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THE CONCEPT OF A DEPRESSURIZED WATER TANK

INTRODUCTION

Water storage tanks are readily constructed of concrete, mainly because of their durability and low maintenance costs. However, they require heavy reinforcement to resist the hydrostatic pressure of the contained water because of the low tensile strength of the concrete. In the case of cylindrical reinforced concrete tanks, the reinforcement amounts to about 15 kg per cubic metre of stored water and a little use is made of the high compressive strength of the concrete. For prestressed concrete tanks, the compressive strength of the concrete is partly utilised in supporting the prestressing tendons made from high tensile steel. This results in a reduction of the total reinforcement to about 10 kg per cubic metre of stored water. The use of concrete is also high, amounting to about 0.20 m³ per cubic metre of stored water in the case of reinforced tanks and to about 0.15m³ per cubic metre of stored water for prestressed tanks.

The high usage of structural materials in water storage tanks would be drastically reduced if the hydrostatic pressure inside could be balanced by the atmospheric pressure from outside. One way of achieving this would be to construct an hermetically sealed tank which could then be evacuated to remove the air from inside. The empty tank would then be prestressed by the outside air pressure, producing mainly compressive stress in a properly shaped tank and fully utilising the compressive strength of the concrete. As the tank is filled with water, the compressive stress decreases but provision can be made to eliminate any undesirable tension. A further consideration is that an hermetically sealed tank will protect the stored water against pollution.

A preliminary study has been carried out in the Department of Civil Engineering, Ahmadu Bello University and a model of a depressurised plain concrete tank has been constructed. These investigations have shown that the concrete required for such a tank can be considerably reduced when compared with a conventional prestressed concrete container even when reinforcing steel is not

used at all.

DESCRIPTION OF TANK AND MATERIALS

The depressurized water tank model is assembled of 32 precast plain concrete curved plates. The pentagonal and hexagonal plates are 30 mm thick and the radius of their curvature is 735 mm. The tank is spherical with internal diameter 1440 mm and capacity 1.66 cu. m. The joints between the plates are filled with epoxy resin. The tank is provided with two sight - perspex glasses, a connector to vacuum pump on the top and another connector to a water source at the bottom.

The tank is founded on a plain concrete base cast in steel sheet cylinder with diameter 810 mm and height over ground level of 555 mm. This cylindrical support rests on a circular concrete mat of diameter 1400 mm.

Casting of the Concrete Plates

The plain concrete plates were cast in accurate timber formwork and compacted on the vibrating table with medium amplitude of vibration. The composition of the concrete mix was 1: 1.25 : 1.8 with w/c = 0.47. The Ordinary Portland Cement, local sand and gravel up to 10 mm were used. Slump of the concrete mix was about 30 mm. The strength of concrete after 28 days of hardening was (36 cubes were tested):

Mean strength: 48.04 N/mm²

Standard Deviation: 3.72 "

Coefficient of Variation: 0.078

These results show that the degree of control was excellent. The characteristic strength of concrete, $f_{cu} = 40\text{N/mm}^2$ was gained after 28 days of hardening and $f_{cu} = 50\text{N/mm}^2$ at the time of assembling the tank.

Joints between the Plates

The concrete plates were manufactured with high accuracy and the gap between the plates is 5 mm. The tank was assembled on the testing site with the joints filled up with epoxy resin

Araldite CY 219, hardener HY 219 and clean siliceous fine filler with ratio 3 : 1 and 3½ : 1 (filler to resin). The resin hardened after 24 hours but did not flow excessively out of the previously mechanically fixed joints. Testing of bond between the hardened resin and concrete on standard briquettes (tension) showed failures out of the layer of resin in all tested specimens.

External Coating of the Tank

The external coating of the concrete tank was provided by the use of 2 to 3 layers of Decadex. This paint is used for covering roofs.

Laboratory tests were carried out to check the use of Decadex for a depressurized structure. The tests were performed on concrete discs with diameter 250 mm and thickness 30 mm which were subjected to vacuum on the uncoated side through the cover of a desicator. Mean results of 5 concrete discs for a specified number of Decadex coatings are presented in Table 1. The applied initial vacuum in all cases is 700 mm Hg. The loss of vacuum in pump is only 150mm Hg within 5 days which is negligible.

INSTRUMENTATION

The unit is designed for continuous collection of ground water from a borehole on the basis of the concept of a depressurized

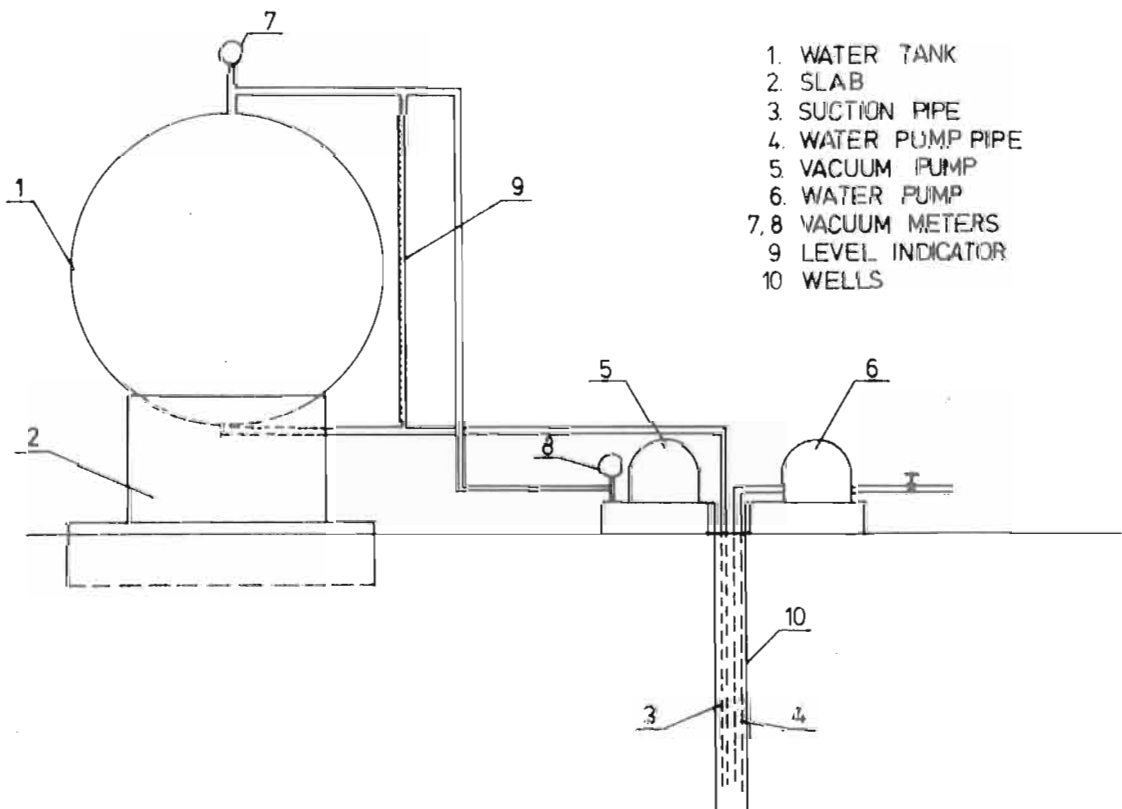
Table 1. Maintenance of Vacuum by Plain Concrete Discs Coated with Decadex

No. of Coatings	Vacuum Maintenance Time
Uncoated	7mins. 10secs
One Coating	8hrs
Two Coatings	14hrs
Three Coatings	100 hrs

water tank with suction pipe lines leading to a borehole as shown in Fig. 1. The storage tank, when depressurized by a vacuum pump sucks water and stores it until its delivery by a water pump to its required destination. The level of water in the tank can be monitored with an external level indicator. The connected vacuum meters in Fig. 1 measure the negative pressure inside the tank before and during pumping. Automatic control is provided which enables the vacuum pump to be turned on when the water level is below that required. The water pump is turned on when water level is above that required and is switched off when the tank is empty. The vacuum pump is of type Spedivac JSC 50B (0.75 HP) while the water pump is of type Bavesford B20A0 (0.25 HP).

TESTING OF THE TANK

The tests presented below were carried out on the tank without any external coating.



- 1. WATER TANK
- 2. SLAB
- 3. SUCTION PIPE
- 4. WATER PUMP PIPE
- 5. VACUUM PUMP
- 6. WATER PUMP
- 7,8 VACUUM METERS
- 9 LEVEL INDICATOR
- 10 WELLS

FIG. 1 THE INSTRUMENTATION AND AUTOMATION OF WATER SUPPLY SYSTEM.

The Empty Tank with Applied Vacuum

The vacuum in empty tank was maintained for a sufficiently long time. A maximum of 50% of absolute vacuum, i.e. 380 mm Hg was applied to the tank to avoid excessive loading. The observed reduction of vacuum is shown in Fig. 2.

The Tank Filled with Water

Water was sucked into the tank at 75 mm Hg vacuum with inlet at the bottom and stored water at ground level. The stability of vacuum was good enough since water was continuously sucked into the tank for some time after closing the supply of the vacuum. The tank was completely filled with water through a 20 mm diameter plastic hose connected to the inlet pipe within 48 minutes. During this period, the reading of the vacuum pump gauge was 178 to 203 mm Hg and the corresponding reading inside the tank was between 50 to 75 mm Hg. The former reading was for the completely filled tank (i.e. water at top of tank).

If the vacuum, in a partially or completely filled tank, is no longer maintained by a vacuum pump, and if the outlet is opened permanently, an interesting observation of the balanced condition between the hydrostatic pressure of water and vacuum was noted. After a short time from this balanced condition,

water flows through the outlet at the bottom of the tank. If such a free flowing of water is required, then the tank is self-emptying. However, the time taken is rather long; e.g. about 20 hours.

STRAIN/STRESS DISTRIBUTION IN TANK

Tokyo Sokki electrical resistance strain gauges, type PC 10 with a gauge length of 10 mm, gauge factor of 2.09 and strain range of 2% were used to measure the strains. The adhesive used was Swiss Araldite. A Tokyo Sokki Strain-Meter equipment was used to record the strains.

The gauges were installed approximately in perpendicular pairs in the circumferential and meridional directions on both the inside and outside surfaces of the tank. Hence, each gauge of the pair was approximately at the same angle of colatitude. There were fourteen gauge pairs on the inside and outside surfaces of the tank. Internal gauges and portions of the leads were waterproofed also with Swiss Araldite.

The experimental stress distributions for the spherical tank both in the circumferential and meridional directions were monitored for the empty tank with 50% vacuum, partially and completely filled tank. With vacuum only, the strains range from - 0.00004 to 0.0008. For the 50% filled tank,

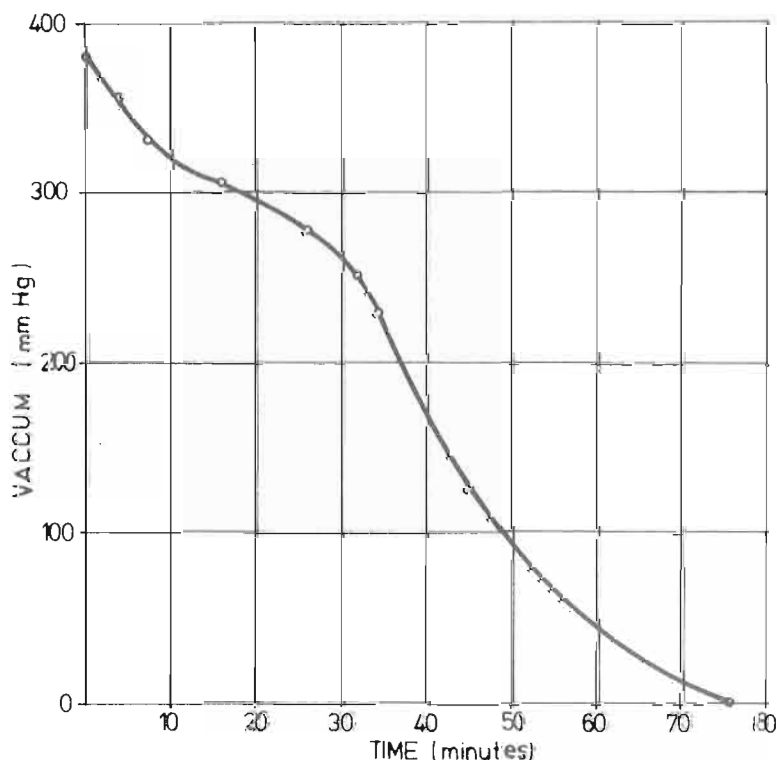


FIG.2 REDUCTION OF VACUUM WITH TIME.

the range of strains were more critical along the meridional direction ranging from -0.00004 to 0.0008 while for the completely filled tank, the corresponding strain range is from - 0.00003 to 0.0009. The stresses were computed from the strains using a nominal value of $E = 34 \text{ KN/mm}^2$ corresponding to the characteristic strength of $f_c = 50 \text{ N/mm}^2$ at the time of assembling the tank. For all cases recorded, the largest variation in stresses is of the range - 1.36 to 30.60 N/mm^2 which are within the permissible working stress zone.

QUALITY OF WATER STORED UNDER VACUUM

A preliminary study on the effect of vacuum on the water quality was carried out in an erlemeyer flask which was maintained at a vacuum of about 250 mm Hg. Groundwater was stored (half-full) in the flask at this vacuum. The water was analysed for its initial parameters including the dissolved oxygen (DO), pH and the total bacterial count. After three days of storage in the flask, the water was again analysed for the same parameters.

The preliminary results indicate a decrease in the DO value to about 13% of its initial value and an increase of about 6% in the pH value. Also, the total bacterial count was observed to decrease by about 45%. The observed decrease in DO value was probably due to difference in its partial pressure in the water and in the air above the water which may result in its escape in an attempt to maintain an equilibrium. Similarly, other gases including CO_2 may escape. The removal of CO_2 may tend to raise the pH of the water. While the vacuum may have some effects on the micro-organisms in the water, prolong storage and other environmental factors may tend to decrease the bacterial counts. However, more research is required in order to establish these results.

CONCLUSIONS

The results of the preliminary experimental tests on the concept of a depressurized water tank lead to the following conclusions:

The maintenance of equilibrium between hydrostatic water pressure and vacuum in tank is easy to keep. Therefore, it is possible to store water with very small stresses in the tank.

All operations required to verify the concept are not complicated and the controls to prevent losses are simple. Hence, in the absence of a skilled operator, a simple safety value can be provided.

The tank may be used as a storage tank to be filled or emptied at will. The outlet of water may be increased or decreased by controlling the vacuum existing in the tank accordingly. Similarly, the tank could be used to replenish a small confined aquifer in its vicinity.

The full compressive strength of concrete can be utilized using the proposed concept with considerable savings in the material even in the absence of any reinforcing steel.

Precast segments of the tank can be mechanically mass produced in concrete factories and easily assembled on site without any construction equipments or with light construction equipment if the tank has very large dimensions.

Additional analytical and experimental research to ascertain fully the above preliminary findings are desirable. Investigations into the use of alternative energy sources and alternative means of water purification just close to the tank are currently underway at Ahmadu Bello University in order to make the tank completely self operational in the production of safe, drinkable water.