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SUSTAINABILITY OF WATER AND SANITATION SYSTEMS

Ferrocement water storage tanks

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FERROCEMENT IS A form of thin concrete reinforced with layers of continuous and relatively small diameter mesh. It is usually made from a mortar of Portland cement and sand applied to steel reinforcement which is often provided in the form of small aperture wire mesh and / or closely spaced small diameter bars or wires. In conventional ferrocement this relatively close spacing of reinforcement throughout the mortar creates a composite material which behaves almost homogeneously; very differently to the way reinforced concrete behaves. However, many so called ‘ferrocement tanks’, although using small meshes, do not have reinforcement widely dispersed through the mortar, but they still function successfully. Although, perhaps, such tanks should strictly be referred to as ‘wire reinforced mortar tanks’, in this paper they will be included within the term ‘ferrocement tanks’.

The aim of this paper is to publicise the advantages that ferrocement has over other materials commonly used for constructing water storage tanks. It also aims to give basic information on the different construction methods which can be used for ferrocement tanks. Further references are suggested for readers who want to examine some published tank designs and to experiment with using this material.

Because of the lack of space , this paper has focused on cylindrical tanks. A hemispherical excavation lined with ferrocement and covered with a domed roof is one cost effective alternative (Nissen-Petersen 1992b). For smaller storage volumes jar shapes are appropriate.

Comparison of ferrocement tanks with other types of tank

Most medium and large sized above-ground tanks around the world are made from one of the following:

- Conventional building materials, particularly concrete and brickwork (both reinforced and unreinforced) but also stone masonry.
- Steel (flat or corrugated sheets, welded, soldered or bolted together).

Advantages of ferrocement

This cost effectiveness of ferrocement over conventional materials results from some of the following factors:

- Ferrocement tanks are usually cheaper than tanks of fibre reinforced plastic, steel etc. because these other materials have high manufacturing costs. Ferrocement has better corrosion resistance and lower maintenance costs than steel.
- Ferrocement tank designs usually make more effective use of cement and aggregate than tanks built using conventional materials. A number of well tested ferrocement designs for capacities between 20 and 50 m^3 use less than 1.3 bags of cement per m^3 of water stored. Capacities of between 5 and 20 m^3 can be built with 1.5 bags / m^3 or less. (Unfortunately, in some situations the sand needed for ferrocement may be more expensive than that used locally for bricklaying or concrete, reducing these cost savings.)
- For ferrocement tanks there is no need to purchase and transport large quantities of masonry stones, aggregates or bricks. (However there will be the additional expense of purchasing reinforcing mesh for the ferrocement.)
- The cost of reinforcing bars needed for large concrete and brickwork / blockwork tanks will be saved and this money can be used towards the purchase of wires and meshes for the ferrocement tank.
- Ferrocement has other advantages over reinforced concrete. Some of these arise from the differences between these two materials which are listed Table 1 and / or described in the next section.
- Although ferrocement construction is labour intensive it requires relatively low levels of skill and few tools. Thus it is ideal for use in many developing countries.
- The tanks can be rapidly constructed. Typically, a 30m^3 tank can be completed in 10 - 13 days with a team of 10 or less workers.
- The raw materials (steel wire and mesh, sand and cement) are widely available.
- It produces much lighter structures than those constructed from brick, stone or concrete and is cost effective for elevated tanks if a suitable support structure (usually steel or concrete) is provided.
- It is suitable for prefabrication either in panels (joined together on site using ferrocement), or for smaller sizes as complete tanks carefully transported and moved into place.

Parameters for ferrocement

A number of parameters are used to characterise ferrocement. The suggestions in this sub-section are from ACI (1993a) except where another ACI publication (ACI 1993b) is referenced.

Volume Fraction: This is the volume of reinforcement per unit volume of ferrocement. A value of at least 5.1 - 6.3%

Table 1. Differences between ferrocement and concrete

is given as typical (this is equivalent to 400 -500 kg / m^3). A minimum total value of 1.8% in both directions is recommended. The author of this conference paper has discovered that this value is not reached in most of the available ‘ferrocement’ tank designs in use in developing countries. The volume fraction in these tanks is only around 1% but the tanks have still performed well.

Average spacing: The average spacing between reinforcing element is of the order of 5 - 10 mm.

Specific surface: This is the bonded surface area of reinforcement per unit volume of composite. A minimum value for ferrocement recommended by one author is quoted as 0.2 mm^{-1} (i.e. mm^2 / mm^3) but ACI then gives a minimum value of 0.08 mm^{-1}, with a recommendation that twice this value is used for water-retaining structures.

Depth of cover: The recommended average net cover to the reinforcement is only 2 mm. In water retaining structures a lesser value is accepted if crack widths are limited to 0.05 mm and the reinforcement is galvanised. The present author had found that in most of the available tank designs used in developing countries the cover depth is much greater than 2mm, at about 20 mm.

Mix proportions: The desirable mix proportions (by weight) for mortar for ferrocement are:

Sand: Cement between 1.5 and 2.5
Water: Cement between 0.35 and 0.5

The higher the sand content, the higher the required water content to maintain the same workability. For watertightness ACI (1993b) recommended that the water cement ratio should be kept below 0.4. The natural moisture content of the sand should be included in this calculation. This ratio had an important effect on the shrinkage potential but shrinkage is also dependent on the sand gradation (excessive fines should be avoided). The mix should be as stiff as possible, provided this does not prevent full penetration into the mesh. Normally the slump of fresh mortar should not exceed 50 mm (ACI 1993b). Mixing mortar for ferrocement using conventional concrete mixers (rotating drum mixers with fins attached to the sides) is discouraged since the mortar is usually too dry to produce a homogeneous mixture using this method. Hand mixing if carefully carried out is satisfactory.

Sand: To achieve a workable, high-density mortar mix well-graded sands are desirable (i.e. with a wide range of particle sizes). ACI (1993b) gives the following recommended grading:

US Sieve No.	*Standard square mesh size (mm)*	*Percentage passing by weight*
8	2.36	80 - 100
16	1.18	50 - 80
30	0.6	25 - 60
50	0.3	10 - 30
100	0.15	2 - 10

Reinforcement

Wires and meshes can be galvanised but with good quality mortar, good crack control and reasonable depths of cover this is not necessary.

Meshes: Fine meshes with small apertures are used in ferrocement to distribute the reinforcement throughout the mortar but the mesh is often also needed to hold the mortar in place when it is first applied. Where multiple layers of mesh are used it is best if the wire grids are offset to produce more widely distributed wires. Figure 1 shows the five main types of mesh in use.

Hexagonal mesh is particularly suited to double curved sections. *Welded mesh* is relatively stiff and is best suited to singly curved sections, although when cut into pieces it

Table 2. Schematic diagrams and descriptions of methods of ferrocement tank construction

can be used for domed roofs. Strong, large aperture welded meshes (e.g. 6 mm diameter bars at 150 mm centres) are often used to form a skeletal framework to support finer meshes. *Woven mesh* is more flexible than welded mesh. Fine woven meshes are suitable for construction method 4 (see table 2). *Chain link fencing mesh* is a special type of woven mesh which is occasionally used. *Expanded metal* is a mesh formed by slitting thin gauge sheets and expanding them in a direction perpendicular to the slits; it has very good mortar retention properties so is ideally suited for construction method 4; it is not suitable for doubly curved sections.

Wires*:* *Plain wire* can be wrapped circumferentially around tanks to provide wires at closely spaced centres. In addition wires can be also be connected to base reinforcement and be carried vertically up the walls to form an in-situ mesh. Some tanks in Thailand use only plain wires (e.g. 3.25 mm diameter) in this way to reinforce tank walls built using construction method 1a. *Barbed wire* is used in some designs because it is more readily available than plain wire. *Binding wire*, an ungalvanised plain soft wire, usually about 1.63 mm in diameter, is used to tie reinforcement together and to hold finer meshes firmly in place so that they do not move during plastering. Like larger diameter plain wires it can be used circumferentially to resist hoop tension.

Bars: Bars or strong welded meshes are necessary to support the finer meshes used in construction methods 2, 3a, 3b and 4. It is important in methods 3 and 4 that the skeletal frameworks of bars or mesh are stabilised by wooden braces and / or inclined ropes tied to pegs driven into the ground.

Moulds: A variety of materials can be used for moulds for cylindrical tanks. For construction method 1a it is important that the mould is slightly absorbent because the mould alone has to hold the first layer of mortar. Segmental steel framed moulds, faced with split bamboo or basketwork, and plastered with clay are used in Thailand for this method of construction. Method 1b and 2 can use a variety of materials including, prefabricated steel or wooden moulds. Often in Nepal small diameter polyethylene pipes are coiled in a horizontal spiral around a vertical wooden framework to form an inner mould for method 1b. Methods 3a and 3b allow the use of flexible sheets of steel or plywood tied to the skeletal steel. Other materials used for the mould for method 3a are a fence of poles or bamboo, or matting or sacking, held in place outside the mesh by spirals of rope.

Typical tank designs

Most of the designs examined by the author have capacities of 30m^3 or less. Many are reinforced with one layer of skeletal steel bars or mesh (typically 6 mm bars @ 150 mm centres) covered with one layer of chicken wire (typically with 25 mm apertures). The larger tanks in this range also use additional circumferential spirals of wire to hold the mesh in place and / or to add additional hoop strength. Wall thickness is typically 40 or 50 mm. Domed ferrocement roofs are often used, sometimes with a central prop.

Conclusion

Ferrocement tanks have many advantages. These can not be fully appreciated until the technique has been used in a particular region. Readers interested in constructing ferrocement tanks are encouraged to obtain Watt (1978), which gives brief details about many methods, or Nissen-Petersen (1992a) which is an excellent photo-manual for tank construction using sacking for a mould using method 3a. Information about other designs which are not so readily available can be obtained from the author at WEDC.

References

ACI (1993a) State-of-the-Art Report on Ferrocement, Reported by ACI Committee 549, Publication ACI 549.R-93, American Concrete Institute, Detroit, Michigan 48219, USA

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Figure 1. Examples of different types of mesh