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Ferrocement reservoirs: how appropriate?

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FERRO-CEMENT RESERVOIRS WERE virtually unknown in the South African water engineering field until the nineties. Prior to that their use had been restricted mainly to spring protection and rainwater harvesting work, and the sizes built were typically 5kl and 15kl. With the dramatic upsurge in the amount of rural water supply work being done in South Africa in the last six years, ferrocement techniques are now better known. Reservoirs have been built up to 400kl in size, and the 100kl ferrocement reservoir is becoming common.

Ferro-cement is labour intensive, and the skills required are easily assimilated in rural areas. They can be built either with or without shutters, but the former method is recommended for controlling quality and appearance. Ferrocement also lends itself to the construction of attractive domed roofs, which are more durable than the corrugated iron roofs often used over masonry reservoirs.

Built correctly ferrocement reservoirs are strong, durable and watertight. But are they cost-effective? Costs are affected by context. In water projects where large numbers of these reservoirs are built, with simple design specifications and appropriate levels of supervision, they are most cost-effective. However in water projects where only one or two reservoirs are built, with complex design specifications imported from standard practice and several layers of supervisory personnel, the percentage cost saving compared with conventional reinforced concrete is unimpressive.

The history of ferrocement

The development of ferrocement technology began in the 1840s with J.L. Lambot who constructed a rowing boat using a composite of wires and cement. At the same time others were developing conventional reinforced concrete. Further development of ferrocement did not occur until the early 1940s when Pier Luigi Nervi resurrected the original ferrocement concept. The development of ferrocement technology has primarily been done in the boat building industry although ferrocement has successfully been used for many other applications such as roof systems and silos (ACI Manual of Concrete Practice).

What is ferrocement?

True ferrocement differs from conventional reinforced concrete in that it consists of closely spaced, multiple layers of mesh or fine reinforcing bars completely impregnated with cement mortar. Reinforcing requirements are specified as a minimum total volume fraction (3.6 per cent volume of steel per unit volume of composite) and a minimum total specific surface area of steel ($0.16mm^2/mm^3$). The result is a thin walled composite material with a much higher volume fraction of steel than conventional reinforced concrete. The mechanical characteristics displayed approximate that of a homogeneous material and are different to conventional concrete in terms of strength and deformation. The effect is not unlike that achieved with fibre glass reinforced resins. Walls are usually much thinner than conventional reinforced concrete and the maximum cover on the reinforcing is as little as 5mm with 2mm being the average recommended cover (ACI Manual of Concrete Practice).

Ferrocement reservoirs

An adaption of ferrocement technology is now becoming commonly used to construct water reservoirs. Most of the so called ferrocement reservoirs constructed differ from true ferrocement in that they include a lower volume fraction and specific area of reinforcing and a higher maximum cover. The quantities of steel wire reinforcing provided do however provide ample strength for the purpose of water retaining structures. The relatively densely distributed wires spread loads through the mortar, away from plains of weakness, preventing failure. The resulting material, which could be termed mesh reinforced mortar, is closer to ferrocement than traditional reinforced concrete (Watt. 1993).

Ferrocement reservoirs have been well proven over many years in extremes of climatic conditions in many countries including the United States of America, the United Kingdom, New Zealand, Thailand, Mali, Zimbabwe and Namibia. Reservoirs with capacities up to 150kl can be constructed with confidence although ferrocement reservoirs with capacities of over 450kl have been successful (Watt. 1993).

Ferrocement reservoirs in South Africa

Ferrocement reservoirs were virtually unknown in the South African water engineering field until the nineties. Prior to that their use had been restricted mainly to spring protection and rainwater harvesting work, and the sizes built were typically between 5kl and 15kl. With the dramatic upsurge in the amount of rural water supply work being done in South Africa in the last six years, ferrocement techniques are now better known. Reservoirs up to 400kl have been constructed with 100kl reservoirs becoming common. Although the vast majority constructed use mesh reinforced mortar, some have used a purer ferrocement technology.

Over 300 ferrocement reservoirs providing total storage of over 7ml have been constructed in KwaZulu/Natal over the last six years. Most of these have been constructed on projects funded by the former Joint Services Boards (now Regional Councils) and the Mvula Trust, but they are now also being used by authorities such as Durban Metro Water and Umgeni Water. An estimate of the total number of ferrocement reservoirs constructed in South Africa to date might exceed one thousand, but no national data is available. Most of these reservoirs have been constructed by rural communities in rural water schemes.

Advantages of ferrocement reservoirs

Ferrocement is labour intensive, and the skills required are easily assimilated in rural areas. In fact construction of a ferrocement reservoir is not unlike the building of a traditional wattle and daub hut, a procedure still widely practised. This allows a high percentage of local labour to be used and at the same time reduces the amount of supervision required.

Materials such as sand, stone, reinforcing wire and cement are commonly available. During the conflict in Bosnia aid workers constructed ferrocement reservoirs as the materials required were all that were available (Deverill. 1997). In many places local communities are able to contribute by collecting local sand for the reservoirs. The sand used should be well graded and pass through an 8mm sieve. If the sand is too coarse it should be blended with plaster sand. Sands that are too fine are however prone to cause cracking.

Only simple inexpensive tools are required such as spades, buckets, hand hocks, floats and pliers. It is strongly recommended that all mixing of the mortar be done by hand. It has been found that when using a mechanical mixer labour tend to add too much water to the mortar in an attempt to prevent it from sticking to the sides of the mixer.

Ferro-cement reservoirs can be built with or without shutters. Experience has shown that good shuttering makes construction more foolproof and is therefore recommended for controlling quality and appearance. Prefabricated shutters made from rolled corrugated iron sheets have been very successful. They are relatively inexpensive and their cost can be shared over a number of reservoirs. If it is not possible to use prefabricated shuttering cheap local material can be used such as timber, iron sheets or even adobe. The main requirement of the shuttering is that it remains rigid enough to support the mortar while it is being applied preventing cracking (Watt.1993). Ferrocement also lends itself to the construction of attractive domed roofs, which are more durable than the corrugated iron roofs often used over masonry reservoirs.

Key specifications

The life of a ferrocement reservoir is expected to exceed 50 years, assuming sound construction procedures are followed (Watt. 1993).

A rich sand cement ratio of 1:3 by volume is recommended. The mortar should be neither too dry nor too wet. A dry mortar is difficult to work into the reinforcing and is likely to leave air voids while wet mortar will be more permeable and is prone to developing slump cracks. It is recommended that the water:cement ratio should be less than 0.5:1 (Watt. 1993). The water:cement ratio should be carefully supervised and the labour will develop a feel for the correct mix. Cube tests taken from reservoirs constructed in Fredville outside Durban had a 28 day strength of 30Mpa. The mortar mix employed used a sand cement ratio of 3:1 while the sand was a blend of 50 per cent river sand and 50 per cent plaster sand.

The wall thickness is usually built up by applying a number of layers of mortar. By applying subsequent layers of mortar onto “green” plaster a better bond between layers can be achieved. Mortar layers which are too thick are susceptible to slump cracking.

Proper curing is often difficult to achieve. Each layer of mortar should be covered as soon as possible with plastic to prevent drying and cracking. At the very least the mortar should be wetted at least three times per day.

Care should also be taken at the joint between the base and the wall as leaks can develop at this point. A successful method of achieving a water joint is to provide a key for the wall in the base. The wall is then thickened at the joint by providing a mortar collar on both sides of the wall. Shear reinforcing is also fixed between the base and the wall on the larger reservoirs. A rigid joint is then achieved.

Provided that these simple precautions are adhered to a structure of sound quality is the result.

Cost effectiveness of reservoirs

Built correctly ferrocement reservoirs are strong, durable and watertight. But are they cost-effective? Costs are affected by context. In water projects where large numbers of these reservoirs are built, with simple design specifications and appropriate levels of supervision, they are most cost-effective as shown in Figure 1.

However, a number of factors can largely influence the cost effectiveness of ferrocement reservoirs. These factors are the design specification for the base and the pipework, the location of the reservoir and number of reservoirs to be built in the project.

A typical 100kl ferrocement reservoir of height 2m will place up to 50kPa bearing pressure on the soil. Such bearing pressures are in the same range as those produced by an average man walking. Complicated foundation specifications are unnecessary as most soils will handle bearing pressures of at least 100kPa. Ferrocement reservoirs usually have bases with a diameters of less than

Figure 1. Breakdown of costs for typical ferrocement reservoirs in rural water projects, KwaZulu/Natal, South Africa. Note that these costs exclude supervision and training costs, which can vary from 20 per cent to 50 per cent of the total cost depending on circumstances.

10m. A raft foundation is usually constructed by providing weldmesh in the base. Provided one takes the precaution of encasing all pipe work under the base in concrete, thus preventing leaking pipes wetting the founding material, this type of foundation will work well. If the founding material is of a reasonable quality and there is adequate drainage, failure of the base is unlikely. The over-designing of the foundation and base decreases the cost effectiveness of the reservoirs, in some cases by as much as 20 per cent.

Complex pipework specifications can also negatively effect the overall cost effectiveness of the reservoir. In some cases the cost of the pipework has doubled the overall cost of the reservoir. Outlets constructed of uPVC pipe can be extremely cost effective and have the potential to last longer than coated steel outlets provided they are not exposed to sun-light. Expensive control valves are often required for inlets, however there are many cases where the use of a manifold of brass float valves is more appropriate and less costly. Overflows and scour valves must be included but are used infrequently and are subjected to low pressures. uPVC can be used for the overflow provided that it is not exposed to sunlight. Scour can be economically provided by providing the overflow with a removable riser pipe.

Ferrocement reservoirs are easily constructed by relatively unskilled labour. Training is simple and can be done on the job. Once a team has been trained in the construction procedures, they can with limited supervision continue to build other reservoirs. Ferrocement reservoirs can therefore have a high local labour content which is not only desirable but is usually more cost effective. The use of local labour or even local contractors does not need increased supervision if specifications are kept simple. Without affecting the quality of the final product it is possible to specify simple mix designs such as a 2:2:1 mix for the base which would be easily understood by a local contractor and would in most cases produce 30MPa concrete. Ferrocement reservoirs also lend themselves to self help water schemes where contributions from communities can be in the form of work and not capital. This can provide significant cost savings which are often required in such schemes.

Exorbitant supervision costs can dramatically reduce the cost effectiveness of ferrocement reservoirs. Factors which can negatively effect supervision cost are: the number of reservoirs being built; complex supervision structures with multiple contractors and consultants; and the skill of the labour.

Ferrocement reservoirs lend themselves to the construction of more distributed storage. Constructing more distributed reservoirs in a project not only improves the cost effectiveness of the ferrocement reservoirs but also reduces peak factors in the pipelines, reducing the overall cost of the project.

References

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