.2m for overlap for tying in all cases)
0.55m	1.72m (1.92m)
1.0m	3.14m (3.34m)
1.5m	4.71m (4.91m)
2.0m	6.28m (2.48m)

- At this point all but the outer (largest) hoop can be put aside until later.
- The next step is to bend the spokes. These are from the **6mm steel** bar. There are eight in number and are bent in the jig to the dimensions shown in Figure 7. The cutting length is 1.33m. To aid the bending, the angles can be marked out on the jig (see Figures 1 and 2) beforehand and then the bent steel can be matched against the marked angles. The angles to mark are:

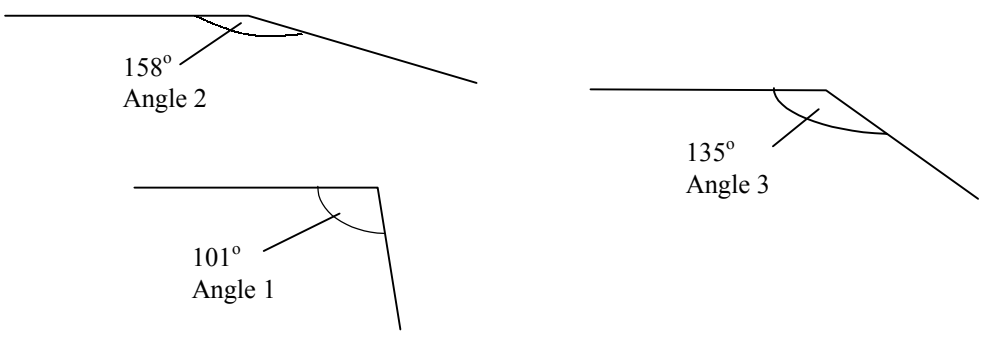

Figure 6 – Angles for spoke bending

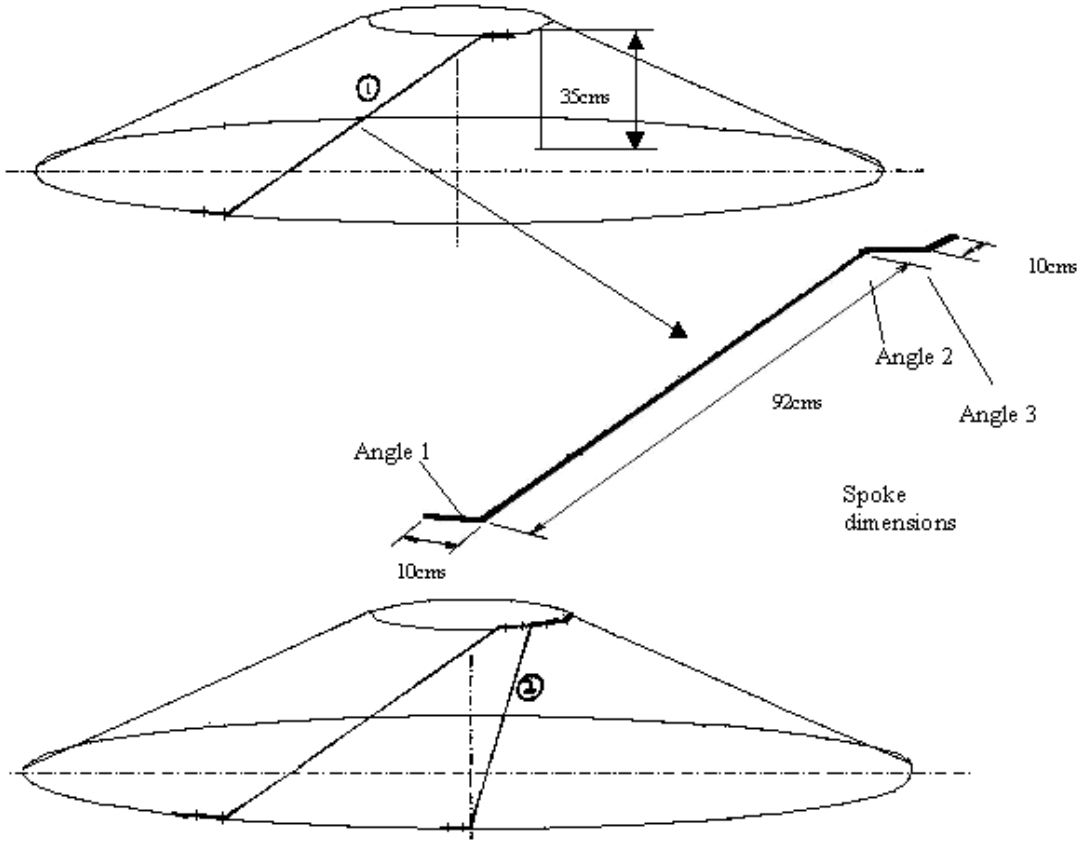

Figure 7 - Dimensions and locations of spokes

- It is recommended that Angles 1 and 3 are bent first. These are bent in the same plane. The spoke is then turned through 90^{o} and Angle 2 is bent.
- Eight secondary spokes are also cut from 6mm steel bar to a length of 75cm. These are wired to the frame as shown in Figure 8 and support the mesh to reduce the 'panel' size.

Figure 8. Assembly of the frame

- Now the spokes are placed one by one inside the outer hoop (as shown in Figure 8.) to slowly form the cover frame. It is convenient to have the outer hoop sitting on the ring marked out earlier with the position for the 8 spokes marked also. THE INNER RING IS NOT USED AT THIS POINT – There is no inner ring. This is made up as the separate spokes are joined together. (See Figure 9). Spoke one is placed on a support (a box or piece of wood) which is 35cm high. This is the height of the frame from the ground to the plane of the circular access hatch.

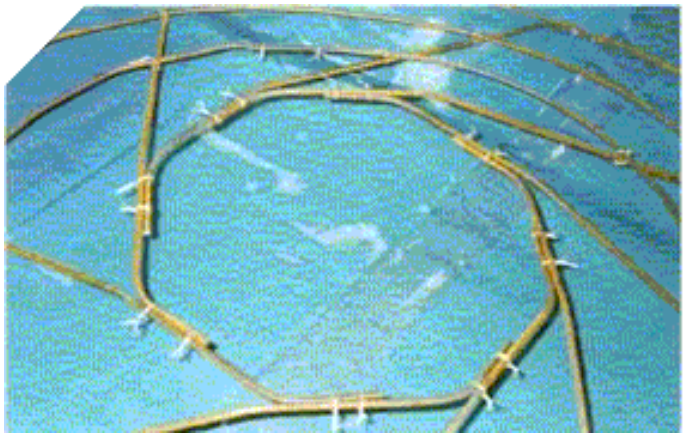

Figure 9. Showing the formation of the inner ring from individual spokes

- Tie the first spoke to the inner side of the outer hoop as shown in Figure 10.

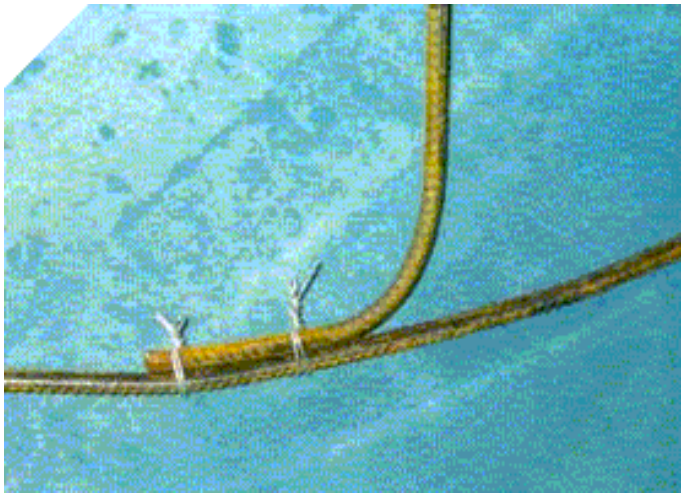

Figure 10. Showing arrangement for tying spoke to outer hoop.

- Place the next spoke 45^{o} around the perimeter hoop (these spacings were marked earlier) and tie it to the first spoke as shown in Figure 9. Continue in this way until the final spoke is tied to the first spoke and all eight spokes are in place.
- Put the two inner hoops in position and tie them in place (Figure 8). The small inner hoop that was formed earlier will be used when the access hatch lip is made later.
- The frame in now ready to have the chicken mesh or coffee tray mesh attached.

- Use chicken wire (0.5 inch mesh size) or coffee tray mesh (4mm mesh size) of 0.9m roll width. If chicken mesh is used, 9.6 metres length is required and two

layers of chicken netting are applied. If coffee tray mesh is used then only one layer and 4.8m length are required.

- Eight pieces of chicken wire or 4 pieces of coffee tray mesh are cut to the dimensions shown in Figure 11. Two pieces can be cut from a 2.4m length of netting if cut as shown. A template can be drawn on the ground to aid cutting.
- Coffee mesh is easier to use, is firmer, and due to the small mesh size very little mortar is lost through the mesh during rendering. It is approximately twice the price per metre length and so the overall cost is similar as only one layer is required.

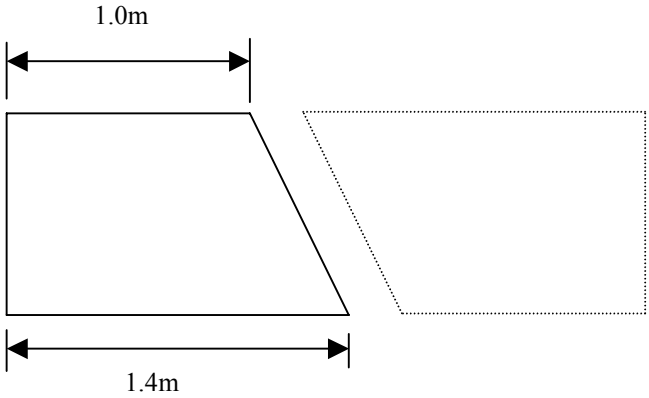

Figure 11. Cutting size for chicken mesh

- The pieces of netting are placed on the frame as shown in Figures 12 and 13 and the overlapping edges tied in place, pulling the wire as tight as is possible without distorting the mesh.

Tip: for chicken mesh, a screwdriver can be used to pull the loose wires or end loops through holes in the mesh to tie the mesh in place. Use the rough edges of the netting to tie the folded edges into place. Use as little tie wire as possible at this point, as the netting will tied securely when the second layer is in place.

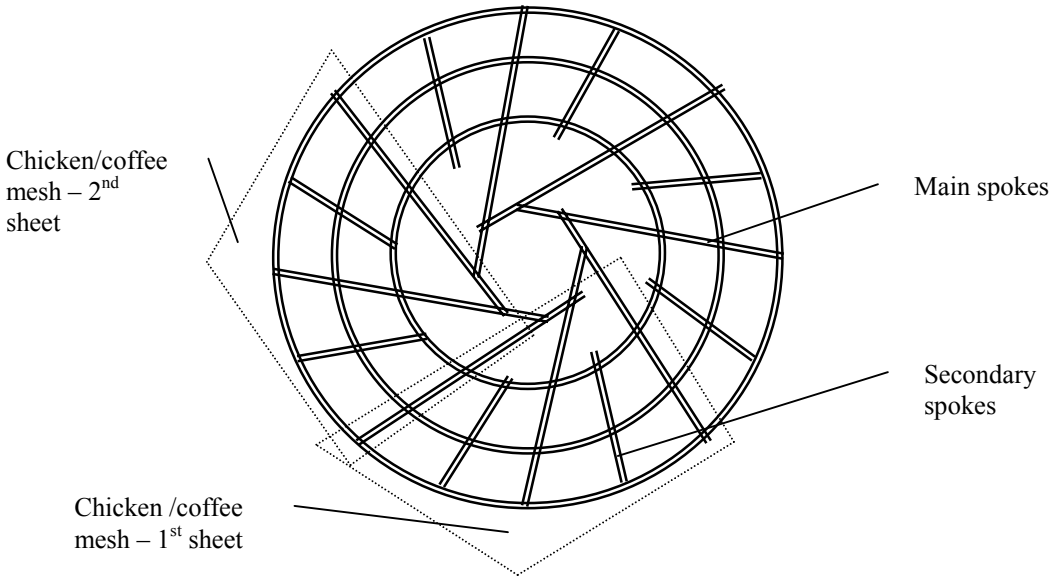

Figure 12. Pattern for application of chicken mesh

Figure 13. Applying the chicken mesh.

- When the first layer of chicken mesh is complete start the second layer one spoke (90^o) out of phase with the first and complete in the same manner.
- Carefully check that the mesh is as flat as possible and, if using chicken mesh, that both layers are close together. Tie the netting at regular intervals using the tie wire so that the netting is close to the steel bar. Bend all tie wires into the plane of the cover. Remember that we are trying to keep the cover as thin as possible and protruding wire ill have to be covered with mortar.
- The cover is now ready for the rendering (Figure 11).

Stage 2 - Rendering the cover

- It is important to use good quality materials and to maintain good standards of workmanship throughout the rendering process. The aim is to apply a layer of mortar to the chicken mesh that is as thin as possible. This, in practice, will vary between about 15mm and 25mm with an average thickness of about 20mm. The first coat is applied from the top and second coat applied from below.
- Put a plastic sheet on the ground so that render mix which falls through during rendering can be reused.
- Elevate the frame so that work can be carried out from above or below. Waist height is most suitable. The frame should be raised on 6 posts or boxes so that it is stable and can withstand the forces applied during rendering. A support should also be placed in the centre to prevent the centre sagging under the weight of the render (see Figure 14).

Figure 14 – the completed cover frame set on 6 supports and ready for rendering

- Render preparation: a mix of 1:3 (cement:sand) is used. A sharp sand should be used i.e. not a fine sand but sand with a moderately large grain size. There should be no silt or other contaminant in the sand. Ordinary Portland Cement (OPC) is used. The quantities should be carefully measured using a container – a bucket for example (do not measure using a shovel as this can be very inaccurate).
- The consistency of the render is very important. It should be dry enough not to fall through the netting while being plastic enough to be workable with a trowel. A mortar plasticiser will improve the workability of the render.
- Adding a plasticiser means that the water:cement ratio can be kept low while still keeping the render plastic. This ratio should be kept to approximately 0.4 by weight (i.e. 10 parts cement to 4 parts water by *weight*). Low water content not only gives a render which is easily applied to the mesh, but also gives improvements in strength and permeability of the cured render. In practice it is difficult to control the water:cement ratio because there is usually an unknown quantity of water in damp sand and plasticity is often achieved before the minimum measured ratio is met. The practical method involves experimentation to achieve the desired plasticity with minimum water content. The plasticiser should be used according to the manufacturers instructions.

Figure 15 – applying the top coat of render to the cover

- Keep mixes small because the render 'goes off' quickly. It may be wise to make a dry mix which is sufficient for the whole job and then add water to small amounts as required.
- Applying the render: this is fairly simple. Use a plasterers float and a small trowel. Put the float behind the mesh and work the mortar through the mesh onto the float as shown in Figure 12. Wipe the float away so that the mortar is slightly smoothed on the underside. Work small areas – take one 'panel' at a time and complete it. Some of the mortar will fall through onto the plastic sheet – this can be picked up immediately for reuse. Remember that the aim is to apply a very thin layer of mortar. The technique can be easily learned with a little practice.

- A basin of approximately 0.5m diameter is used to form the access hatch. The basin can later be left in situ and can act as the filter. These basins usually have sloping sides and so the basin can be inserted until it fits tightly.
- A lip is then built up around the basin to about 50mm deep and 50mm wide. The remaining steel hoop is built into the lip.

- Once the first layer of mortar has been applied the cover should be left for a day to allow the render to gain strength.

Figure 16 – showing the lip being built up around the basin – note the steel hoop in place

- After one day the underside can be rendered. Again use a 1:3 mix and keep the render quite thin, just covering the steel bars and wire mesh.
- The cover is then cured for 7 days. The tank should be wetted twice daily and covered with plastic sheeting to prevent evaporation of the curing water. It is essential that curing is carried out properly.
- A coat of 'nil' (pure cement water slurry) can be applied to top and bottom after two days of curing.

Figure 17 – Showing the underside of the cover after rendering is completed

Figure 18 – Curing the cover under plastic. The cover is wetted regularly during curing.

Putting the cover in place on the tank

- When the cylindrical tank body is being constructed, some thought should be given to the method of fixing the cover to the tank. If the cover is to be fitted to a thin walled ferrocement tank four (or more) tie wires should be left protruding from the tank wall and these are tied to the cover when it is in place. For brick, block or masonry walls, the cover can be laid on a bed of stiff mortar and then blended with the tank as shown in Figure 19.

- The cover can be lifted into place by four or six strong people. Special care should be taken not twist the cover or put any undue stress on it as this could cause it to crack.
- If the tank wall is quite high then a raised platform should be constructed (from earth or timber) to stand on.

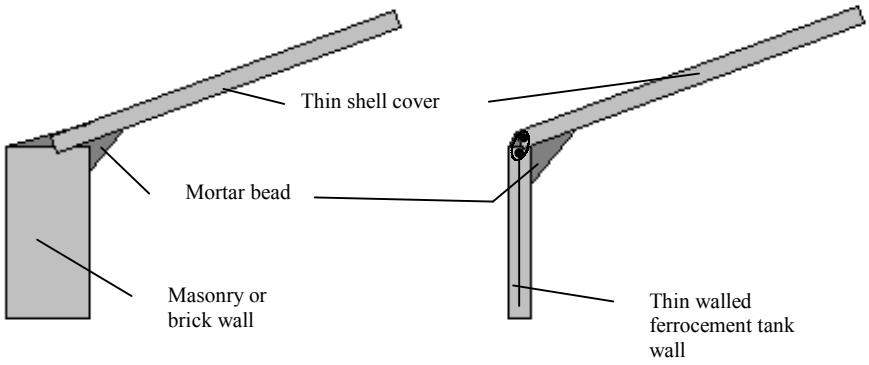

Figure 19 - Blending the cover with the tank wall.

Figure 20 – A completed cover fitted on a partially below ground tank in Uganda

Tank testing

Tests were carried out on the tank cover in the UK. The cover was uniformly loaded to 1000kg and there was minimal deflection. It was also point loaded to 160kg, again with minimal deflection and no visible sign of cracking or damage.

Figure 21 - Tank cover loaded to 1000kg