Synopsis

It is averred that water loss from concrete service reservoirs is primarily a function of the permeability of the floor slab. On this basis recommendations are made for maximum permissible losses for watertightness acceptability tests.

Summarizing

Dit word beweer dat water lekkasie van betonopgaan/ende hoof-saaklik 'n funksie van die deurkantheid van die vloer is. Met hierdie bewering as basis word maksimum toelaatbare watervloeië vir waterdiggheidstoetses aanbeveel.

Permeability of concrete

It is accepted by the National Building Research Institute that a sound and durable concrete should have a coefficient of permeability not exceeding 5 x 10⁻⁷ mm²/s at an age of 28 days as determined from test samples that have undergone three days' initial curing by immersion, followed by 11 days in a 50 per cent relative humidity room and 14 days' drying in an oven at 50°C. On further immersion of the concrete, the coefficient of permeability decreases as the cement continues to hydrate and after a year or so may be expected to be appreciably less than 1 x 10⁻⁷ mm²/s. Seepage through concrete may thus be expected to reduce with time and after a few years to approach a constant value.

In a comprehensive thesis on the permeability of concrete, Robson advanced a novel hypothesis, based on an interpretation of experimental data, that permeability is dependent on the number of large diameter pores that pass through the particular sample and then developed an ingenious statistical approach to the problem to show that a finite number of pores is present for each sample tested. For concrete, it is thus evident that porosity alone is not necessarily a valid indicator of permeability. It is also evident that individual test specimens do not necessarily yield a representative value of the permeability of concrete.

Parrott suggests that the permeability of cement paste is proportional to P to the power where P is the large diameter (is more than 4 nm) porosity, which according to Parrott can be reliably estimated using a computer model of hydration. The total porosity of cement paste reduces only marginally with time, which implies that with hydration large diameter porosity is converted to small diameter porosity. Parrott stresses the fact that the water-cement ratio is of considerable importance in respect of permeability and emphasises the need for adequate moist curing to promote the hydration process. The permeability of concrete as distinct from cement paste is largely associated with microcracks and pores resulting from bleeding and entrapment of air, but such voids too tend to be filled, reduced in size or isolated by the products of hydration.

Fulton states that since the gel that forms as a result of complete hydration occupies about 2.2 times the volume of original cement in the paste, any concrete made with a water-cement ratio in excess of 0.38 by mass cannot have the space originally occupied by mixing water completely filled by the products of hydration.

Thus, for workable concrete, even the mature paste is porous and total capillary discontinuity is unlikely in practice. Fulton pointed out, however, that microporosity resulting from the use of an over-wet mix is generally far preferable to the macroporosity caused by over-dry concrete, which cannot readily be compacted.

Reservoir leakage

Assuming that in a concrete reservoir there is no loss of water through sealed joints, a fall in water level would (even after allowance for absorption and evaporation) still be expected, owing to water permeating through the floor and walls.

Generally, the thickness of floor slab to water depth ratio varies from about 2.7 per cent for deep tanks to 3.2 per cent for shallow tanks. The walls are usually much thicker than the floors. Moreover, for flat-bottomed tanks the average water pressure on the wall is half that on the floor and for most tanks the wetted area of the wall is less than that of the floor. Seepage through walls is therefore generally far less than that through floors and will not be considered further in this analysis but should be separately evaluated for unusually deep reservoirs, particularly those with comparatively thin post-stressed walls.

Expected leakage through floors

The expected drop in water level (h) due to seepage through the floor (after a suitable period for absorption) is given by the Darcy relationship as follows:

\[ h = k l \]

where \( k \) is the coefficient of permeability of the concrete in m/s and \( l \) is the hydraulic gradient (ie the water depth \( H \) divided by the floor thickness \( t \)).

For a reservoir with a floor-slab thickness equal to 2.7 per cent of the average water depth

\[ h = \frac{5 \times 10^{-7}}{10^{-3}} \times \frac{H}{0.027H} = 1.85 \times 10^{4} \text{ m/s} = 11.2 \text{ mm/week} \]

This figure agrees fairly well with the value of 12 mm of allowable water loss in seven days given in the now superseded CP 2007: Part 2, 1970, and for normal concrete practice this would seem to be a realistic and generally achievable specification. It should be noted that, provided the floor slab thickness is 2.7 per cent of the average water depth, the expected value of 11.2 mm/week is independent of water depth. The minimum thickness of floor slab in a shallow tank would be about 100 mm, so that for water depths of less than about 3 m the figure of 12 mm would imply that concrete for such depths could be more permeable than that for depths of greater than 3 m and yet pass the test.

Trowt et al state that for concrete reservoirs a normal allowance for...
unavoidable leakage is 3 mm per day (ie 21 mm/week), but that it should be possible to achieve a better result. Hughes gives an allowable drop in water level of 1/1 0000th of the average water depth in a period of seven days. This is a particularly harsh requirement for reservoirs less than about 10 m deep.

More recent specifications
In BS 5337: 1976 the specification for maximum drop in water level for reservoirs was reduced to 10 mm per seven days, which is equivalent to a permeability coefficient of 4.96 x 10⁻⁷ mm/s for reservoirs with floors of a thickness equal to three per cent of water depth.

Amendment No 2 to BS 5337, issued in June 1982, specifies a permissible drop in water level over a period of seven days of 1/5000th of the average water depth or 10 mm, whichever is the lesser. Fig 1 illustrates the relationship between various permissible weekly drops in water level cited.

Recommendations
In the past decade or two the average depth of concrete service reservoirs has tended to increase substantially because such reservoirs generally have capacities greater than those built previously and accordingly have to be deeper so that the optimal unit cost of storage can be achieved.

There is a reluctance among designers to increase the floor thickness beyond about 200 mm for deep tanks, and although such slabs may be structurally sound it should be appreciated that the allowable water loss rate is affected by this.

It is contended on the basis of permeability considerations that a limiting drop in water level of 0.3H/7 mm per week is a reasonable requirement, and Fig 2 shows the recommended maximum allowable loss rate for various floor slab thicknesses. This limiting drop in water level is based on the assumption that the floor slab thickness is 2.7 per cent of the average water depth, that leakage through the walls is negligible and that the permeability of the concrete is 5 x 10⁻⁷ mm/s. Where the walls of the reservoir are particularly thin, suitable adjustments should be made to the loss obtained from the graph.

It is expected that by autogenous healing of large diameter pores in the matrix a reservoir barely passing the test will, after it has been in service for a period of about two years, have its seepage losses reduced to one-fifth of the initial test value or less.

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References

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- Take a management decision. Productivity improvement starts with agreement in principle to make productivity a priority. From there, follow through all the steps: alerting employees to productivity, measurement of performance, problem identification, training, targeted action plans, monitoring progress.
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