ANNALS OF FACULTY ENGINEERING HUNEDOARA
- INTERNATIONAL JOURNAL OF ENGINEERING
Tome IX (Year 2011). Fascicule 2. (ISSN 1584 - 2665)

[1.] Ala'a M. DARWISH

STABILIZATION OF EMPTY UNDERGROUND CIRCULAR STORAGE TANKS AGAINST UPLIFTING UNDERGROUND WATER FORCES

[1.] DEPARTMENT OF BUILDING AND CONSTRUCTION ENGINEERING,
UNIVERSITY OF TECHNOLOGY, BAGHDAD, IRAQ

ABSTRACT: Circular swimming pools or, in general, underground tanks can be mobilized due to two coincide factors: the first is when they are emptied for maintenance, while the second factor is when underground water level rises up to be close to the natural ground surface. Under such circumstances an underground circular tank will be subjected to a buoyancy force equal to the weight of the displaced underground water minus the weight of the tank.
In this research eleven prototype models were tested to simulate the mentioned case. The base diameter of each model was different than the other, with an increment of 1cm each time. Water head required to float each model was recorded. Test result shows that: Stabilizing of an empty underground circular tank can be reached by extending it's base diameter. Finally, the equation of calculating the required base extension was derived.
KEYWORDS: circular tank, swimming pool, underground tank, buoyancy, stabilization, state of-the art design approach

❖ INTRODUCTION

During a maintenance process for a circular reinforced concrete swimming pool, it was found that there were some visible cracks along its circumference. These cracks were situated exactly between the pool walls and its surrounding shoulders. Moreover, after excavating few holes in the burying soil around the pool in order to fix its piping system, it was noticed that there were some movements/ disorientations in the piping fittings which had made the maintenance process a bit more complicated.

After verifying the mentioned case a complete analysis was done to find the cause of these engineering defects. The analysis result indicated that the pool was suffering from a noticeable amount of uplifting buoyancy force due to the rising of the surrounding water table level.

Going through the literature of the subject, it was found that; no concern had been paid to fix a swimming pool against uplifting pressure. This might be due to their shallow depth, normally 2 to 4 meters, in addition to the rare condition of the augmentation of buoyancy forces.

Taking the general case of deeper buried circular tanks (actually cylindrical tanks), it was found that some tanks are based upon reinforced concrete piles which can resist the calculated uplifting forces (Westbrook 1984). But, "Piles penetrating into a stratum having a confined hydrostatic head will be subjected to uplift, possibly sufficient to raise them from their end bearing. Seepage around piles in un-watered excavation may reduce skin friction to less than the hydrostatic uplift", (Chellis 1992). While (Darwish 2008) had complained about using piled foundation for this purpose arguing that "Even if the piles are not lifted up, they are still subjected to repetitive high tensile stresses. These tensile stresses may be grater than the pile's concrete tensile strength and cracks near the pile heads can be expected. Crack formation across the entire cross section of a pile head will lead to an increasing tendency for corrosion of its reinforcing steel. Usually, sub-soil can support an underground tank without using any pile, because it is overburdened by the weight of the excavated soil which is normally greater than the weight of the filled tank. But if the tank becomes empty, during the rise of the underground water level, such soil even if it is hard as rocky soil can do little to resist tank floatation".

(Darwish 2008) had also solved the problem of anchoring empty underground storage rectangular tanks against underground- water-induced floatation by using two parabolic profile cables passing through the long side walls of a tank and anchored to sub-grade soil at their ends. While this solution is appropriate for rectangular and square cross-section underground tanks, it is not so for underground cylindrical tanks.

To study the case of unstable pools and, in general, underground circular tanks, prototypes of a steel circular tank with variable base diameters were used to simulate the case and to find a reasonable solution. The solution was based upon finding a balancing weight which can counter the net uplifting buoyancy forces. By changing the diameter of the prototype tank base, it was found that: with each increment of base extension there was an increase of the water head required to float the tank. Contentment was reached that the weight of the surrounding soil situated directly, as a ring of soil, over the tank base extension can manage to counter the net buoyancy force tending to lift the buried tank.

In spite of the complication of each case due to the variable water head height, the shape of the slipping surface, friction between the tank walls and the surrounding submerged/non-submerged soil and the length of the base extension, an equation was derived to calculate the required length of the base extension which can stabilize any tank with an average safety factor of +17%.

❖ EXPERIMENTAL WORK. MATERIALS & TESTING PROCEDURE

- □ Transparent square plastic container having the dimensions of 50cm×50cm and a depth of 20cm.
- □ Clean sand with the following properties:
  - ❖ Specific weight = 2.61
  - ❖ Dry density = 1.8 gm/cm^3
  - ❖ Wet density = 1.42 gm/cm^3
  - ❖ Submerged density = 0.42 gm/cm^3
  - ❖ Angle of repose = 35°
- □ Four water inlets to the container, one on each side, to discharge a controllable amount of water near the inner face of the container base, see Fig.1.
- □ Four measuring stickers, one on each corner of the container.
- □ A changeable base cylindrical steel pan having an outer diameter of 20 cm, depth of 10cm, and a wall/ base thickness of 1 mm. Its weight was 732gm.
- □ Variable Steel bases, all with a thickness of 1mm, were used through the test. Their diameters start from 20cm to 30cm with an increment of 1cm. The first four columns of Table -1 show Notations, diameters and weights of the pan and its different bases.
- □ Two dial gauges were attached to indicate any upward movement in the level of the buried pan.

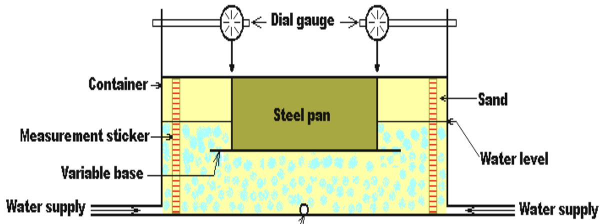

Fig.1 Testing device

Table 1. Theoretical and Actual head of water required to mobilize each pan

Notation	Base diameter (cm)	Weight (gm)	Theoretical head (cm)∗	Actual head of water (cm)
Pan #0	20	732	2.33	3.7
#1	21	758	2.41	4.3
#2	22	784	2.50	5.3
#3	23	812	2.58	6.0
#4	24	841	2.68	6.8
#5	25	871	2.77	7.5
#6	26	902	2.87	8.1
#7	27	935	3.00	8.6
#8	28	968	3.10	9.1
#9	29	1003	3.20	9.6
#10	30	1040	3.30	10.0

∗ Only the weight of the pan was considered.

The container was filled with wet sand for half of its depth, the cylindrical steel pan #0 was placed on the sand and then the container was completely filled with wet sand. Water was allowed to seep slowly through the four inlets with a rising speed of 10cm/h.This rate was chosen to let the water surface to be at the same level allover the area of the container and to facilitate recording the rise of water by the four measuring stickers that were placed at the four inner sides of the container. Zero level was fixed at 10cm above the level of the inner face of the base. Mean value of water level was considered in the next calculations. Two dial gauges were attached to the container walls to measure any perpendicular movement might occur in the level of the steel pan.

The following observations were noted:

- ❖ The cylindrical pan was stable in its place until the height of water recorded 3.7cm. Suddenly, the pan was lifted and it continued to rise directly with the increase of water level.
- ❖ The same test was repeated using pan #1 which had a base extension of 1cm instead of pan#0 with no base extension to monitor the effect of increasing the diameter of the base of a buried tank on its stability against floating. After supplying the container with the same rate of water through the four water inlets, the steel pan remained stable until the level of water reached 4.3cm, then the pan started to rise and it continued to move upward directly with the rise of water level.
- ❖ The same procedure was repeated with pans #2, #3 and #10 on turn. The results are listed in table-1. It shows the theoretical water head required to lift the weight of each pan with respect to the actual recorded head of water.

❖ RESULTS& COMMENTS

One of the well known principles is that: the water floating force equals the weight of the displaced water by a submerged body. By applying this concept to pan #0, with no base extension, it indicates that a water level of 2.33cm is enough to push it up, but during the test the pan remained stable when water level reached this point. Pan #0 started to move up only when water level reached 3.7cm. The mentioned difference means that an extra force is required to lift the empty pan. The explanation is simply that the pan was not free to float and the extra force was required to overcome the friction between the outer surface of the pan's wall and the surrounding sand, see Fig.2-a.

Repeating the same testing procedure but with pan #10, with a base of 30cm diameter, the pan remained stable until the water level reached 10cm in depth. Taking into account that the displaced water was approximately the same for the two pans #0 and #10, in other word the required uplifting force should be very close, but test results showed that this is not true. The main difference between the two pans was the extended base of pan #10. This extension showed that it was active in stabilizing pan#10 against floating. It required (10-3.7 = 6.3cm) of an extra head of water to initialize its upward movement. While pan #0 required an extra force to overcome the friction between the outer surface of the pan's wall and the surrounding sand, pan #10 did not require such extra force because there was no direct slipping between the pan's wall and the surrounding sand. Actually, the base extension had shifted the slip surface away from the pan's wall, see Fig.2-b.

By calculating the weight of the submerged ring of sand around the pan, see Fig.3, which was situated directly over the base extension, a hollow 10cm high cylinder with an interior diameter of 20cm and an exterior diameter of 30cm, it was found that it's weight equals: $(15^2 - 10^2) \times \pi \times 10 \times 0.42 = 1650\ gm$

While the uplifting force of the extra head of water equals: $10^2 \times \pi \times 6.3 = 1980\ gm$

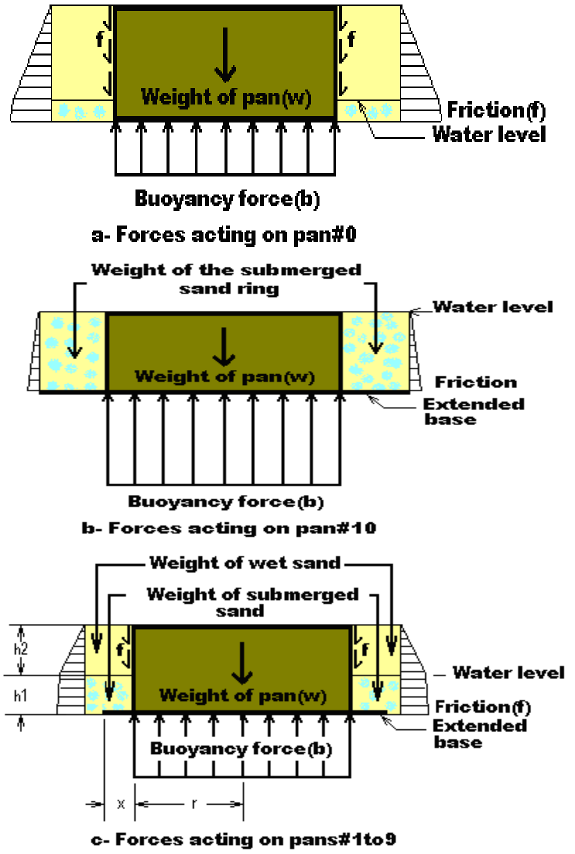

Fig.2 Forces distribution on testing pans

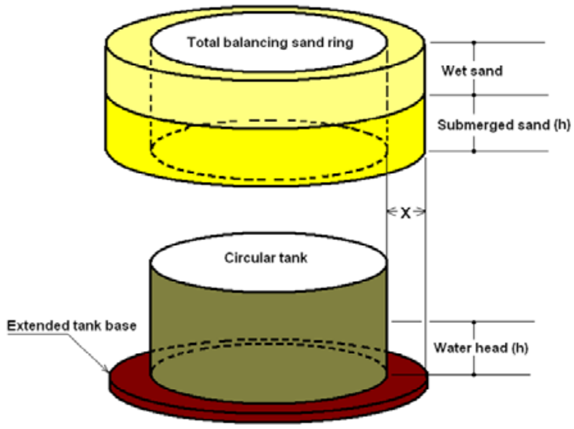

Fig.3 The balancing sand ring

By reducing the difference of weight between the two pans (1040-732= 308gm), the net extra uplifting force will be: 1980- 308 = 1672gm

The difference between the weights of the surrounding submerged sand ring and the net uplifting force is equal to: 1672- 1650 = 22gm

This force was required to overcome the friction between the submerged sand particles along the slip surface. It is worth to compare between that force and the force required to overcome the friction in the case of pan #0 which was equal to: $10^2 \times \pi \times (3.7- 2.33) = 430$gm. It is clear that, pan #0 required an extra uplifting force of 430gm to overcome friction compared to 22gm required by pan #10 for the same purpose, that is justified due to the decrease of friction coefficient by the effect of submerging.

During the test, the procedure was repeated using different pans with a base extension increment of 0.5cm each time as mentioned in table-1, pan#1 with a base extension of 0.5cm to pan#9 with a base extension of 4.5cm. The mean level of water head required to mobilize each pan was recorded and listed in table-1.

It should be noted that these nine pans were different in boundary conditions than pans#0&#10, while pan#0 was mobilized immediately after overcoming the soil friction with its walls and pan#10 was mobilized after it was surrounded completely by submerged sand, in the case of these nine pans, see Fig.-2-c, there were the following factors influencing their bouncy:

- Generation of a mechanical resistance for floating due to the base extension.
- The surrounding soil was partially submerged.
- The slip surfaces were started from the end of the base extension upwards.
- The slip surface was not identical around each pan; it came close to the upper part of the pan's wall from one side and shifted away from another side. In other word no specific slip surface angle could be defined.

Table-2 Percentage of the difference between actual/ theoretical floating water head

Notation	Weight of stabilizing soil ring (gm)	Equivalent head (cm)	Theoretical head (cm)	Total required head (cm)	Actual Water head (cm)	Head difference percentage %
Pan #0	0000	0.00	2.33	2.33	3.7	+58%
#1	0320	1.00	2.41	3.41	4.3	+26%
#2	0543	1.73	2.50	4.23	5.3	+25%
#3	0820	2.61	2.58	5.19	6.0	+16%
#4	1023	3.25	2.68	5.93	6.8	+15%
#5	1185	3.77	2.77	6.54	7.5	+15%
#6	1323	4.21	2.87	7.08	8.1	+14%
#7	1448	4.61	3.00	7.61	8.6	+13%
#8	1538	4.90	3.10	8.00	9.1	+14%
#9	1594	5.07	3.20	8.27	9.6	+16%
#10	1650	5.25	3.30	8.55	10.0	+17%
						Σ = +17%*

*Pan #0 was not included.

A further calculation was done for each case based upon the bouncy force minus both of the weight of the pan and the weight of the composite, submerged& non-submerged, soil ring with a base equal to the extension of the base. Percentage of the actual extra water heads are shown in table-2. Excluding pan#0 with no base extension, the average actual water head required to mobilize the rest of pans having different base extensions is +17% greater than the theoretical required head, with a minimum of +13% for pan#7. As mentioned earlier, this increment is required to overcome friction forces which have different surface modes. Due to the accuracy in calculating buoyancy forces and all the weights of the pans and the surrounding soil rings, it could be concluded that protecting an underground circular tank against flotation can be done by adapting a weight of submerged/ non-submerged soil ring equal to the buoyancy force minus the weight of the pan/ tank. According to the required weight of the soil ring the length of the extension(x), see Fig.2-c, in any underground tank base can be determined by the following equation. This solution can guarantee an average safety factor of +17%:

$$V\gamma_w - w = \{(r+x)^2\pi - r^2\pi\}h_1\gamma_{sub} + \{(r+x)^2\pi - r^2\pi\}h_2\gamma_s$$

where: V = Volume of tank, γ_w = Density of water, w = Weight of tank, r = Outside diameter of the tank, x = Length of the tank's base extension, h_1= Underground water head measured from tank base level, γ_{sub} = Submerged soil density, h_2 = Height between soil top surface and underground water level, γ_s = Density of soil

The simplified form of the above equation can be written as follows:

$$2rx + x^2 = \frac{V\gamma_w - w}{\pi(h_1\gamma_{sub} + h_2\gamma_s)}$$

CONCLUSION

The following points can be concluded:

- Circular underground tanks are subjected to floating due to buoyancy forces created by the rise of water table level.
- Circular underground tanks constructed in soils having high water table levels should be stabilized against uplifting.
- Increasing the diameter of the base of an underground tank can increase its stability against floating.
- The required increment in the radius of the base of an underground circular tank can be safely taken equal to the thickness of a surrounding soil ring having a submerged/ non submerged weight, according to the highest expected underground water level, equal to the buoyancy force minus the weight of the tank.
- The mathematical derived equation for calculating the required base extension x is given as follows:

$$2rx + x^2 = \frac{V\gamma_w - w}{\pi(h_1\gamma_{sub} + h_2\gamma_s)}$$

REFERENCES

[1.] Chellis, R.D. (1992). Foundation Engineering, Chapter 7, McGraw-HILL Book Company, USA.
[2.] Darwish, A.M. "Anchoring of empty underground tanks against underground-water-induced floatation by using arched cable system", The IES Journal Part A: Civil & Structural Engineering, Vol. 1, No. 3, The Institution of Engineers, Singapore, August 2008.
[3.] Westbrook, R. (1984). Structural Engineering Design in Practice, 1st ed, Longman Inc., New York, USA.