Journal of Civil Engineering (IEB), 36 (2) (2008) 79-86

Journal of
Civil Engineering
IEB

Use of arched cables for fixation of empty underground tanks against underground-water-induced floatation

Ala'a M. Darwish

Department of Building & Construction
University of Technology, Baghdad, Iraq

Received 9 January 2008

Abstract

An empty underground storage tank, constructed within the fluctuating rise and fall of the underground water level, can be mobilized by an uplifting pressure equal to the weight of the displaced water minus the self weight of the tank. This research presents the detail of a suggested method to use Arched Cables to fix empty rectangular reinforced concrete tanks against any floatation caused by the uplifting pressure which might be generated by the rise of the underground water level. The equations required to design such system was demonstrated to show the application of the suggested procedure. Finally, it can be concluded that: the suggested arched cable, which is placed through a parabolic profile duct embedded in the concrete of the tank walls and anchored from its both sides by earth anchorages, has the ability of countering the uniformly distributed uplifting pressure by exerting a linear equivalent downward uniformly distributed force resulting in a more practical and economical solution to maintain empty tanks in their positions.

Keywords: Underground tanks, floatation of a tank, fixation of a tank, lifting up pressure, arched cables.

1. Introduction

Due to many aspects, a lot of storage tanks are constructed totally or partially underground. In some areas, like Iraq where this study was done, underground water level fluctuates very close to the ground surface, i.e. less than 0.5m. In such circumstances, there will be a huge uplifting pressure tending to float an empty tank in a way similar to a ship in a sea.

The magnitude of the uplifting pressure is equal to the weight of the displaced water minus the self weight of the tank. Of course this is a well known critical design case, which always has been taken into consideration by structural engineers (Westbrook 1984). The solution, some times, is done by increasing the weight of the tank to be greater than the weight of the displaced water. But for large size storage tanks this solution is not practical due to the increasing amount of the uplifting pressure. In such cases a raft foundation supported by several piles may be required. Even with this structural solution piles will be subjected to tension forces, as shown in Fig. 1.

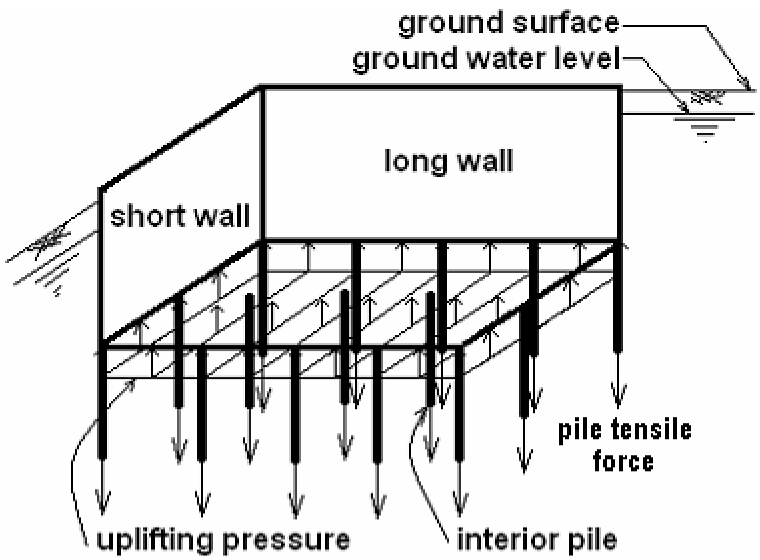

Fig.1- A bottom isometric view of a rectangular underground tank subjected to an uplifting pressure.

For a typical interior pile supporting an underground reinforced concrete tank with the following properties, 10m depth, 0.5m thick walls, and 2m on centre of piles, it is easy to calculate that: this interior pile will support a compression of 460kN, when the tank is filled with water and the ground water level falls below its floor, while it must be prepared to resist a pulling up tensile force of 300kN, when the tank is empty and the ground water level rises to its maximum.

In spite of the high cost of constructing pile foundations, it has many defects, which can be listed as follows:

- 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 unwatered excavations may reduce skin friction to less than hydrostatic uplift (Chellis 1992).

- Even if the piles will not be raised or lifted up, they will be subjected to a repetitive high tensile stresses. These tensile stresses may be greater than the pile's concrete tensile strength. Then, cracks near the pile heads can occur.

- 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 piles, because it was overburden 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 the rocky soil can do nothing to resist the tank floatation.

- From the structural point of view, tension forces in piles will vary between interior piles and exterior ones. This variation will increase the complication of the design process. While in the following suggested solution all the piles will be eliminated.

According to the above brief introduction mentioned above, the author feels that the current structural solutions to the problem of rectangular underground tanks floatation are not very satisfactory. In the present study a suggested solution for the mentioned problem will be presented. The suggestion includes the use of high tensile steel cables instead of piled foundations to stabilize underground empty tanks against floatation. These cables with their defined profiles and end anchorages have the ability to counter floatation forces in an active and economical manner.

2. Definition of the arched cable system

A typical storage tank is shown in Fig. 2. It consists of floor, roof, and four side walls. For any rectangular tank there are two long walls and the other two walls are short.

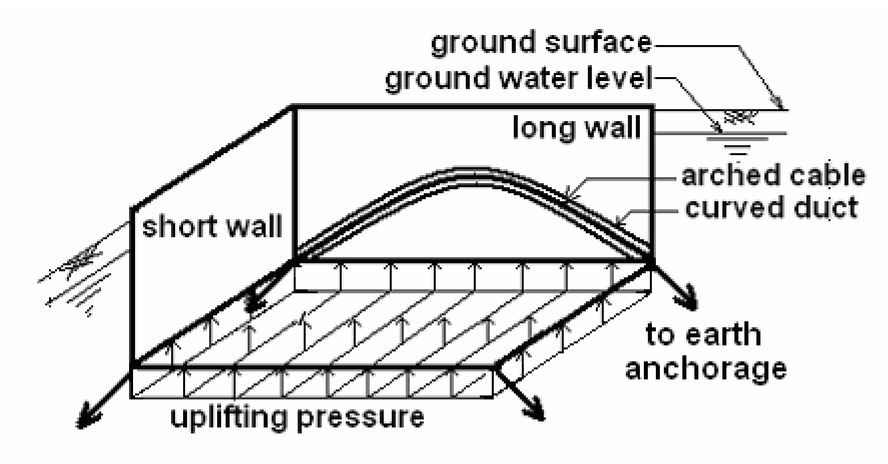

Fig.2- A typical rectangular underground tank stabilized by two arched cables.

Uplifting pressure due to the displaced underground water is a uniformly distributed upward pressure applied to the tank floor. If the two long walls of the tank can be fixed in their positions, and this is the aim of this research, then the design of the tank floor will be similar to a one way slab subjected to an upward uniform load.

A parabolic duct is required to be constructed inside the concrete of each of the long tank walls, as shown in Fig. 2. The path of each duct must pass through the wall two bottom corners and rise to a given height in the middle of the wall according to a parabolic equation (will be given later). A high tensile steel cable is required to pass through each duct taking its parabolic shape. Each of the two cable ends has to be well anchored to a soil anchorage. The anchorage has to be able to resist all the calculated vertical and horizontal forces or in other words to sustain the cable pulling out tensile forces. In this case, the adoption of four soil anchors, one under each tank corner, will eliminate the need for any pile leading to an acceptable escape from the mentioned problems that might be arise when pile foundations are used.

This system looks like an arch but actually it is just a cable, for this reason it is called the arched cable system. The system has the ability of exerting a downward uniformly distributed linear force subjected perpendicularly along each of the long tank walls. Each tank requires two arched cables to be fixed in its original place.

3. Govermimg equations of geometry & structural action of arched cables

According to the mathematical procedures used to derive the governing equations of the geometry and the structural action of arches and suspension cables (Wang 1962, Ramamrutham 1988 and Thomas-1974). The shape, length, reactions, tensile force and loading of arched cables can be derived as follows;

3.1 Vertical reaction V

The arched cable is not like other structural systems. It might have no end reactions if the tank floor slab is not subjected to any uplifting pressure. Moreover, it has no end reactions even due to its self weight. But if it is activated by a floating uplifting pressure, subjected to the tank floor slab, then there will be a great deal of end reactions.

Figure 3 shows an arched cable a, b. This cable is exerting a uniformly distributed stabilizing downward force *w* per unit run on the horizontal span *l*, so it will be subjected to a tension force *T*. Point *c* which is situated along the cable path is representing its highest point with respect to its end anchorages a, b. This maximum height is denoted by the symbol *h*. The vertical end reaction *V* at each anchorage is calculated according to the following equation;

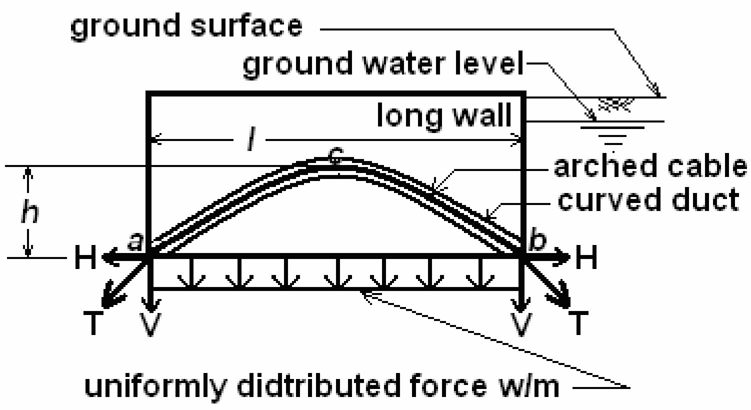

Fig.3-Type of loading exerted by an arched cable.

$$V = +\frac{wl}{2} \downarrow \tag{1}$$

3.2 Horizontal end reaction H

$$H = \frac{wl^2}{8h} \quad \text{Directed away from tank center} \tag{2}$$

3.3 Maximum Tension Tmax.

Maximum tension (Tmax) = Resultant reaction at a or b

$$\therefore T\max. = \frac{wl}{2}\sqrt{1+\frac{l^2}{16h}} \tag{3}$$

The tension force along the cable varies from its maximum at the cable ends to its minimum at point *c*. This is because of the elimination of the vertical component at point *c*.

3.4 Shape of the arched cable

Let the coordinate of any point p of the cable be (x, y) with respect to c, as shown in Fig.5. Let us consider the equilibrium of the part pc.

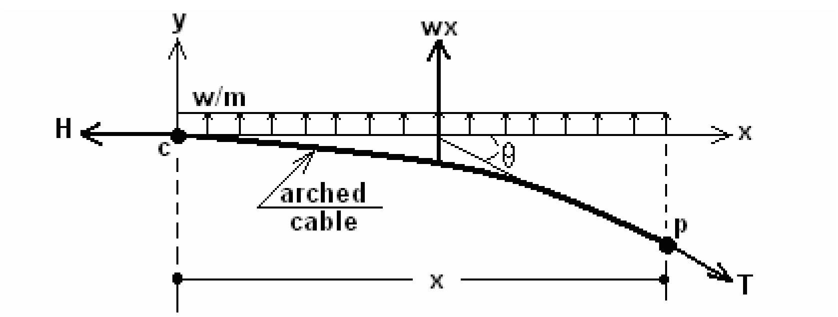

Fig.4 The forces acting on a portion of an arched cable.

The forces keeping the point p in equilibrium are the following:

i. External load (wx) acting perpendicularly upwards.
ii. Tension (To) = H acting horizontally at c.
iii. Tension (T) at (p) acting along the tangent at p.

Let ө be the inclination of the tangent at p with the horizontal. Resolving the forces on this part vertically and horizontally we get:

With either support as origin, the equation to the parabolic cable is:

$$y = \frac{4hx(l-x)}{l^2} \tag{4}$$

3.5 Actual length of the arched cable L

The actual length of the curved cable passing through the tank wall can be calculated by the following equation.

$$\therefore L = l + \frac{8h^2}{3l} \qquad (5)$$

In practice an additional extra length is required to link the cable with its end soil anchorages.

4. Example

To illustrate the use of the suggested arched cable system, a simplified reinforced concrete rectangular storage tank is shown in Fig.5. Its external dimensions of (20×8×10) m, and its roof, floor and wall thicknesses (0.5) m are all assumed to simulate the required procedure. Also, the highest underground water level is assumed to reach up to 0.5m below natural ground surface.

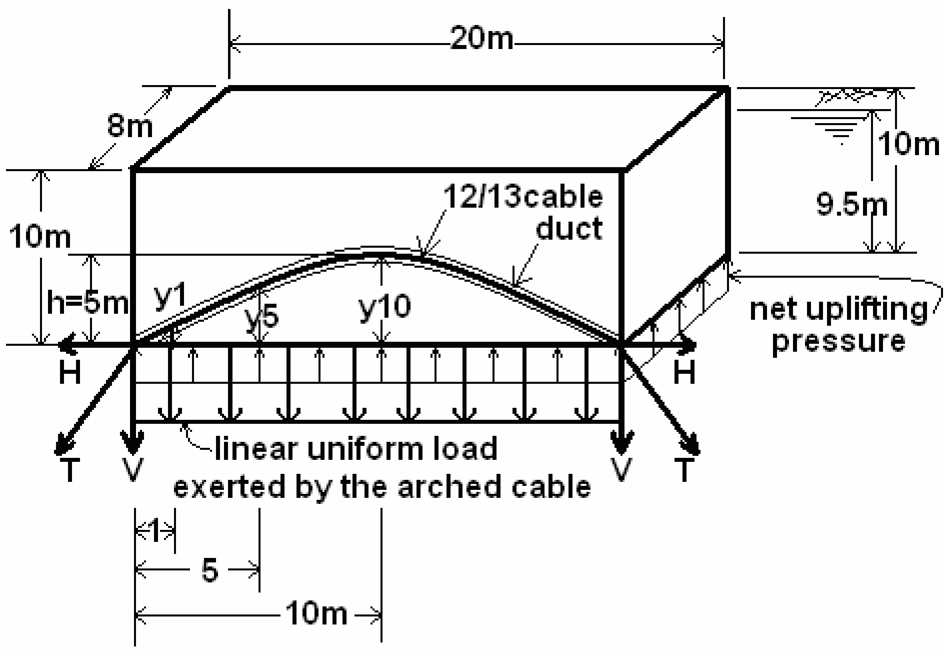

Fig.5- A rectangular reinforced concrete underground tank, stabilized against floatation by two arched cables.

Volume of concrete = (20×10×8)-(19×9×7) = 403m^3
Weight of concrete =403×25 = 10075*kN*

Weight of displaced water = 20×8×9.5×10 = 15200*kN*
Net uplifting force = 15200-10075 = 5125*kN*
Net uplifting pressure = 5125/ (20×8) = 32kN/m^2
Net uniform uplifting linear force/ long wall = 32×4 = 128 *kN/m*

Adapting a cable type 12/13 having the following properties (Westbrook-1984):
Strand diameter = 120.5*mm*
Cable diameter = 52*mm*
Strand c/s area = 94.2mm^2
Cable c/s area =1130mm^2
Ultimate load =1980*kN*
Initial force = 1380*kN* = 138*Ton*

- Vertical reaction V = *wl*/2=128×20/2 =1280*kN*
- Horizontal reaction H = *wl/8h* = (128×20)/(8×5) = 64*Kn*
- Maximum cable tension force T_{max}

$$T_{max} = \sqrt{V^2 + H^2} = \sqrt{(1280)^2 + (64)^2} = 1281kN$$

T_{max} = (1281*kN*) < T_{all} (1380*kN*) ⟹ O.K.

- Cable Length L

The actual curved length of the cable (extra length is required for End anchorages) is calculated as follows:

$$L = l + \frac{8h^2}{3L} = 20 + \frac{8 \times 5^2}{3 \times 20} = 21.7m$$

- Profile of the arched cable

The cable has to comply with the parabolic path of the duct. To calculate the coordinates of any point along this path, the following calculations show the coordinates of points at 1, 5 and 10m from the bottom corner of the tank long wall;
The parabolic equation of the arched cable is:

$$y = \frac{4hx(l-x)}{l^2} = \frac{4 \times 5 \times x(20-x)}{400} = \frac{20x - x^2}{20} = x - \frac{x^2}{20}$$

at x = 1*m* from left corner

$$y_1 = 1 - \frac{1}{20} = 0.95m$$

$$y_5 = 5 - \frac{25}{20} = 3.75m$$

$$y_{10} = 10 - \frac{100}{20} = 5m$$

* Note: it is required (by the same way) to calculate the coordinates of the cable each 0.5m, in order to make it easy to fix the duct and the cable during construction.

5. Conclusions

Conclusions have been drawn based on an approved theoretical solution for a practical case, as follows:

- An empty underground rectangular storage tank, constructed in an area of high underground water level, will be subjected to an increasing amount of lifting pressure directly proportional to the volume of the displaced water.
- Such tanks can be mobilized from its original positions due to the huge floating pressure.
- To fix such tanks, it is suggested in this paper that the use of two earth anchored curved profile cables in a system called the arched cable system. The parabolic geometry of each cable can exert a uniform downward force on each of the two long walls of the tank. The amount of the linear downward force can be well calculated to counter the uniform uplifting pressure which is trying to float the tank.
- By applying the arched cable system to an underground rectangular tank, it can be assured that the tank will remain stable and safe in its place.
- Using the suggested system can eliminate the use of the current disputed pile foundations.

References

Chellis, R.D. (1992), "Foundation Engineering", McGraw-HILL Book Company, USA.

George, B., Thomas, J. R. (1974), Calculus & Analytical Geometry, 4th Edition, Addison- India.

Ramamrutham, S. (1988), Theory of Structures, Hindustan, Offset Press, New Delhi,

Wang, C.K., (1962), Statically Indeterminate Structures, McGraw-Hill International Book Company, Tokyo, Japan.

Wesley Publishing Company, California, U.S.A.

Westbrook, R. (1984), Structural Engineering Design in Practice, 1st ed, Longman Inc., New York, USA.