Research into single skin, externally reinforced, brick tanks

Interim Report
April 1999
Mr. D. G. Rees
DTU, University of Warwick

Table of Contents

1. Introduction

1.1 Project background

This work is being carried out as part of a programme titled 'Domestic Roofwater Harvesting in the Humid Tropics', which is an international 3 year, four partner, European Union funded, programme which started in August 1998.

Warwick is leading the sub-programme titled 'Low cost storage', the aim of which is to develop a number of techniques for construction of low cost water storage tanks or cisterns. As part of the programme we will look at several techniques for reducing costs, improving quality and improving health through good design and construction practice.

One such possible low cost design that will be investigated in detail is the externally reinforced, single skin brick tank. This Interim Report discusses the early research work that has been carried out on this design idea with the aim of clarifying the findings of this work and the further work that is required to provide enough useful detail to confidently promote such a technology.

1.2 Brick tanks – design philosophy for Developing Countries

The design philosophy adopted for water storage tank design is one of local manufacture using materials that are available with relative ease in the locality. Cost control is of major concern in order that the technology becomes more accessible to the poor of developing countries.

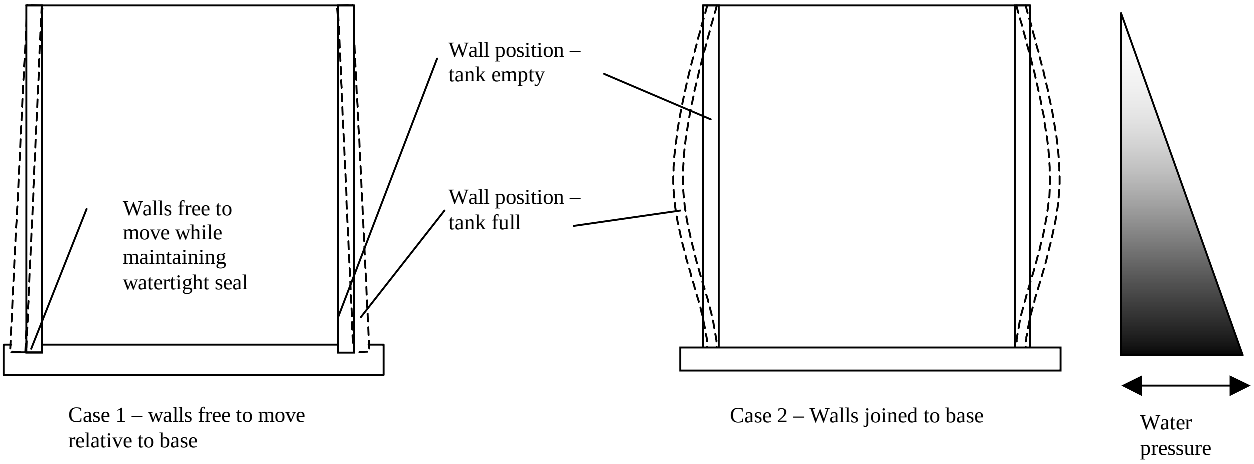
Brick is one such locally manufactured, widely used, readily available material which is ideally suited to wall construction, but not quite so well suited to conventional larger volume tank construction. In this report we look at methods of improving the suitability of brick to low cost tank manufacture by using external steel reinforcing to give additional hoop strength to cylindrical brick tanks. We also look at methods of lining such tanks for water tightness – at this stage limited mainly to internal cement render. Plastic lining of tanks will be discussed in a later report.

2. The theory of stresses in cylindrical tanks

Cylindrical tank walls experience a ‘hoop stress’ which is proportional to the diameter, D, of the tank, the pressure, p, on the walls of the tank and the thickness of the tank wall, t (Equation 1). The stress on a cylindrical tank wall is also affected by the type of joint between the tank base and tank wall. There are two obvious cases to consider as illustrated in Figure 1 below. Taking Case 1, if the tank wall is free to move at its base and still maintain a watertight seal, then the strain induced in the wall will cause the diameter of the tank to increase until the hoop stress is taken up by reinforcing in the wall (obviously the increase in diameter is exaggerated here for effect). In this case the force exerted by the water pressure on the tank walls will be taken up solely by the hoop tension in the walls. The maximum hoop stress will be experienced at the base of the wall and will decrease proportionally (linearly) according to Equation 1.

$$\sigma_t = \frac{pD}{2t}$$

Equation_1 – Hoop Stress



Case 1 – walls free to move relative to base

Case 2 – Walls joined to base

Figure 1 – The two cases for wall and base union in cylindrical tanks

Taking Case 2, if the wall and base are monolithic i.e. the wall and base are continuous, the situation becomes more complex as bending stresses are set up in the wall as a result of the restraining effect of the base slab. There now exists a complex combination of bending, shear and hoop stresses. Gray and Manning[4] suggest that if the wall is not free to move at its base, then the loading caused by the outward pressure is counteracted by a combination of hoop resistance and cantilever resistance. This is illustrated in Figure 2 which shows the load distribution diagram suggested by Gray and Manning. As the base of the wall is now restrained there is no freedom for the wall to move and take up the hoop stress and so the hoop stress there is reduced to zero. Maximum hoop stress is now experienced higher up the wall of the tank. All the restraining forces acting at the base are due to the cantilever.

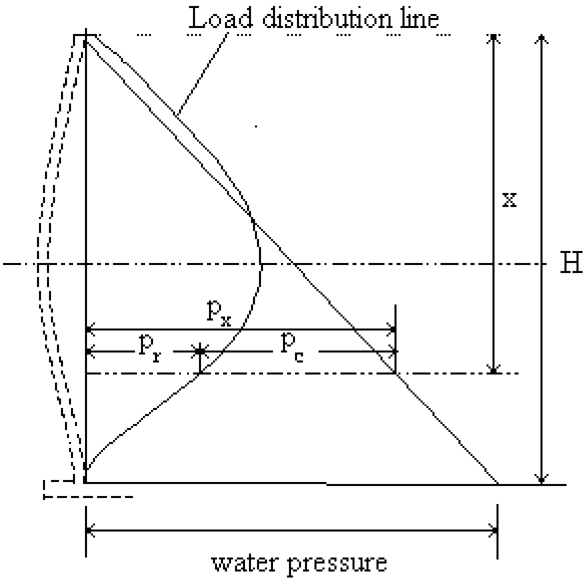


Figure 2 – Typical Load distribution diagram for a tank wall which is monolithic with base (modified slightly from Gray and Manning[4].

p_x – Total outward pressure load to be restrained
p_r – Portion of the load restrained by hoop stresses or radial constraints
p_c –Portion of the load restrained by cantilever
x – distance from top of tank
H – total depth of tank

As illustrated in Figure 2, the total pressure p_x at any depth of wall is composed of p_r (the portion of the load carried by the hoop restraints) and p_c (the portion of the load carried by the cantilever), such that,

$$p_x = p_r + p_c$$

The profile of the 'load distribution curve' is governed by the profile of the tank. Gray and Manning give a number of load distribution curves for a variety of tank profiles (see Figure 3). The tank profile is related to the distribution curve by Equation 2, all tanks with equivalent values of K having similar load distribution curves.

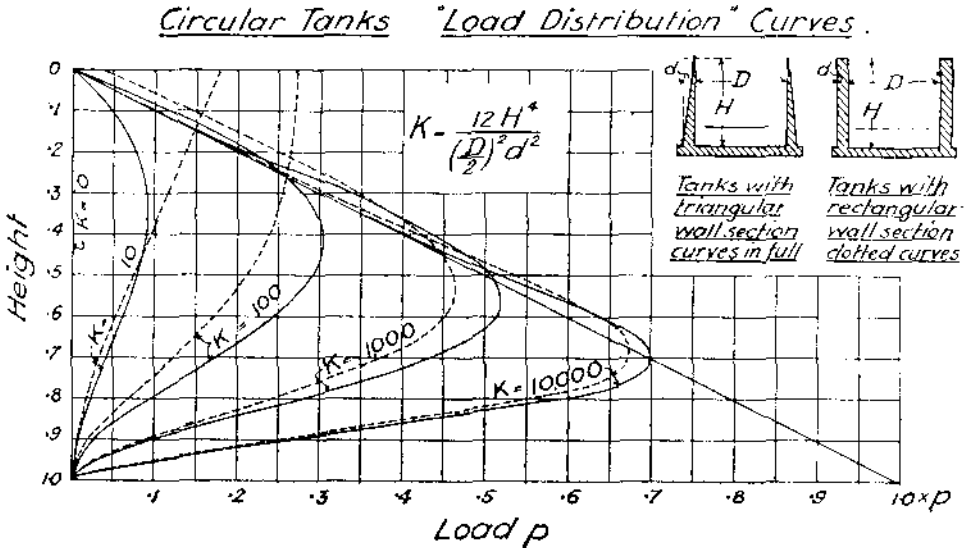


Figure 3 – Load distribution curves for a variety of K values (Gray and Manning[4])

$$K = \frac{12H^4}{\left(\frac{D}{2}\right)^2 d^2} \text{....................} Equation\_2$$

where,
H = height of tank
D = diameter of tank
d = thickness of wall at foot

It is noted that cantilever load increases for diminishing values of K. K is tightly controlled by the value of H such that K increases to the fourth power of H. We also see that K falls as tank radius and wall thickness increase.

If we consider a typical cylindrical single skin, brick tank with homogenous wall and base of diameter 2m, height 2m and wall thickness of 0.1m, then we obtain a value of K equal to 19,200. This is beyond the value shown in Figure 3 and suggests a regime where p_r dominates i.e. the outward pressure load is resisted predominantly by hoop stresses. Cantilever forces act only at the extreme base of the tank wall (within the bottom 20%). The tank can therefore be dealt with as if the hoop stresses induced are similar to those of a tank with a free base joint. This still leaves the high bending and shear stresses in the base of the wall to be evaluated. Watt[2] suggests that the maximum bending stress on the inside face of the tank wall will be almost double the induced hoop stress for a similar tank profile. This can easily be compensated by increasing wall thickness at the base of the tank. As demonstrated by Equations 3 doubling the wall thickness, d, effectively decreases the bending stress in the wall by a factor of four.

Bending stress, $$\sigma_b = \frac{M\left(\frac{d}{2}\right)}{\left(\frac{bd^3}{12}\right)} = \frac{6M}{b}\left(\frac{1}{d^2}\right) \text{.............} \mathit{Equation\ 3}$$

where, $\frac{bd^3}{12}$ is the Second Moment of area

and b is the width of a strip of wall carrying local bending moment, M

Shear stress is very small compared with the bending and hoop stresses (Watt) and can therefore be neglected for the sake of this analysis.

Work is currently being carried out to develop a computer software programme for a fuller analysis of stresses set up in a variety of tank shapes and sizes.

2.1 Calculating hoop stresses in reinforced brick tanks

The task of calculating hoop stresses in the tank under consideration now becomes a simple task. We treat the tank as if its walls were unconstrained at the base and can thus use Equation 1. We will then deal with bending stresses separately by increasing wall thickness locally at the base as required.

For a tank with a brick wall and external steel reinforcing we need to understand what stresses are induced in each material and what function each material is performing. Table 1 shows a hoop stress analysis for the two materials that have been used during tests at the University. These materials are high tensile steel packaging straps (of 13mm width x 0.5mm thickness), and brick masonry (in this case with cement mortar). If we analyse the two materials separately we can see from Table 1 that the ability of the brick masonry to withstand the imposed hoop stress is unpredictable due to the unpredictable nature of the quality of the material. High tensile steel, on the other hand, has reliable and predictable strength and will afford almost four times the required hoop strength. The steel, then, provides the tensile strength required to prevent failure due to excessive hoop stress.

The brick masonry, on the other hand, provides the stiffness required to prevent failure due to bending stresses. For the example shown below the stiffness of the brick is many orders of magnitude greater that the ‘virtual’ steel wall stiffness (virtual wall thickness is the thickness that would exist if the straps formed a continuous steel shell - the straps themselves actually provide no vertical stiffness).

We therefore see that one material compliments the other. The steel provides a hoop strength up to eight times that of the brick masonry whilst the brick masonry provides the stiffness that could only be achieved in a steel tank with hundreds of times the quantity of steel used in the example given.

Properties	**High tensile steel strap (13mm x 0.5mm) – two straps per course of bricks**	**Brick masonry**	**Units**
UTS (Mpa)	833	0.1 – 1.0	Mpa
Yield strength	450		Mpa
Youngs modulus	210	25 - 100	Gpa
Wall thickness (equivilant)	173×10^{-6}	0.1	m
Tank diameter	2	2	m
Water depth	2	2	m
Hoop stress exerted by water force	113.19	0.196	MPa
Safety factor	3.98	0.51 – 5.10	

Table 1 – Hoop stress analysis for steel and brick masonry in cylindrical tank of 2m diameter and 2m height

2.2 Construction and application regimes to ensure strength

Some thought has to be given to the interaction between the brick masonry and the steel strap. The two materials must interact in such a way as to enhance the properties of the other as explained in the previous section. This can only be achieved when the construction of the walls and application of the steel strapping is performed in a certain way. The steel is applied externally to the brick wall, using a tool specially designed for applying this kind of strap. The strap should be applied with sufficient pre-tension to be able to counteract the normal water force that will be exerted upon the wall upon filling the tank. In consequence, the masonry is initially put into compression and remains in compression as the tank is filled. This will protect the brick masonry against failure (cracking) should the hoop strength of the masonry be unable to accept the load (due to inferior workmanship or poor material quality). Referring to Table 1, the hoop stress exerted by the water force is 113.19 MPa (say 114 MPa). Experiments were carried out at the University to confirm that such a pre-tension can be applied to the tank and the description and results of these experiments are shown in a subsequent chapter.

2.3 Stresses in tank foundations and base

Little work has yet been done to calculate stresses in the tank base. This will be included in the next report.

2.4 Stresses due to other factors

Stresses due to other factors such as wind forces, cyclic loading and seismic activity have not been considered in this analysis.

3. The theory of cracking in cement render

(This section is the work of Dr. T. H. Thomas from a paper titled ‘The Causes and Prevention of Leakage through Cementitious Renders in Water Tanks’)

3.1 Cementitious renders

Renders of cement or lime mortar are commonly used in water tanks when the tank itself is constructed of rather permeable materials such as brick, stabilised soil or even (in the case of underground tanks) of unstabilised soil. The render’s primary purpose is water-proofing, for which it should have a sufficiently low permeability to protect the main tank material and to reduce water loss through walls to a tolerable level. Thus we might demand that the render keep wall leakage in a 10 m^3 tank to under 1 litre per day. The render may have secondary functions such as reducing the roughness of a masonry surface so that it can be easily cleaned down, or even of providing a little stability to the wall behind it.

Cementitious renders are usually sufficiently impermeable in themselves, but are so brittle and so intolerant of *tensile* strains that they commonly crack. It is the cracks that leak and preventing cracks should be a focus of research effort.

3.2 Sharing out any shrinkage between ‘many’ cracks

Shrinkage of a render constrained by underlying masonry is the main mechanism for producing cracks. Tensile stresses in the render are relieved by cracking. Tensile strains are replaced by a combination of strain-free mortar interspaced by cracks carrying no tension forces. For a given shrinkage and a given material, the total volume or total width of cracks may be more or less fixed. However that total may be variously distributed between few or many distinct cracks. Consider for example the inside of a masonry tank of diameter 2 m where a render incapable of supporting any tensile strain has contracted by 1000 microstrain (0.1%) relative to the masonry. Around a circumference we might expect a total crack width of about 6 mm divided between say n individual cracks. We would certainly expect the leakage through an individual crack to be a rising function of its individual width. We might expect the total leakage to fall with rise in n - e.g. for two 1 mm cracks to leak less than one 2 mm crack.

Consider an individual crack of length L and width W penetrating a render of thickness T across which there is a pressure drop, from liquid to liquid, of p. The leakage velocities are very low and the key dimension (W) is small, so the Reynolds Number will certainly indicate laminar flow. As water behaves as a fairly Newtonian fluid, we can assume a viscous shear stress in the fluid proportional to the transverse velocity gradient in that fluid. Provided velocities are small compared with that corresponding to conversion of pressure head into velocity head, (i.e. $v^2 << 2p/\rho$) this gives a velocity profile of :

$v = \frac{p}{2T\mu}\left(Wy - y^2\right)$ where v is water velocity in the layer distance y from the side of the crack.

The consequent flowrate through the whole (assumed rectangular) crack is:

$Q = L\int_0^W v\,dy = \frac{pL}{12T\mu}W^3$ which is proportional to W^3, hence Q/W is proportional to W^2.

This suggests that replacing one large crack by two smaller (half-width) cracks will usefully reduce leakage by a factor of 4.

Inserting numbers: a 100 mm long crack of width 0.1 mm in a render 10 mm thick and subject to a water pressure of 10 kPa (1 m head) will leak 20°C water (μ = 1 mPa s) at nearly 750 litres per day. Replacing this crack by ten 0.01 mm cracks will reduce leakage to 7.5 litres per day. Even this is usually unacceptable, so we are looking to get crack widths below 10 µm. However at these capillary sizes, surface tension effects become dominant.

Surface tension is likely to prevent *any* flow through a plane crack whose thickness W is less than $2\gamma/p$ where γ is the surface tension of water (in Nm^{-1}). Thus for water at 20°C for which γ = 72.5 mN/m, a head of 1 m will not cause leakage through a gap smaller than 14.5 µm.

3.3 Prevention of cracking or of leakage through cracks.

Render cracks may form during 'manufacture' of a tank or when water pressure is first applied after manufacture or during moisture cycling through the life of a tank. We are studying the various shrinkage and crack-formation mechanisms associated with cementitious materials. Generally such materials experience shrinkage of up to 2000 µstrain.

Strategies to prevent or reduce leakage through cracks include:

	Approach	Technique
a	Use non-shrinking render	1. Use mortar with very low water content 2. Pre-shrink the render 3. Cure under water
b	Remove the constraint provided by underlying masonry/reinforcement	1. Add reinforcement after curing 2. Use flexible mortar to lay bricks/blocks 3. Use very-slow setting mortar to lay them 4. Masonry same as render
c	Reduce constraint of base plate	1. Flexible or sliding wall-base joint 2. Thicken wall to reduce bending stresses
d	Distribute cracks (convert into more but smaller cracks)	1. Reinforce with mesh 2. Reinforce with fibre 3. Manipulate bond with masonry
e	Stagger cracks in multi-layer render	1. Plaster, cure, replaster 2. Plaster, cure, groove, fill
f	Use a flexible render	1. More (hydraulic) lime in mix 2. Add polymers like latex to mix
g	Prevent cracks opening under stress (strain induced by water pressure)	1. Hoop tension the reinforcement after curing the render 2. Do so before curing the render. 3. Thicken the masonry to reduce changes in strain when under load.

Table 2 – strategies for preventing cracking in cementitious renders

4. Building materials

One of the aims of this research is to investigate the behaviour and suitability of the materials listed in this chapter for use in construction of a water storage tank and to make recommendations for tank construction techniques using these materials. Tests and test results are shown later in this document. Now we will discuss the general nature of the materials and the general theory postulated for design.

Fired clay brick is a rigid, brittle building material. It is usually used in conjunction with a cementitious binder (such as cement or lime mortar) to form a wall which is strong in compression but weak in tension. There are a number of techniques used to give extra strength where required: this usually takes the form of laying the bricks in a regular pattern to form an interlocking matrix of brick and mortar. Ties, buttresses, and other building aids and techniques give extra, localised strength where required. It is difficult to improve the tensile strength of brick masonry without creating a composite material by adding steel or timber.

The predominant stresses that will be set up in a tank wall are tensile stresses. As explained in an earlier section, these stresses are due to the water in the tank exerting hoop stresses and bending stresses in the structure. The brick and mortar construction alone cannot be expected to withstand these stresses and it is for this reason that steel strapping is used to take up the predominant tensile stresses. The brick gives rigidity (i.e. stiffness) and mass to the structure while the steel, with it's high tensile strength, performs the task of providing hoop strength. Together, using the cylindrical wall structure, they combine properties to provide a rigid structure with sufficiently high tensile strength.

A further requirement of the tank wall material is that it be watertight, and that it remain watertight for the lifetime of the tank. Brick masonry rarely achieves this requirement and so we will also look at methods of providing a waterproof membrane or lining within the tank. Therefore, we also look at cementitious renders which are applied to the inner surface of the tank wall to provide a continuous waterproof membrane. Later (in a later report) we look at low-cost plastic liners for water tanks.

We investigate the properties of these materials used together (brick masonry – steel – mortar render) to determine the optimum design specification that will give adequate strength, rigidity and watertightness, while minimising the quantity of material used (with the aim of keeping costs to a minimum). Each of the individual materials mentioned above has it's own unique behaviour and the biggest challenge comes in trying to match these materials in such a way that they act in synergistic fashion to provide a composite that gives the required properties.

Much thought has been given to the process required to achieve this synergy. A number of mortar and render types have been investigated and the methods of application and construction regimes have been considered carefully. In this report we will look in some detail at the following aspects of tank design and construction:

- behaviour of lime and cement mortars
- application of steel strapping to cylindrical steel tanks
- stresses in steel strapping in cylindrical brick tanks during application and under load conditions
- initial investigations into shrinkage and cracking in thin renders

4.1 Tank construction materials

Fired clay brick.

Low quality fired clay brick is a building material which is commonly found in many, many countries throughout the world. Brick masonry is a building technique that has existed for more than 4000 years. A variety of soils are available for the process of brick making and the process itself varies in complexity from small field based batch kilns capable of producing a few thousand bricks to large scale continuous mechanised technology capable of producing hundreds of thousands of bricks per day.

Cement mortar.
Nowadays, the most common methods of bonding fired clay bricks is with cement mortar. Cement mortar is a hydraulic binder made from a controlled mixture of sand and Ordinary Portland Cement (OPC), with or without a variety of admixtures that improve the properties of the mortar. Plasticisers are used to reduce the water requirement of mortar and hence improve strength, or to improve the workability for a given water content. Bagged lime is sometimes added to improve workability. A typical mortar would be made up of 1 part OPC to 4 parts clean, well-graded sand, although the quantity can vary enormously depending on strength requirements.

Lime mortar.
Lime has been used as a building material for over 2000 years. To make a lime binder or mortar, calcium carbonate (limestone) is burnt at a temperature of about 900^oC to drive off the carbon dioxide and produce calcium oxide (quicklime). The quicklime is then ‘slaked’ (water is added) to produce hydrated lime powder. If further water is added a lime milk is formed and this is allowed to settle and mature for some time (months) in a pit to form a lime putty. This can then be used for a variety of applications including mixing with sand to form a lime mortar.

Lime mortars have certain benefits over cement mortars. The lime mortar slowly absorbs carbon dioxide from the atmosphere and this causes the mortar to harden as it returns to it’s initial state as limestone. This process can take many years and in the meantime the mortar remains plastic. This can be beneficial where flexibility is required or where other less flexible materials are used in close proximity.

5. Reinforcing materials

5.1 Choice of reinforcing material

A number of materials were considered for use as external reinforcing for the tank. There are examples of similar designs from Thailand of brick masonry and steel wire tanks (Vadhanavikkit[6]), and from Uganda of stabilised soil cement blocks with barbed wire reinforcing (personal correspondence with Mr. Kimanzi Gilbert of the Uganda Rainwater Association) and other examples of brick and barbed wire tanks from Botswana.

As mentioned in the introductory chapter it is important that the materials used for the tank construction be available widely in the areas where they will be built (less developed tropical regions) and that the materials be of low cost. Those materials mentioned above i.e. steel wire and barbed wire, as well a number of other similar materials are readily found for other construction and agricultural applications.

In the cases mentioned above there is some concern (on our part) as to the control of the application of the reinforcing material and the amount of tension that can be achieved and maintained. Tying knots in wire, and maintaining tension at the same time, is a difficult business, especially when the wire needs to be tight against the surface of a wall. We are therefore considering packaging strap as an alternative for the following reasons:

- it is widely available in any country where there is a reasonable manufacturing base;
- the strap is ideally suited to this application with a high tensile strength and flat surface that lays flat against the brick face;
- it is cheap once the tools have been purchased (even the tools themselves are not prohibitively expensive for a mason of reasonable standing). More research is currently underway into prices of strap and tools in developing countries;
- application is easy with the dispenser, tensioning and crimping tool
- a high pre-tension can be easily applied to the strap applying compression forces to the masonry.

Depending on feedback from a number of countries (Sri Lanka, Uganda, India, Kenya in particular), we will later reassess the suitability of this material and possibly look at alternatives.

5.2 Spacing of steel straps

Following on from Chapter 2.1 we are now able to calculate the spacing for the steel strapping, assuming pure hoop stresses are induced by the outward water pressure.

Virtual wall thickness, $t = \frac{w \times t_s}{s}$ .... *Equation 5*

where, w = strap width
t_s = strap thickness
s = maximum strap spacing

Maximum strap spacing, $s = \frac{2\sigma_{ma} w t_s}{\rho g H d}$ .... *Equation 6*

For the tank considered in Table 1, we can rearrange Equations 1 and 5 to give Equation 6. If we specify a value for maximum acceptable hoop stress in the strap, σ_{ma}, of say 150 Mpa (one third of the yield strength of the steel), we can easily calculate the strap spacing using a simple spreadsheet calculation. Table 3 below is the data output from such a spreadsheet calculation for a small variety of tanks of a similar size and profile to that being considered.

	Distance from top water level						
Tank diameter (m)	<0.5m	0.5m - 0.75m	0.75m - 1.0m	1.0m - 1.25m	1.25m - 1.5m	1.5m - 1.75m	1.75m - 2.0m
1.00	398	265	199	159			
1.25	318	212	159	127			
1.50	265	177	133	106	88		
1.75	227	151	114	91	76	65	
2.00	**199**	**133**	**99**	**80**	**66**	**57**	**50**
2.25			88	71	59	50	44
2.50				64	53	45	40

Table 3 – Maximum strap spacing for a variety of tank diameters and depths

It can be seen that the minimum strap spacing (at the base of the wall) is less than the thickness of one course of bricks (80mm) and so two straps will be used on each course of bricks, giving a spacing of approximately 40mm.

6. Laboratory experiments

6.1 Introduction

The experiments described in this chapter were carried out at the University of Warwick between January and April 1999. Forming the basis for the tests were a number of brick masonry cylinder specimens built on a civil engineering ‘strong floor’. Such a specimen is shown in Figure 4 below. The specimens were of internal diameter 1.5m and varying height. These specimens allowed experimentation and observation of mortar behaviour, cracking of renders with a number of different additives, application and loading of steel packaging strap, as well as providing through practice an insight into the merits of the construction technique.

Figure 4 – Brick masonry cylinder specimen

6.2 Mortar observation – lime and cement mortars

Two types of mortar were used for constructing the cement mortar specimens; cement mortar and lime mortar. The main purpose of this test was to observe the following:

- the plasticity of the mortar and the associated ability of the brick masonry to ‘move’ in compression;
- the behaviour of the brick masonry under load – particularly the load transfer characteristics of the masonry;
- render behaviour (particularly cracking) when applied to each type of brick masonry.

The cement mortar is composed of the following:

Sand cement ratio	5:1
Water cement ratio	0.5 (i.e. water content 50% by weight of cement)
Mortar plasticiser	10% of water content

The lime mortar is made up of 3 parts well-graded sand to one part lime putty. No water is required.

The first part of the experiment consisted of simply observing the brick masonry when applying the steel strap for signs of movement and, secondly, observing the tension in the strap to determine the ability of the masonry to go into compression without distortion (i.e. that the masonry is sufficiently rigid). Early in the experiment it was decided that the lime masonry was insufficiently rigid in the early days after construction and that, without further investigation of its properties it would be unwise to use this material for this application. Although the characteristic property of lime mortar to remain plastic can, in some cases, be a positive advantage (we subsequently see that render cracking is greatly reduced - almost eliminated even - when using lime mortar), it does mean that a wall built using lime mortar will be far less rigid than its cement mortar equivalent.

Cement mortar gives a strong, rigid wall with no sign of movement during application of the strapping. The load that can be applied to a cement mortar, brick masonry tank is outlined in Graphs 1 and 2. The figures shown in this graph demonstrate the rigidity of the material at characteristic loads (and beyond). Detailed tests of this nature have not been carried out to date on the lime mortar specimen, but visually the wall of the lime mortar specimen can be seen to move when strapping is applied.

The behaviour of renders on each of the specimens is detailed in the following chapter.

6.3 Render – shrinkage and cracking

A number of tests were carried out to observe cracking of renders of different types on specimens constructed with two different mortar types (cement and lime mortar). The base render was made up of 4 parts sand to one part OPC and a water content of 0.4 (this was slightly exceeded in most cases to provide a workable render) Mortar plasticiser was added in all cases at 10% of water content. The render thickness varied due to the uneven surface onto which it was being applied, but in general the thickness remained within 5 – 15mm. After a day the wall was painted with a thin white paint to help with the location of cracks (see Figure 5 below). Any visible crack was measured using a hand held x20 microscope. Shrinkage was measured by observing the separation of the render from the wall at the top of the specimen. In

Table 5, separation is indicated as a percentage of the visible joint line over which separation occurred and the minimum and maximum value of separation width (in mm).

Figure 5 – Cracks in renders

The additives used during the tests are shown below:

- **Mortar plasticiser** – a proprietary plasticiser used for mortars and renders in the building industry.
- **Re-in fibre** – a polypropylene fibre of 50 micron square cross-section and 6mm in length. This is a UK construction industry building material used for preventing cracking in thin renders and screeds.
- **Febond SBR** – a proprietary waterproofing solution for use in renders and for other application. It is a styrene-butadiene co-polymer latex specifically designed to improve water resistance and durability.

Five render types were tested. All were cement based renders. These are listed below in Table 4.

Render type number	**Sand : cement ratio (by weight)**	**Water cement ratio (by weight)**	**Mortar plasticiser content (as %age of water)**	**Other additive**	**Curing regime**
01	4:1	0.4 – 0.5	10%	none	basic*
02	4:1	0.4 – 0.5	10%	none	7 days**
03	4:1	0.4 – 0.5	10%	re-in fibre	basic*
04	4:1	0.4 – 0.5	10%	re-in fibre	7 days**
05	4:1	0.4 – 0.5	10%	sbr	7 days**

Table 4 – composition of renders used for cracking and shrinkage tests
*** basic infers no special curing regime employed – render left to cure in open air**
**** 7 days curing under soaked Hessian cloth**

Cement mortar used to lay bricks

Render type (see Table XX)	Ave. crack length (mm)	Crack length per (mm /m^2)	Ave. crack width (mm)	Maximum crack width (mm)	Separation *
01	70.37	1135	0.13	0.35	90% 0.05 – 0.75mm
02	54.5	2546	0.29	0.55	10% 0.1 – 0.75mm
03	31.0	53	0.1	0.1	90% 0.05 – 1.5mm
04	No test				
05**	No test				

Lime mortar used to lay bricks

Render type (see Table XX)	Ave. crack length (mm)	Crack length per (mm /m^2)	Ave. crack width (mm)	Maximum crack width (mm)	Separation *
01	No test				
02	0	0	0	0	no separation
03	No test				
04	0	0	0	0	no separation
05**	69.33	2207	0.32	1.3	no separation

Table 5 – Cracking in cement renders – values for a number of test results after 7 days
*** Separation given as a percentage of separation at the visible joint around the perimeter at the top of the specimen wall. Variation in crack width also given.**
**** although manufacturers instructions were followed carefully there is some concern about the validity of these results – possibly an incorrect quantity of SBR was added to the render.**

The results given in Table 5 lead us to a number of tentative conclusions:

- the re-in fibre (renders 03 and 04) significantly reduces cracking in renders;
- improved curing of renders on cement mortar wall (renders 02, 04 and 05) helps prevent separation at the cost of increasing cracking i.e. adhesion to the wall improves causing greater cracking – this is advantageous if we then seal the cracks with a nil coat (cement slurry) or other proprietary sealant ;
- separation of render is much greater on cement mortar walls due to the rigidity of the wall. In the case of lime mortar, the wall moves as the render shrinks, preventing cracking – as mentioned in an earlier chapter this is very beneficial for achieving crack-free renders but not so beneficial in terms of loss of rigidity.
- no conclusions are made about the characteristics of SBR render due to uncertain results

Further work is required to gain a better understanding of renders and their behaviour on internal tank walls. This work is outlined in the final chapter of this report.

6.4 Reinforcing straps – initial tensile strength tests

Initial tensile strength tests were carried out on a number of packaging straps to determine the strength of each (manufacturers specification was not available for all). The aim of the tests were to investigate the strength of woven polypropylene strap and the effect of crimping steel straps. The tests were carried out at the Universities civil engineering laboratory using the tensometer machine (see Figure 6).

Without going into detail here it can be stated that the *polypropylene* strap was insufficiently strong for the application under consideration with an Ultimate Tensile Strength half that of steel with ten times the strain.

In all cases the singly crimped steel band broke at the crimp at well below maximum UTS. During practical tests on the brick specimens, in which the strap had been fitted with two crimps, the strap broke remote from the crimp at a value close to UTS.

6.5 Reinforcing straps – applying the strap

This experiment aimed to investigate:

a) the pre-tension set up in the reinforcing straps during application with the tensioning tool - as mentioned in chapter 2 it is necessary that sufficient pre-tension exists in the strap after application to support the masonry in compression and prevent cracking when the tank is initially (and subsequently) loaded.
b) the distribution of the tension in the strap upon application – this experiment was to test the assumption that circumferential tension in the strap would vary due to the friction between the wall and the strap, from a maximum near the tensioner, to a minimum on the opposite side of the tank.

The experiment involved measurement of the strain in the reinforcing strap using strain gauges. The strain gauges had been calibrated beforehand (see Figure 6 below) so that the load in the strap could be derived directly and accurately from the strain values. Three strain gauges were placed on a single strap, at 0, 90 and 180 degrees around the specimen circumference, and readings taken as the strap was applied (see Figure 7).

Figure 6 – Calibration of strain gauges using tensometer

Figure 7 – Showing strain gauge fitted to the steel strap

Box 1

Applying the steel strap

The strap is applied to the brick masonry specimen using a manually operated tensioning tool. Once fully tensioned the strap is crimped (see Figure 9 below) using specially designed crimps and crimping tool and then the tensioning tool is removed. It can be seen from Figure 8 below that the tensioning tool holds the strap away from the wall in order to allow access for the jaws of the crimping tool. After initial experiments there was some concern about the loss of tension when the tool is removed.

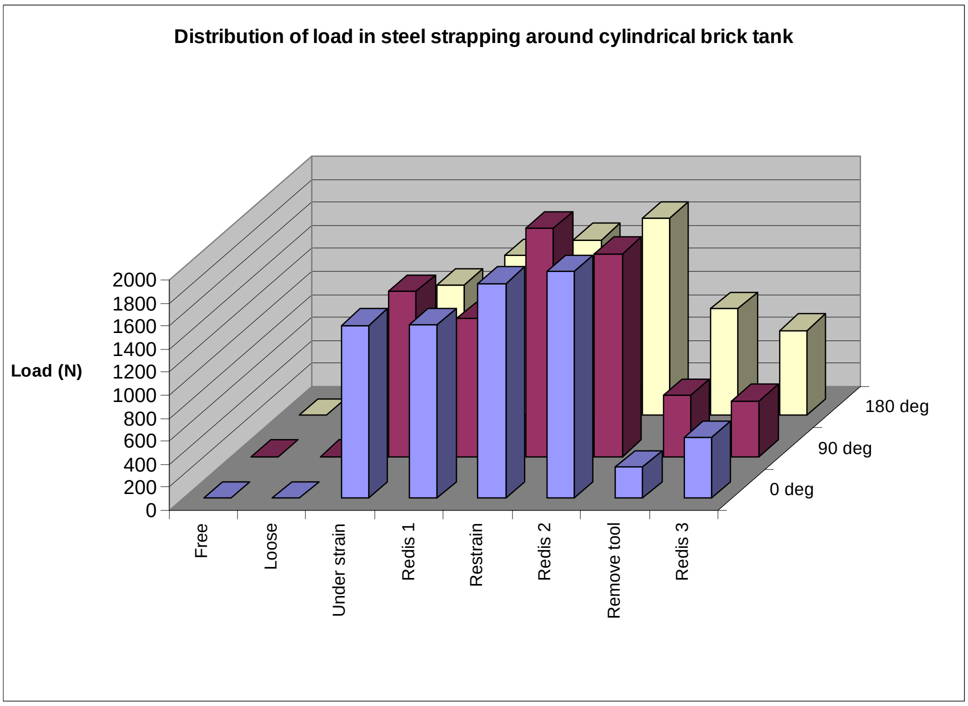
Graph 1 shows the steps taken during the experiment and the load registered by the strain gauges. The term ‘redis’ in the graph means redistribution of the load. This was achieved by using a screwdriver to prise the strap away from the masonry slightly (moving around one brick at a time) to allow the tension in the strap to be redistributed.

Box 2

Strap pretension required to balance water pressure forces and prevent tensile stress being set up in masonry

- From Table 1, maximum hoop stress in steel due to water pressure is 114 Mpa
- Area of cross section of steel strap = 6.5mm^2
- Tension required in strap = 6.5 x 114 = 741 N

An analysis of the graph clearly shows the increase of tension in the strap as the strap is tightened and also shows that a certain amount of redistribution of that load takes place during the ‘redis’ phase. The drop off in tension during removal of the tool without packing (as illustrated in Figure 8) is completely unacceptable with the final tension being a small fraction of the tension created by the tool and insufficient to put the masonry into compression (see Box2). We see, however, that the tool is capable of tensioning the strap sufficiently – values of almost 2000 N being achieved during the tensioning phase.



Graph 1 – Distribution of load in steel strap around cylindrical brick tank during application

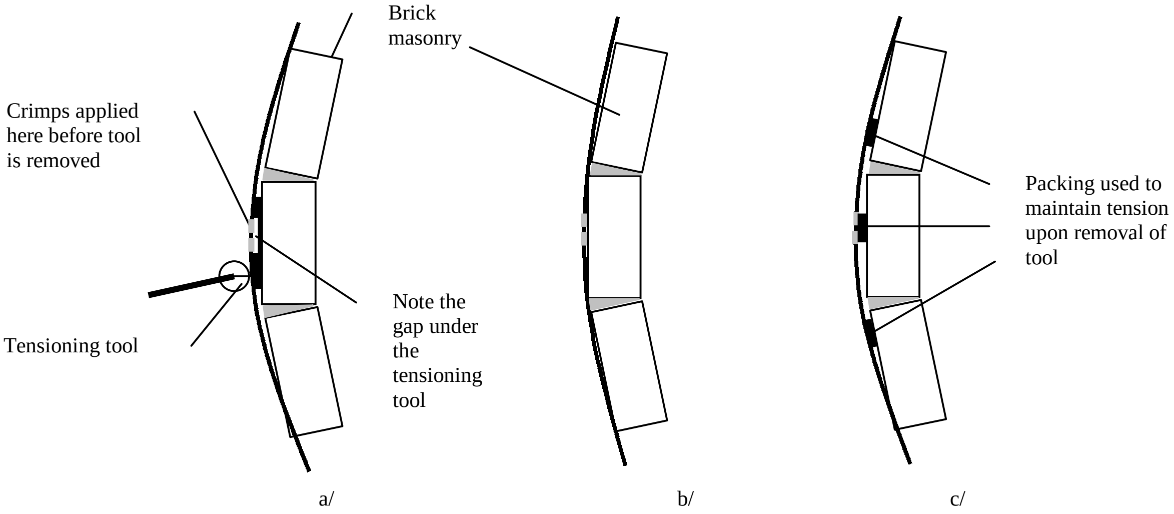
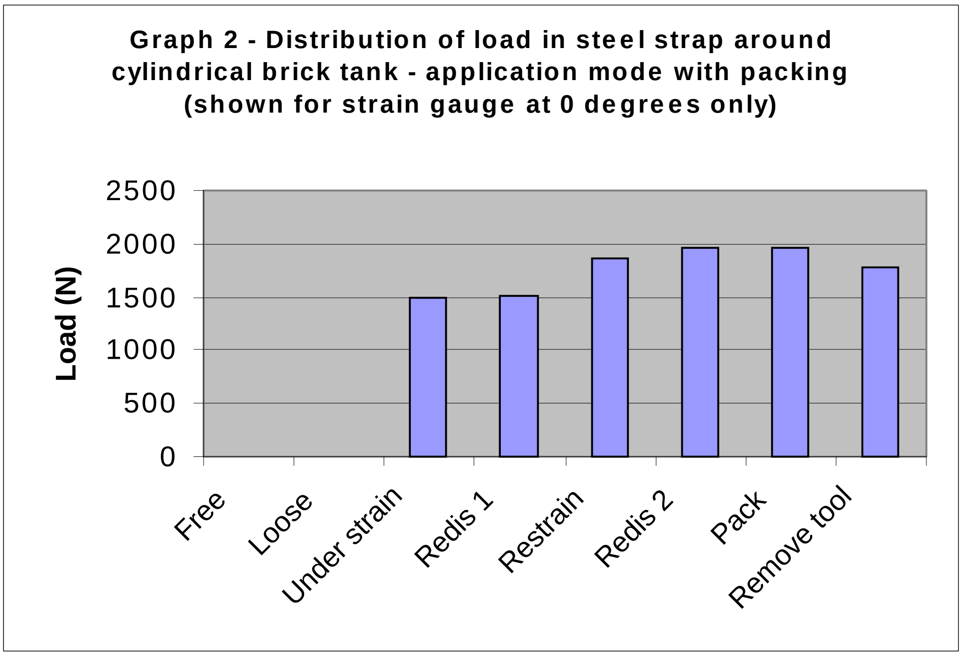


Figure 8 – showing tensioning and crimping arrangement for steel strapping a/ during the tensioning and crimping process b/ when crimping is complete and the tensioning tool has been removed and tension reduced c/ maintaining tension by using packing

Figure 9 – photograph of straps showing crimps

Figure 8 shows the method used to pack the strap to prevent loss of tension upon removing the tensioning tool. If this process is carried out the tension can be maintained as shown in Graph 2. In this case the tension, at 1777 Newtons, is more than double that required to prevent the masonry going into tension upon pressure loading. Practically, this involves placing some packing material behind each strap as it is applied. Further work is needed to define a practical method and a suitable material for this purpose.



Graph 2 - Distribution of load in steel strap around cylindrical brick tank - application mode with packing (shown for strain gauge at 0 degrees only)

6.6 Reinforcing straps – loading and ultimate tensile strength

A test was carried out to determine the maximum load that can be applied to an externally reinforced brick tank. The aim of the test was to simulate water pressure acting on the wall of the tank and to observe the behaviour and failure mode of the tank as pressure was increased. Ideally the test would have been carried out using a sealed tank that could be pressurised to the point of failure but this was not practical at the University, especially indoors on the civil engineering strong floor. To simulate water pressure a steel expansion ring was manufactured as shown in Figure 10 below. The ring was made from 3mm mild steel to provide enough rigidity to prevent buckling but enough flexibility to take up the shape of the interior surface with which it came into contact. The ring was expanded using two 1 tonne hydraulic jacks, as shown in Figure 11. A load cell was placed in series with the jack to measure the applied load and is also shown in Figure 11 (this had been calibrated earlier). The ring spanned 2 courses of bricks that with hindsight, should have been free floating, but were not. The straps on the specimen were fitted with strain gauges at 0^{o}, 90^{o}, and 180^{o} to measure the stress induced in the strap. Thus we could monitor the increase in load in the strap due to increased (simulated) water pressure.

Figure 10 – Specimen under test, showing expansion ring

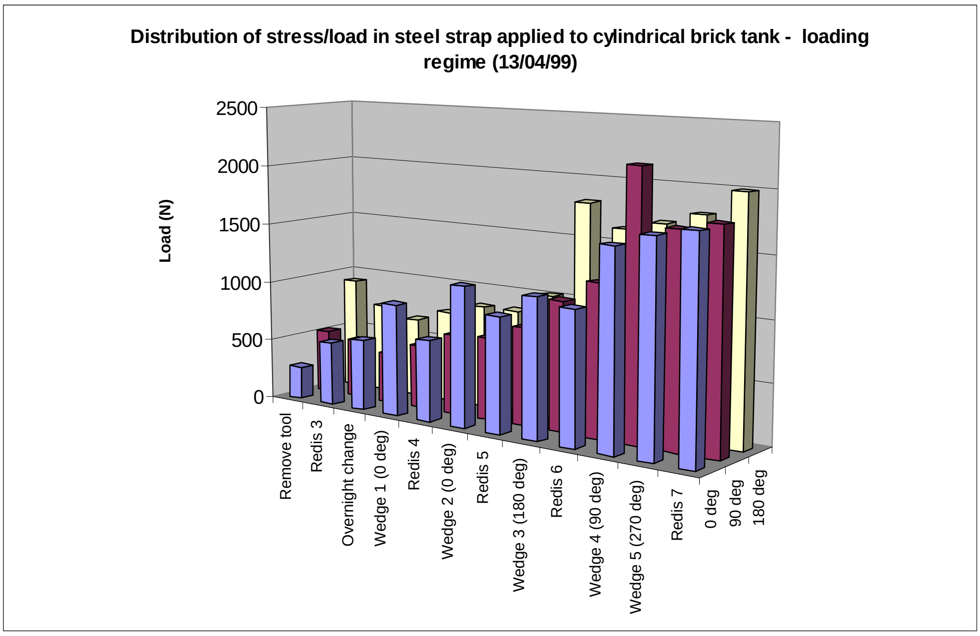
As the hydraulic jacks were extended the ring slowly expanded putting the strap into tension. The jacks continued to be extended until the straps failed and the masonry broke. During this time observations were made of the following:

- the applied load
- the cracking of the render
- the cracking of the masonry
- the strain (and hence load) in the strap

Graph 3 (histogram) shows the general trend of increased load in the straps as the expansion ring is opened. Noting the horizontal axis of the histogram we see that jack pressure in the expansion ring is not rising continuously. Graph 4 shows a clearer representation of what is happening in one of the straps – namely the strap at 90^{o}. There are some interesting phenomenon to observe:

1. Firstly, the force in the expansion ring is much greater that the force in the strap. There are a number of possible explanations for this:
    - the two courses of brick under test are not free-floating and so some energy is being required to stress the lower courses of bricks
    - in the early stages of the test, until the masonry fails, some of the load is taken by the masonry itself
    - there are four straps fitted on the specimen, all of which are accepting some of the load – two strap are directly under load

2. We see two distinct regions (see Graph 4 below), one where the pressure in the ring rises linearly with the load in the strap (region 1) and then a region where the pressure in the ring rises little, and indeed starts to fall, as the load in the strap increase and the ring continues to expand (region 2). This can be explained as follows (either or both of the following acting at any time):
    - as the cracking in the specimen worsens, the energy that was taken up ‘bending’ the lower part of the wall is now redistributed in the upper part of the wall (the test area) as the joint between the two fails.
    - the masonry breaks locally, and there is a significant repositioning of the brick (local to the ring) within the masonry as the ring expands further.



Graph 3 – Loading cylindrical tank using expansion ring

3. Large vertical and horizontal cracks appear (see Figure 12):
    - the horizontal cracks are due to shear as the upper section of the specimen wall shears away from the lower section
    - the vertical cracks are obviously the result of tension as the pressure is applied to the ring

Figure 11 – Specimen under test, showing close up of hydraulic jack and load cell

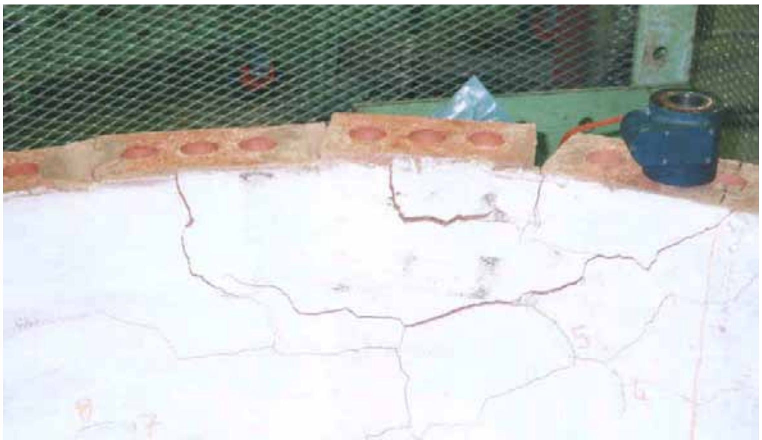
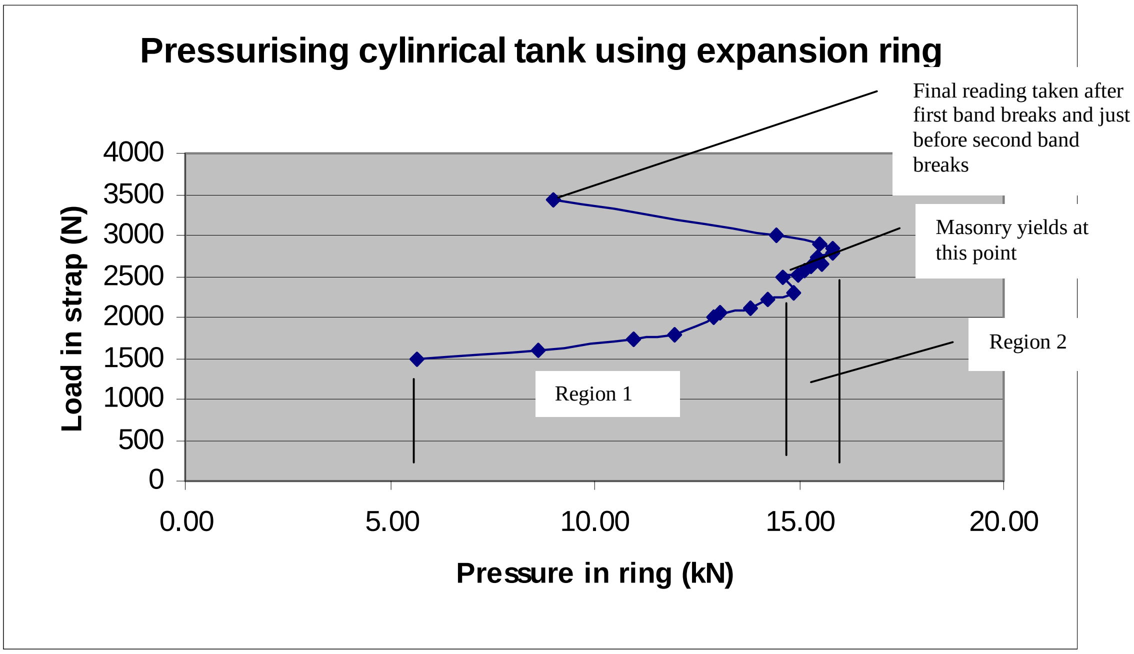


Figure 12 – Cracking in specimen after pressure test



Graph 4 – Pressurising cylindrical tank using expansion ring – strain gauge readings at 90 degrees

In conclusion it should be strongly noted that although what we see is a realistic representation of what was going on in the test specimen during the test, and is of some value to us in understanding the behaviour of cylindrical tanks, it is not what we were looking for! This was due to improper experimental design. A further test will be carried out on a free-floating specimen i.e. a specimen set on a sliding ring to simulate an elemental horizontal slice of tank. This will hopefully yield results that will be of more interest to us.

7. Conclusions

The general conclusion is that the single skin, externally reinforced, brick tank is a viable alternative to more costly tank types available at present. The experiments carried out so far have shown that the construction technique adopted is sound, but further work is still required to achieve a full analysis of the ideas under discussion which will lead to a final design and set of construction guidelines for this type of tank. The work that still needs to be carried out is outlined in the following Chapter

8. Further work to be undertaken

The following have been identifies as areas needing further work:

From section number:	Description of work
1.2	Research into plastic linings for tanks
2.1	Carry out full computer analysis of stresses in cylindrical tanks
2.3	Analysis of stresses in foundations of tanks Foundation design
2.4	Analysis of stresses due to other forces (e.g. wind, earthquakes)
5.1	Research the alternatives to steel strap e.g. methods of adequately tensioning steel or barbed wire
6.2	Further tests on lime mortar specimens - strap application and loading tests
6.3	Further tests to characterise the behaviour of renders – cracking, shrinkage and adhesion with a variety of admixtures and curing regimes
6.6	Tests of free-floating brick cylinder specimens using both cement and lime mortars
Other	Preparation of design and construction guidelines for this style of tank. Construction of full size tank to look at the following: ▪ tank construction techniques ▪ stress analysis in full size tank – including cyclic loading and temperature effects ▪ shrinkage and cracking due to water pressure loading ▪ leakage

9. References

1. Stulz, Roland and Mukerji, Kiran, Appropriate Building Materials, SKAT, Second impression, 1998
2. Watt, S.B., Ferrocement Water Tanks and their Construction, IT Publications, 1978
3. Holmes, Stafford and Wingate, Michael, Building with Lime, IT Publications, 1997
4. Gray W.S. (revised by Manning, G. P.), Reinforced Concrete Reservoirs and Tanks, Concrete Publications Ltd, 1960
5. Shigley, J. E. and Mischke C.R., Mechanical Engineering Design, McGraw-Hill International Editions, 1989
6. Vadhanavikkit, Chayatit, Brick Water Tank, Paper presented at the Regional Rainwater Catchment Seminar and Workshop, Khon Kaen, Thailand, IRDC, 1983

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/

February 1999

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. 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 0.5m. The cover pitch is 25°. 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

Reciprocal frame construction guidelines – for 2m diameter cover

Materials and tools

Materials	Tools
♦ 8mm reinforcing bar – 40m	♦ hacksaw
♦ tie wire – 0.5kg	♦ pliers
♦ chicken mesh (0.9m wide; 10m long; ½” mesh)	♦ tin snips
♦ sand	♦ vice (handy if available)
♦ cement	♦ masons trowel (small)
♦ mortar plasticiser	♦ masons trowel (large)
♦ water	♦ plasterers float
♦ plastic sheeting (reusable)	♦ shovel
	♦ buckets (2)
	♦ wheel barrow (optional)

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).
- The first step is to set up a jig for bending the reinforcing bar. The jig is made up of two pegs 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.

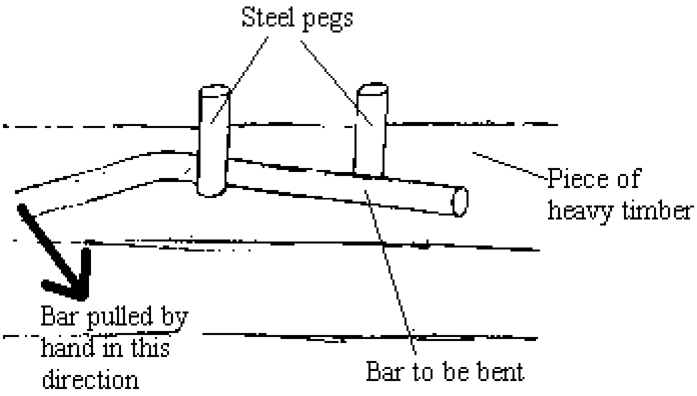


Figure 1 – Jig for bending steel reinforcing bar

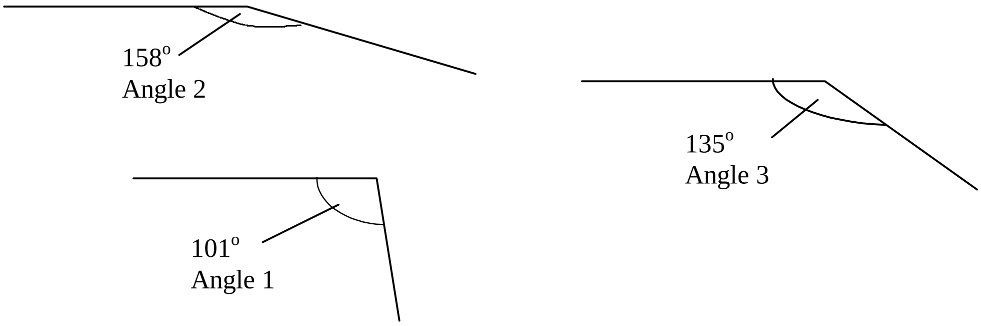
Tip:
When bending the re-bar it does not bend exactly where it makes contact with the jig peg. The bending takes place a cm or two on the pulling side. This has to be allowed for when bending. The bending radius can be quite large because of the thickness of the steel. This doesn't present any real problems 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° 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 1. 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.

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. There are eight in number and are bent in the jig to the dimensions shown in Figure 2. The cutting length is 1.33m. To aid the bending, the angles can be marked out on the ground (or on a bench) beforehand and then the bent steel can be matched against this. The angles to mark are:



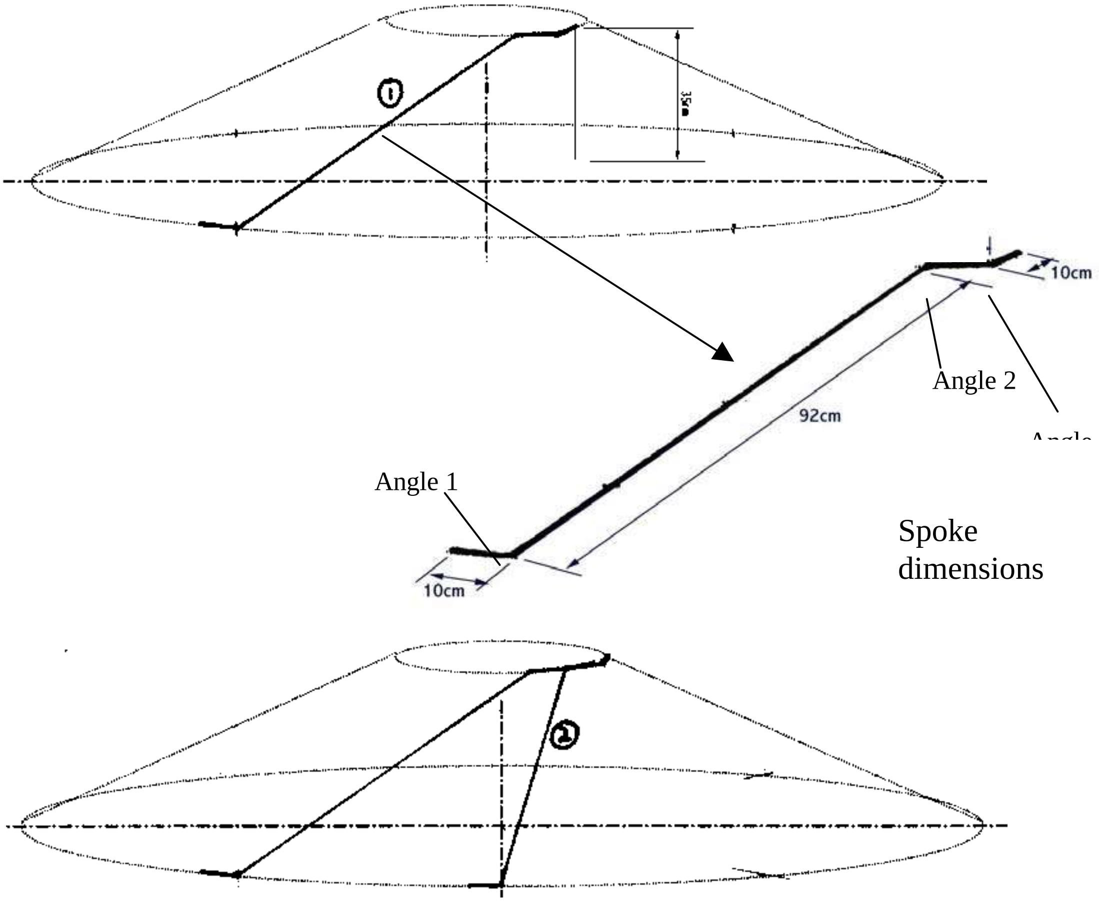
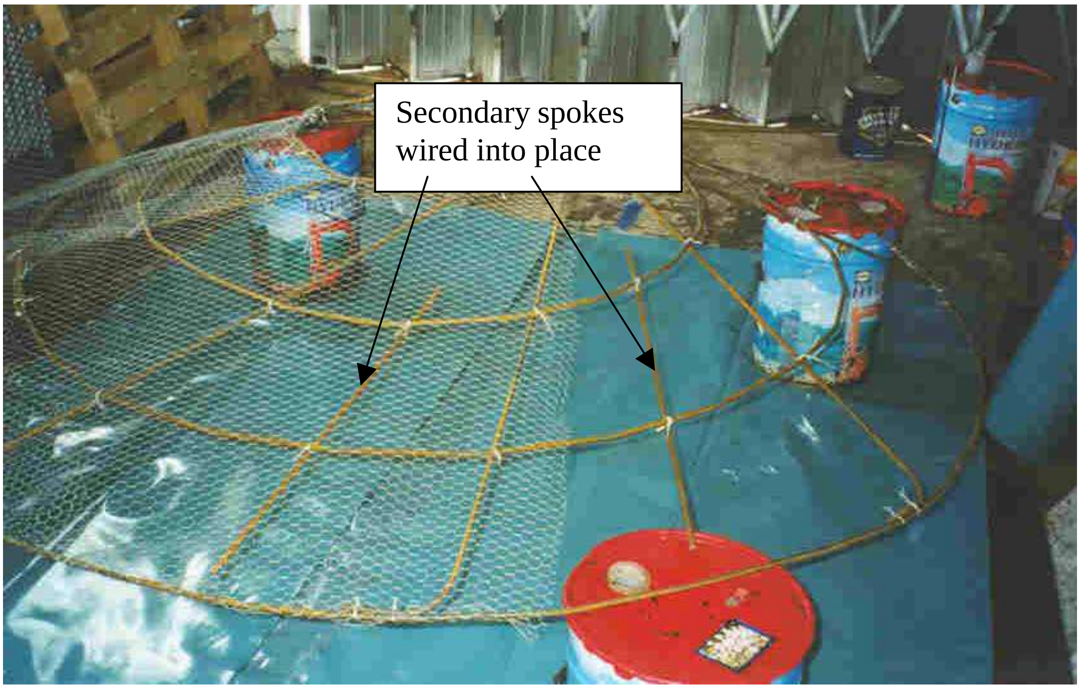


Figure 2. Dimensions and locations of frame spokes

- 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° and Angle 2 is bent.
- Eight secondary spokes are also cut to a length of 75cm. These are wired to the frame as shown in Figure 3 and support the mesh to reduce the ‘panel’ size.



Secondary spokes wired into place

Figure 3. Secondary spokes in place

- Now the spokes are placed one by one inside the outer hoop (as shown in fig 2.) 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. THERE IS NO INNER RING. This is made up as the separate spokes are joined together. (See Figure 4). 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 cover opening.

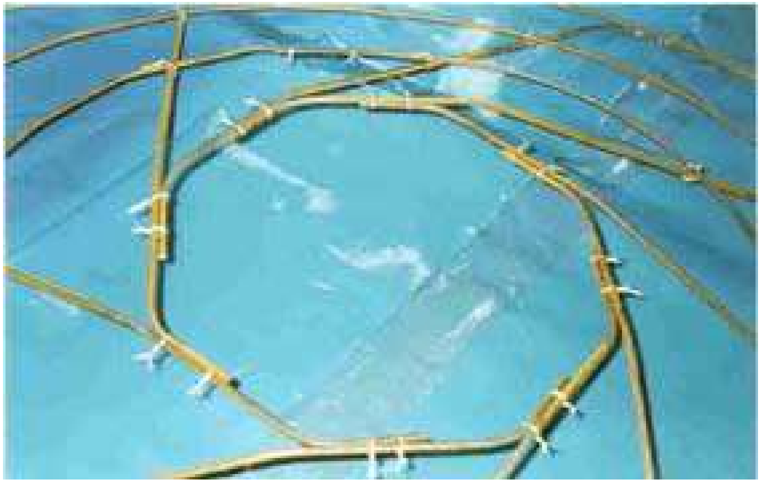


Figure 4. Showing the formation of the inner ring from individual spokes

- Tie the first spoke to the inner side of the outer hoop as shown in Figure 5.**(no 11).**

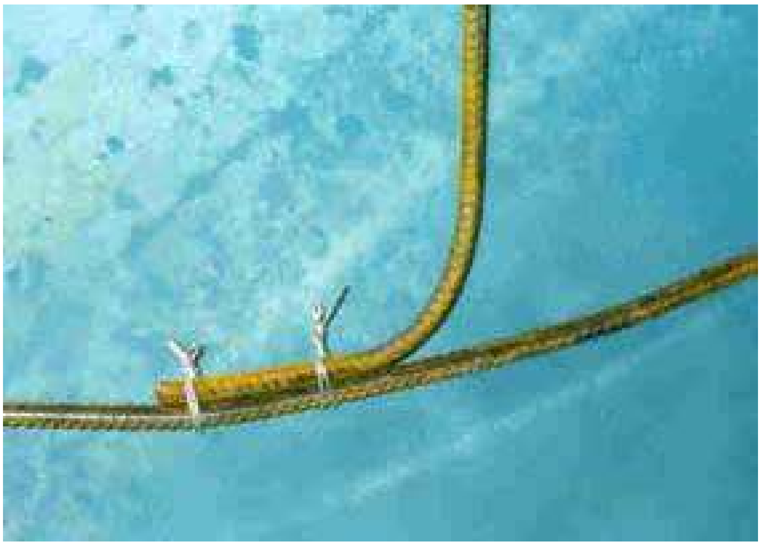


Figure 5. Showing arrangement for tying spoke to outer hoop.

- Place the next spoke 45° around the perimeter hoop (these spacings were marked earlier) and tie it to the first spoke as shown in Figure 6. Continue in this way until the final spoke is tied to the first spoke and all eight spokes are in place.

Figure 6. Arrangment for tying spokes to each other.

- Put the two inner hoops in position and tie them in place (Figure 7). 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 attached.

Figure 7. The frame with hoops in place.

- Use chicken wire of 0.9m roll width with a mesh size of ½ inch. Ten metres length is required. Two layers of chicken netting are applied.
- Eight pieces of chicken wire are cut to the dimensions shown in Figure 8. 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.

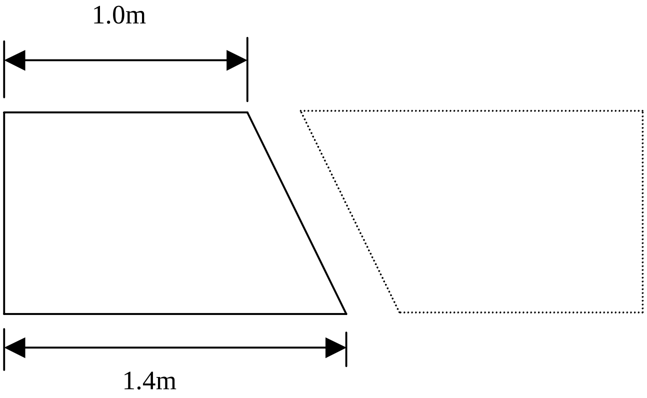


Figure 8. Cutting size for chicken mesh

- The pieces of netting are placed on the frame as shown in Figure 9 and Figure 10 and the overlapping edges are folded over and tied in place, pulling the wire as tight as is possible without distorting the mesh. 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.

Tip: a screwdriver can be used to pull the loose wires or end loops through holes in the mesh to tie the mesh in place.

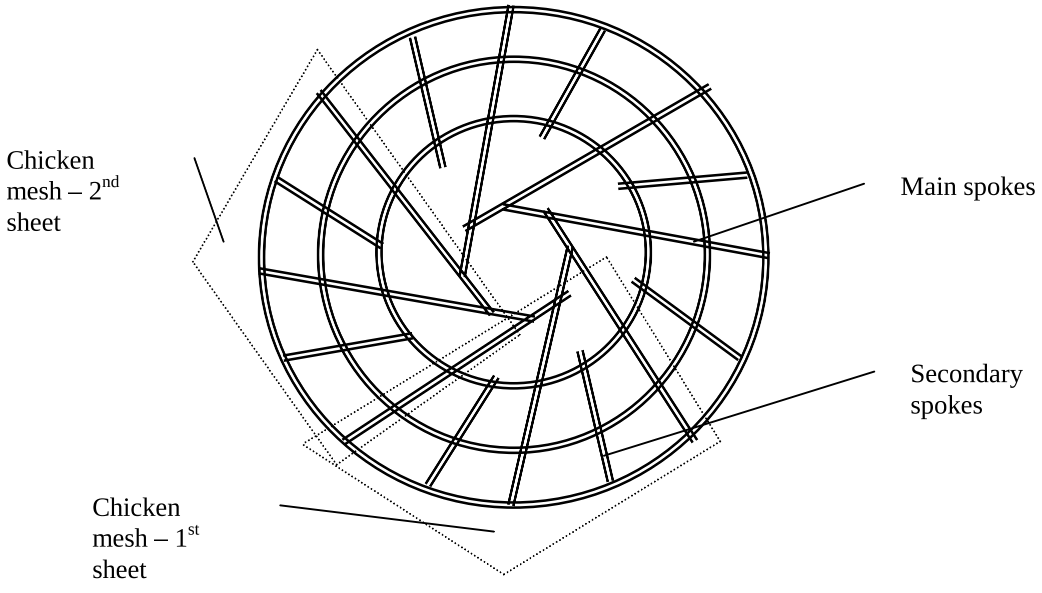


Figure 9. Pattern for application of chicken mesh

Figure 10. Applying the chicken mesh.

- When the first layer is complete start the second layer one spoke out of phase with the first and complete in the same manner.
- Carefully check that the mesh is folded as flat as possible and that both layers are close together. Tie the netting at regular intervals using the tie wire so that the netting is close to the rebar. Bend all tie wires into the plane of the cover. Remember that we are trying to keep the cover as thin as possible.
- The cover is now ready for the rendering (Figure 11).

Figure 11. Cover ready for rendering

Stage 2 - Rendering the cover

Materials

Sharp sand – 150kg
OPC – 30kg
Mortar plasticiser – 0.5 litres (soap powder can be used as a substitute)
Water - 20 litres (approximately)

Procedure

- 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 4 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 11 above).
- Render preparation: a mix of 3:1 (sand:cement by *volume*) 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. (**See guidelines for checking sand quality)**. 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 is required to improve the workability of the render. This 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.

Tip: use soap powder instead of mortar plasticiser. Experiment to find a suitable quantity.

- Keep mixes small because the render 'goes off' quickly. It may be wise to mix enough render for the whole job and then add water to small amounts as required.
- Applying the render: this is fairly simple to do. 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.

Figure 12. Applying render to the chicken mesh.

- Where the cover stands on the supports, leave a small section of the outer hoop un-rendered. Wires can be threaded through these gaps later for lifting the cover into place and any securing to the tank body can be done here.
- The outer edge of the tank should be rendered roughly as this will blended into the tank wall when it is put into place.
- Once the first layer of mortar has been applied the cover should be left for a day to allow the render to gain strength.
- The area within 10cms of the inspection opening should be roughened for keying in the lip. A strip 20cms wide from the outer edge to the inner edge should also be roughened to take the access strip (see Figure 13). Tie wires should also be poked through from the underside to tie the access strip reinforcing in place when the render has gained strength.

Figure 13. Showing finished access strip and old tyre used as former for access hatch lip.

When the rendered cover has been sitting for one day the following work can be done:

- Three lengths of steel should be cut and placed radially where the access strip is to be located. They are tied in place. The access strip is then laid using 3:1 mix render to a depth of 2cms. This is then scored to give grip when climbing to the access hatch.
- The lip of the inspection chamber is built up with mortar to a total thickness of 4cms. The 0.55m steel hoop of is placed on top of the existing render and the lip built up to the desired shape. A former can be manufactured to aid in this process or an old car tyre can be cut to give the correct diameter and supported in place (see figure 133 above). A greater lip thickness gives a greater feeling of security to people working on or in the tank.
- 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) is applied to top and bottom after two days of 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 14 below.
- The cover can be lifted into place by four strong people. Strong wire can be placed around the outer hoop where the cover was left un-rendered. Two strong timber poles can be placed through these wires. These poles are then lifted by four (or eight) people Alternatively two poles can be placed under the rim of the cover, but this makes it more difficult to set the cover down.
- 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.

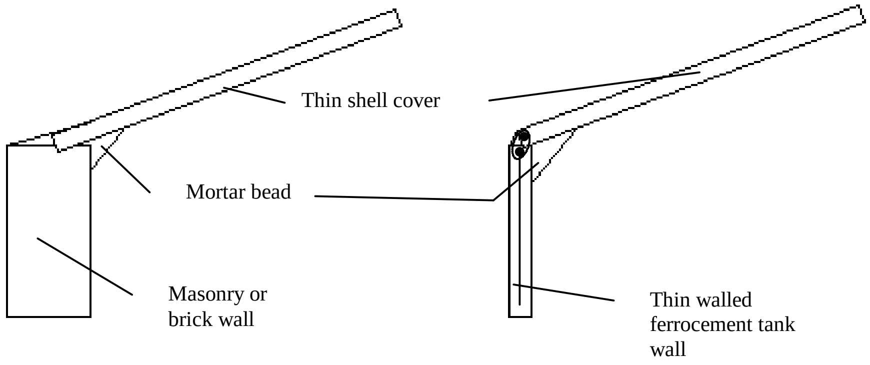


Figure 14. Blending the cover with the tank wall.

- A suitably sized ferrocement disc can be cast as the access hatch cover or another option used if so desired. This should be well fitting to prevent insects and contaminants entering the tank.

Tests for thin-shell, ferrocement tank cover

1. Point loading

The following load was applied with no adverse effect to the cover:

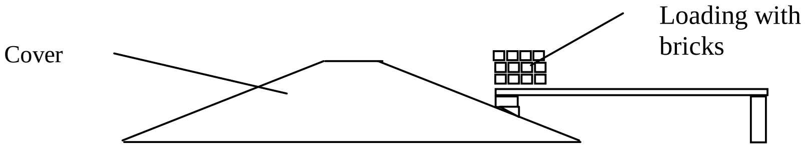


Figure 1 – Loading for point load test

Area of point load = 200 x 100mm = 20,000mm^2

Load applied 160 kg

i.e. 8kg / mm^2

2. Uniform loading

The cover was tested in two modes: constrained at the periphery to prevent slipping and unconstrained. In both cases the cover was loaded to approximately one thousand kg using house bricks (see Figure 4 below) and the deflection at the centre was less than 2mm in both cases, measured with a dial micrometer (Figure 3).

Figure 2 below shows the deflection against load for the constrained and unconstrained uniform loading.

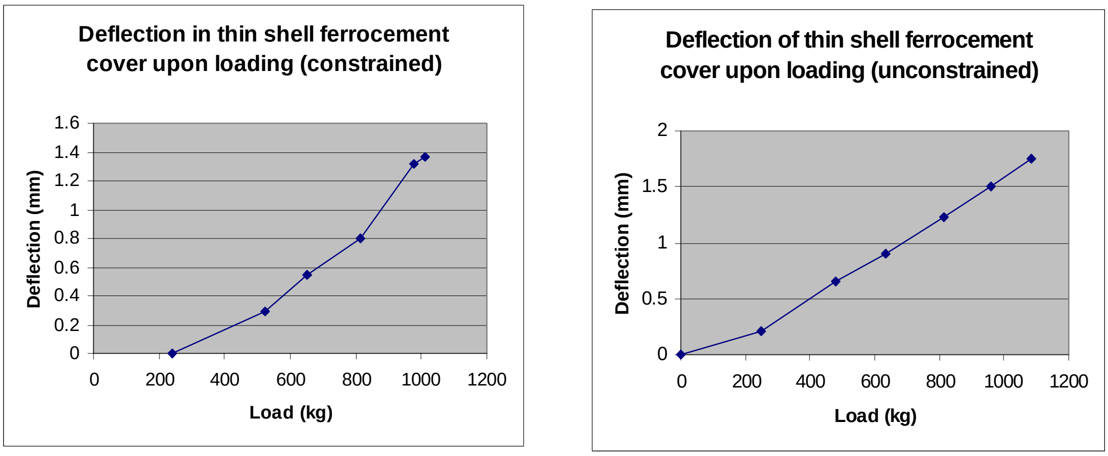


Figure 2 – Deflection of thin-shell ferrocement cover under load a/ constrained at edge b/ unconstrained

Figure 3 – dial gauge in place to test deflection of cover under load

Figure 4 – Thin-shell cover under a load of 1000kg of bricks – an evenly distributed load

The mortar dome cover – guidelines for construction

(Taken form a DTU working by Terry Thomas, Ben McGeever and members of URDT, Uganda)

1. Introduction

The mortar dome cover was developed as part of a collaborative project between the Development Technology Unit and the Uganda Rural Development and Training Programme (URDT), Kampala, Uganda. The cover is being reported here as an example of very low-cost technology for Roofwater Harvesting. The cover was part of a design of tank for underground storage of rainwater. The cover is also suitable for use on above ground tanks.

The Cover is a dome of mortar (containing almost no reinforcement) connected to a reinforced ‘ring beam’ set into the ground. The mortar dome and the ring are made at the same time over a carefully shaped mound of earth. Set into the mound are a bucket and a large plastic bowl. The bucket is to create a way for the rainwater to enter. The bowl is to create a hole to hold the plug in which the pump is set. It has to be large enough (e.g. 0.45 meter diameter) for a man to enter through. The 5 steps in making the dome will now be explained in turn.

2. Construction steps

Step 1 - Making the ‘template’ for shaping the dome

The shape of the mortar dome comes from the shape of the mound of earth it is built on. We therefore need a template to accurately form that mound of earth. Before building the first tank it is necessary to cut this wooden template. Once made, the template becomes a tool that can be used for many more tanks. The template must be the right shape and also strong enough to carry around and use without getting broken. It therefore consists of a piece of plywood, or thin planks, cut to that shape and stiffened by strips of thicker wood.

The right shape for the dome is approximately a upwards ‘catenary’. A downwards catenary is the shape taken by a chain hanging between two nails on a wall, so we mark the template out using such a chain (e.g. 1 or 2 lengths of bicycle chain) and then turn it upside down.

First cut the plywood so that it measures 125 cm by 100 cm and has square corners. Figure 3a shows 2 nails spaced 2.2 meters apart on a horizontal line drawn across a flat wall using a spirit level. Draw a vertical line down the wall from midway between these two nails and mark a short line (the ‘mark’) across it 80 cm below the horizontal line. Hang a light chain between the two outside nails and adjust its length until it just reaches down to this mark. (If you do not have enough chain to do this, see the alternative below.) Slide the thin plywood behind the chain without touching it, so that the long top of the plywood touches the left-hand nail and the right side of the plywood lies along the vertical line. With a pen, copy the shape of the hanging chain onto the plywood, remove the plywood from the wall and saw along the line you have just marked. (Using planks instead of plywood, first nail them rigidly to their stiffening bar so that they can be placed behind the hanging chain; then continue as for plywood).

Although it is easiest to make the catenary with two bicycle chains joined end to end, it can also be done with only one. This has to be hung so that it forms just over half the full U-shaped catenary: one end of the chain is attached to the left-hand nail, the other end is held low and pulled until the lowest point of the chain falls exactly over the 'mark'. You can now drive in another nail ('alternative nail position' in Figure 1) to attach the chain to, while you are copying the chain's shape onto the plywood.

It is necessary that the chain has no twists and that it hangs freely, otherwise it might take up the wrong shape. The right shape ensures that the mortar dome is strong (by being everywhere 'in compression'). Rope is not usually suitable instead of chain, because most ropes twist and are not heavy enough to hang properly.

To finish the template, stiffen it with good wooden strips. Now turn the template over so that the long straight side is on top and write the word 'TOP' next to it. Smooth the sharp corners to make it safer to carry.

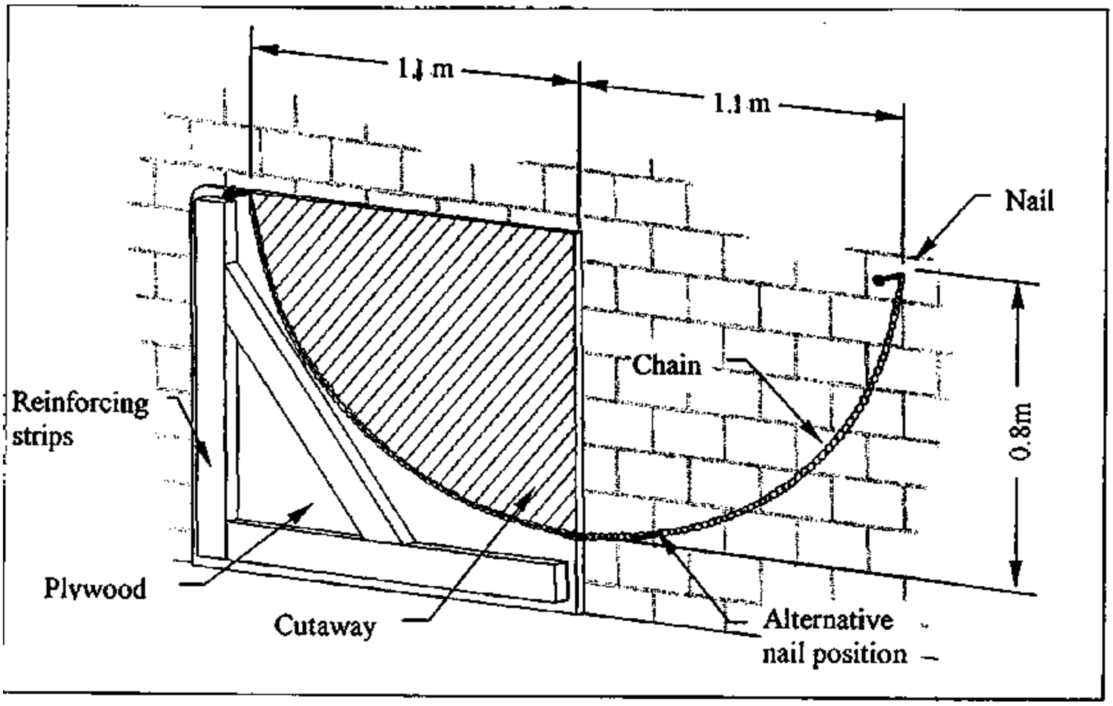


Figure 1 Making the template

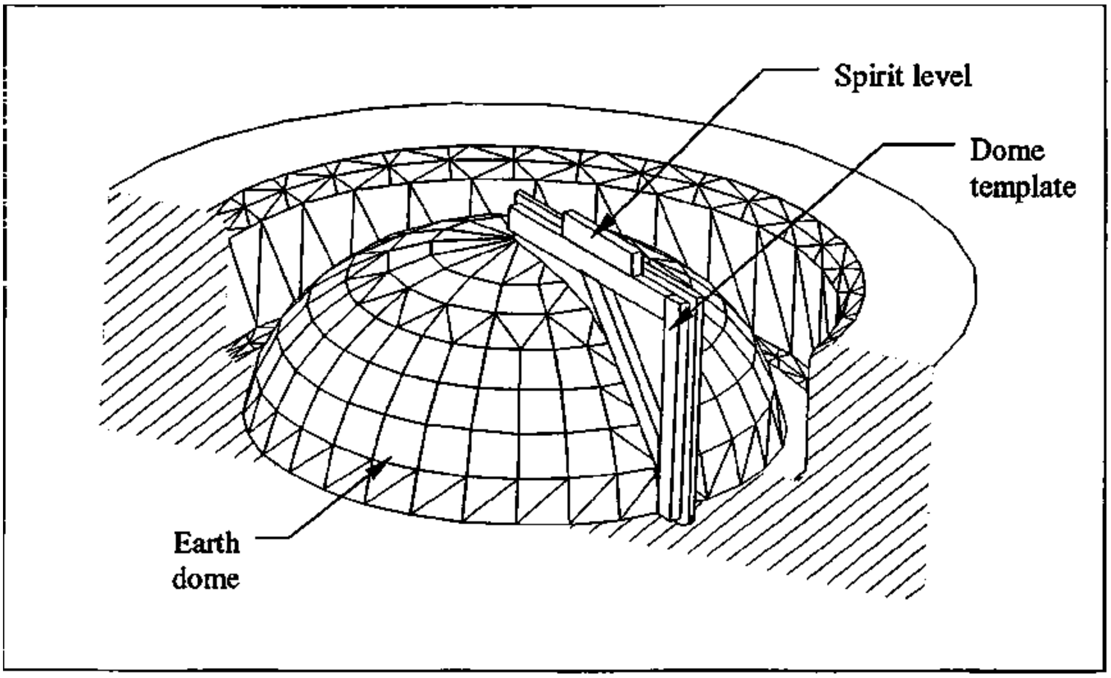


Figure 2 Forming the earth mound

Step 2 Marking out and making the trench and earth mound

The centre of the cover should be marked by a firm and vertical (use a spirit level) thin stake. Make a clear ink mark or cut a ring round the stake about 30 cm above the ground. Using a string 110 cm long looped once round the stake, mark out a circle of diameter 220 cm on the ground. This circle marks the inside edge of the trench in which the ring beam will be cast.

Dig a narrow trench (one hoe’s width) outside this circle and throw some of the soil into the centre round the pole. The idea is to dig down 50 cm leaving a mound of firm soil inside the ring rising up to the ring round the stake. The shape can constantly be checked using the template - now with ‘TOP’ at the top - placed against the stake and rotated like a scraper. The template should be kept level by means of a spirit level and at the right height with its lower corner touching the ring marked on the stake. This is shown in Figure 2.

If the mound is rough or loose or fissured by drying, it can be plastered with more mud and wooden ‘floated’ to make it smooth and firm.

Chicken mesh can be fixed in the trench so that later on it can be used to improve the joint between the mortar lining the tank wall and the mortar of the ring beam. Make a single strip of mesh by cutting a 1.5 meter length into 5 strips each about 18 cm wide and twist joining them end to end - the final strip should be adjusted to fit round the inside face of the trench like a ring. This ring should now be folded longwise into the vee-shape shown in Figure 3 and the inside half buried in the earth of the dome. To do this you will have to cut out some earth from the inside of the trench, place the chicken mesh then plaster back the earth again.

The trench is now too wide for the ring beam, so fill back a step 10 cm high round its outside so that its bottom becomes only as wide as your foot - about 10 cm. (You will need to walk round this slot when you are plastering the dome). This too is shown in Figure 3. The bottom of the earth dome that faces into the trench should be grooved with a trowel or stick: these grooves will be ‘copied’ onto the inner edge of the ring beam and will later help ‘key’ the plaster joint to be formed there.

Finally place the bucket and the basin on the dome as shown in Figure 4. The bucket (the inlet) should be on the side nearest the house, with its edge touching the stake. The large basin (for the excavation access and later the pump hole) should be on the other side of the stake and with its edge 25 cm from the stake. Weight down the bucket and basin with stones and push them into the soil mound so that they do not rock; local excavation will allow the bucket to be sunk a desirable 20 cm into the soil. Put a small fillet of mud round each bowl as shown.

Pull out the stake without disturbing the mound.

Step 3 Preparing the reinforcing bars

Use 6 mm bar; it does not matter whether it is round or knobbly. Make a ring whose diameter is 230 cm, folding over and linking the ends and hammered the link tight so that there is no play in the joint. This ring will take about 8 meters of bar. Test that the ring will sit in the middle of trench without getting close to either its inner or outer edge.

Make two further such rings but much smaller, one each for the bucket and the bowl. Each ring should have a diameter bigger than its bucket/bowl so as to leave a clearance of 3 cm all round it where it enters the soil dome.

Step 4 Casting the ring beam and the pierced dome

The dome and the ring beam that forms its bottom edge are made of strong mortar in the manner shown in Figure 5. The mix is 1:3 (cement : sand) and 2 bags of cement should be ample. Concrete, mixed 1:4:2 (cement : sand : small sharp aggregate), is an alternative where such aggregate is available or can be made; a concrete dome needs only 1.5 bags of cement. (Concrete is more difficult to place as a plaster than is mortar and the surface finish achievable is not so good.) The ring beam is about 10 cm x 10 cm, while the rest of the dome is covered with 2 cm of mortar. However round the bucket and bowl this depth is increased locally to about 8 cm to make a good lip to hold the bucket/bowl and to cover the reinforcing rings there. As usual all three rings of reinforcing bar must be in the middle of the mortar with several centimetres of cover on all sides. So they must be placed as the mortaring progresses. The big ring, in the ring beam, is therefore placed only after 5 cm of mortar is already in the trench.

It is important to check the mortar thickness nowhere gets less than 2 cm as you work up the dome. There should be no joints in the mortar: the whole dome and ring beam should be made (plastered) in a single session with a mix that is dry enough not to slump. As the soil dome may suck water out of the mortar or concrete applied on top of it, it should be thoroughly wetted before plastering the dome starts. Moreover in a hot climate it is wise to do this plastering early in the day so that the new dome can be covered with wet straw before the sun gets very hot.

Step 5 Curing the dome

As soon as the mortar is firm, gently remove the bucket and basin from the top of the dome.

Once the dome is cast it needs to cure under moist conditions for 14 days to develop a high strength. The simplest way to ensure it is kept moist is to cover it with plenty of grass and douse this with a jerrycan of water every morning and afternoon.

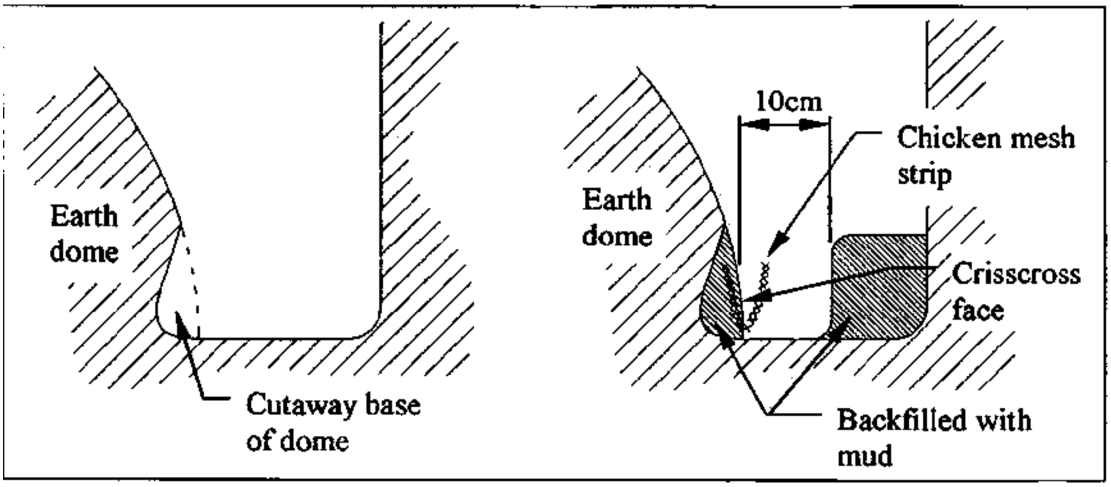


Figure 3 Details of trench (mesh is optional)

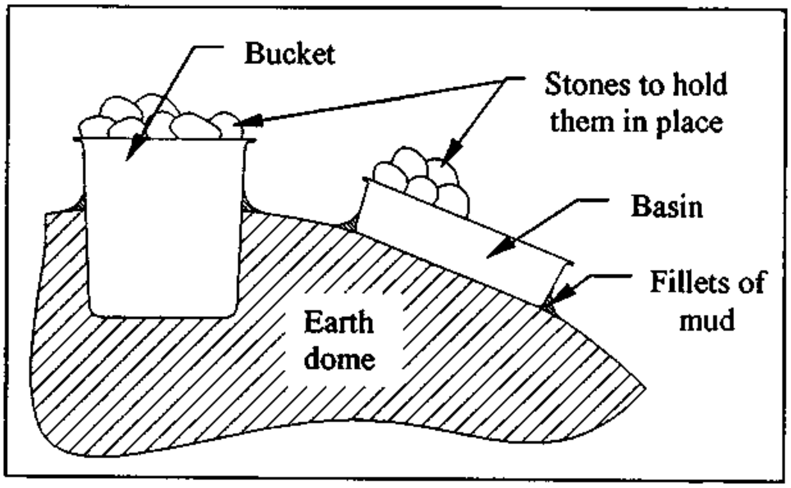


Figure 4 Basin and bucket on mound

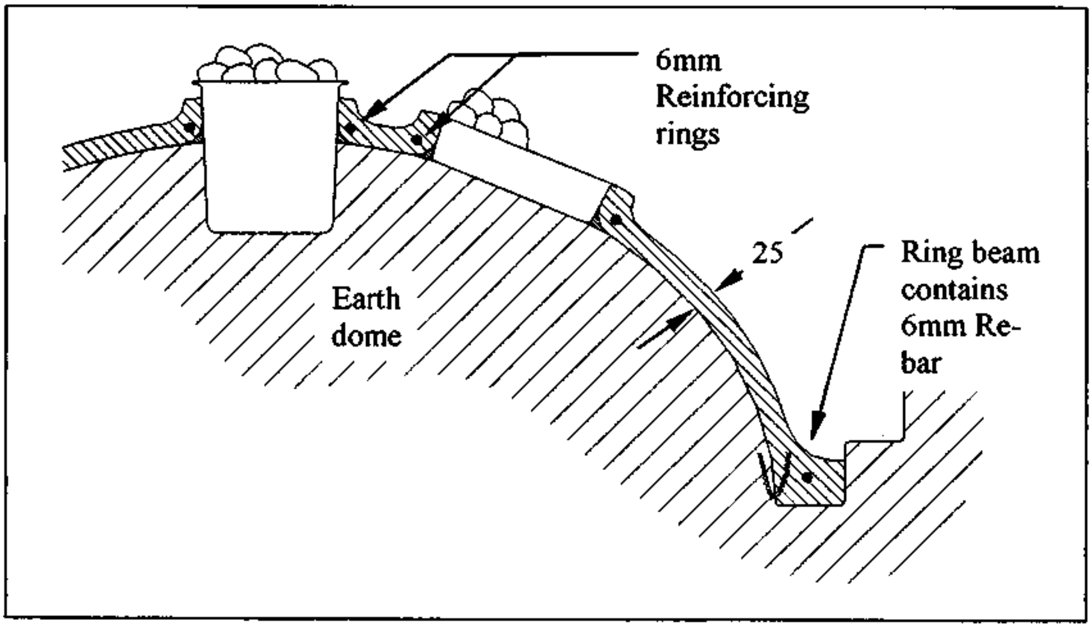


Figure 5 Completed dome