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REACHING THE UNREACHED: CHALLENGES FOR THE 21ST CENTURY

Reinforced blockwork water storage tanks

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ONE OF THE most important needs of any community development is a safe and adequate supply of potable water. Unfortunately, there is still a shortage of clean water supply in rural regions of many developing countries like, for example, in Tanzania. A large proportion of the rural population in such countries rely on the availability of man-made wells, natural springs and rivers, and recently on limited piped water supply schemes. The majority of such sources are not at economical distances from the dwellings.

The effectiveness of piped water supply depends on the availability of water storage tanks. Reinforced blockwork tanks are used as water distribution and storage facilities in some rural areas in Tanzania. They consist of reinforced concrete roof and floor slabs while the walls are made of reinforced blockwork. The blockwork is made of concrete blocks that contain grooves into which reinforcing bars are laid and embedded in cement mortar.

This paper will discuss matters related to design and construction of such tanks. Since severe cracking and leakage were observed physically to be the major problems, the authors intend to present, in view of research results, ways by which the tanks can be designed to minimise crack widths and water losses through them.

Economic importance of storage tanks

Piped water supply schemes are costly but necessary infrastructural requirement for the development of any community. A survey which was conducted in Tanzania (Senyange, 1985) indicated that water storage tanks constitute about 30 per cent of the total cost of water schemes. The majority of large tanks are made of reinforced concrete while smaller ones (< 150m³) are made of reinforced blockwork walls and are mainly located in rural areas.

Suitability of blockwork for tank walls

Rural areas of developing countries are characterized by low technology in terms of skilled manpower, equipment and transportation means. Construction of reinforced concrete walls for water retaining structures requires:

- adequate compaction of concrete by using surface vibrators;
- low water-cement ratio by using admixtures for enhancing flowability;
- sufficient curing under tropical temperatures, which can hardly be fulfilled in rural areas of developing countries.

Blockwork construction is one of the appropriate technologies in such a situation because it requires simple skills and tools, it is labour intensive, may create jobs and is cheaper. Basic materials for the wall construction are concrete blocks with grooves, cement mortar and reinforcing bars, all of which are locally available.

Problems for designers

The major problem with the existing tanks is cracking and leakage that is accompanied with heavy water losses. In order to reduce the heavy losses it is recommended to design future tanks by taking account of crack width limitations. The designers of existing tanks lacked adequate knowledge about the behaviour of reinforced blockwork in tension, crack formation, and the control of shrinkage and load induced crack widths. The majority of tanks were designed for ultimate limit state to bear the tensile ring forces caused by water pressure .

Research on reinforced blockwork

It is well known from reinforced concrete structures that the reinforcement ratio required for controlling crack widths to specified sizes is significantly higher than that required purely for the stability of the structure. This was the reason for conducting a research to investigate:

- tensile strength of blockwork;
- crack formation, initial and final crack patterns;
- tension stiffening after cracking has taken place;
- crack widths in relation to steel stresses;
- water flow through separation cracks in blockwork;
- bond characteristics of reinforcing bars in mortar.

The investigations involved testing of 18 reinforced blockwork wall panels in axial tension for which axial deformation, crack widths and spacing, as well as reinforcing steel stresses were measured. Bond stresses of plain and deformed bars in mortar were investigated on 45 specimens by pull-out tests and 21 beam splice test methods. A total of 18 axial tensile tests on mortar and small aggregate concrete were carried out as well to investigate crack widths, crack spacing and their relation to bond stresses.

In addition water permeability of cracked blockwork was performed by which the amount of water flowing through a crack of particular width and length was measured. In such tests water pressure was varied and D'Arcys formula for lamina flow through parallel walls was applied for the determination of flow coefficients.

Results of experimental investigations

The results of the investigation were as follows (Shirima, 1996):

- Self healing of cracks may take place only if their widths do not exceed 0.10mm. Therefore reinforced blockwork tanks should be designed for cracks less than or equal to 0.15mm, to minimise losses due to leakage.

- A formula for the estimation of tensile strength of blockwork in axial tension was derived from the results of tensile tests on mortar and small aggregate concrete. The tensile strength of blockwork can be estimated as follows:

$$f_t = \alpha_m f_{tm} + (1 - \alpha_m)\frac{f_{tb}}{2} \quad (1)$$

  where α_m is the proportion of mortar in the overall cross section of the wall, f_{tb} and f_{tm} are tensile strength of blocks and mortar, respectively. They can be estimated from the compressive strengths:

$$f_{tb} = 0.2\, f_{cb}^{2/3}\,;\ f_{tm} = 0.1\, f_{cm}^{2/3} \quad (2)$$

  where f_{cb} and f_{cm} are respective compressive strength strengths of blocks and mortar. A comparison with test results is shown in Figure 1.

- The average gross strain of blockwork in axial tension $\in_m$, depending on steel stress was derived and reads as follows:

$$\varepsilon_m = 0.60\frac{\sigma_{sl}}{E_s} = 0.60\frac{f_t}{\rho\, E_s} \quad (3)$$

  for initial crack formation, e.g. shrinkage and

$$\varepsilon_m = \frac{\sigma_s}{E_s}\left[1 - 0.55\left(\frac{\sigma_{sl}}{\sigma_s}\right)^{1.5}\right] \quad (4)$$

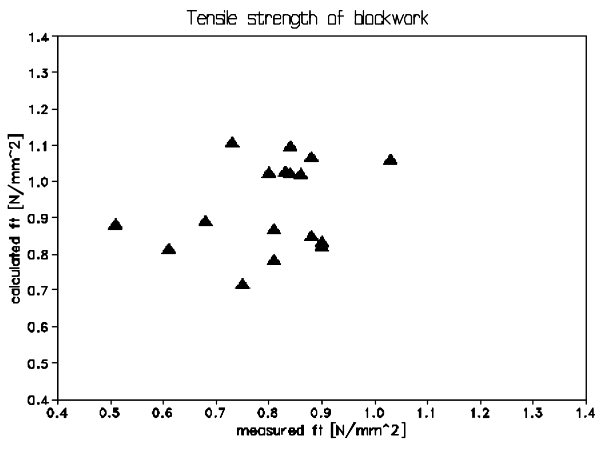

Figure 1. Strength of blockwork in tension

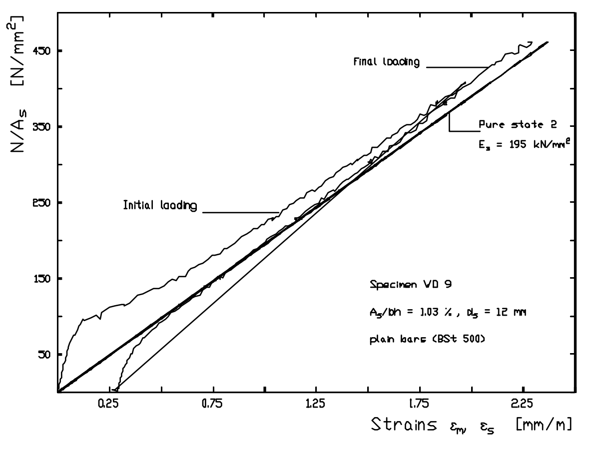

Figure 2. Load-deformation curve

  for final crack formation, where E_s is the modulus of elasticity of steel bars, ρ the reinforcement ratio, σ_{sl} is the cracking stress, i.e. steel stress upon formation of the first cracks, and σ_s stands for service steel stress.

- Formulas for prediction of crack widths were determined, from which design tables and charts can be produced and used for the determination of bar sizes and reinforcement ratio required for bearing ring stresses in the walls. The average crack spacing may be estimated by the equation:

$$s_m = 50 + 1.5\,\frac{\sigma_{sl}\, d_s}{4\,\tau_m}\ [\mathrm{mm}] \quad (5)$$

  where d_s and τ_m stands for bar diameter and mean bond stress, respectively. The mean crack width w_m and characteristic crack width w_k can be calculated:

$$w_m = \varepsilon_m\, s_m \quad (6)$$

$$w_k = k\, w_m \quad (7)$$

  where k = 1.3 for initial crack formation and 2.1 for final crack formation. Bond stresses τ_m to be used for design are 1.6 for deformed bars and 0.7 for plain ones.

  Comparison between test results and calculations using the formulas above is shown in Figure 3.

Materials and construction

The materials used for the construction of blockwork water tanks should meet some basic requirement. For example, the compressive strength and density of concrete blocks should correspond to concrete grade 15 or above. This can be achieved by a mix proportion, 1 part cement: 3 parts sand: 6 parts course aggregates (< 8mm). Strong and dense mortar is necessary for the protection of reinforcement against corrosion. A mix of 1 part cement

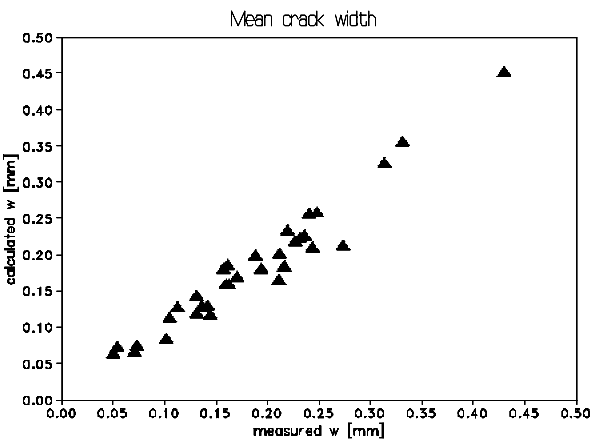

Figure 3. Comparison of mean crack widths

to 3 parts sand is recommended. All cross and bed joints should be completely filled with mortar and well compacted.

It is quite common to find plain bars in use in developing countries. Whenever deformed bars are available, it is highly recommended to use them in favour of plain ones. When only plain bars are available, then proper curtailing procedure should be followed; the bars should be hooked at their ends for adequate anchorage.

Laying of concrete blocks should be conducted carefully. All joints must be thoroughly flush and filled with mortar. Reinforcing bars should be fully embedded in mortar (recommended α_m is about 0.30). Blocks should be wetted a short while before laying them, to allow a good bond with mortar and reduce the risk of mortar losing the water it requires for hydration to dry blocks.

Low water / cement ratio for the mortar will reduce the pore content and therefore the carbonation rate although it may bring about workability problems. Experienced masons are able to judge the proper consistency of mortar.

Surface finishing

Blockwork surface is normally rough, therefore the interior side of a blockwork tank requires plastering and screed, in order to be smooth. The materials used for the purpose should be inert and nontoxic; they should not form a breeding ground for fungi or other microorganisms.

Water tightness can be improved by using plasters or coats that contain components which may dissolve in water and deposit into small cracks. There are already products for such purpose like, for example, HEY'D1 slurry used in some northern parts of Tanzania. It is used for replastering of interior surfaces of tank walls and has shown good results.

Another important reason for plastering both interior and exterior surfaces is to reduce the danger of rapid shrinkage of mortar joints, especially when one considers the climatic conditions in Africa which are hot and sometimes dry.

Shading

Potable water should have a comfortable temperature. The practice of covering water tanks by soil, i.e. partial burying, is one way of insulating them in addition to the structural benefits of reducing ring stresses and therefore crack widths. Any shading of a water tank from direct sun radiation is a welcome step towards maintaining comfortable temperature of the stored water.

Conclusion

When properly designed and constructed, reinforced blockwork tanks may perform well for storage of water in developing countries. It is therefore important to provide adequate reinforcement, by choosing suitable diameter of bars and ensure that they are well anchored in the embedding mortar. Compaction of mortar, plastering of blockwork surfaces, and proper design of joints are crucial considerations with regard to water tightness.

The equations presented in this paper enable the estimation of suitable bar size and reinforcement ratio for particular crack widths. Further research is required, especially in the area of improving the durability of reinforced blockwork tanks, since mortar cannot offer adequate protection against the corrosion of reinforcing bars.

References

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