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Circular tanks on two-parameter Wlasow's elastic subsoil

Abstract:
The calculations of concrete tanks in engineering practice are carried out by subsoil modeling using two hypotheses regarding subsoil:
- linear passive earth pressure at the foundation level
- Winkler's elastic subsoil (hypothesis of subsoil coefficient)

In accordance of the linear passive earth pressure assumption, one presupposes that subsoil reaction is uniform and linear if loading is symmetrical in respect of axis of a base slab or a foundation ring and trapezoidal linear in case of eccentricity of loading.
In accordance with Winkler's assumption, one presupposes that the displacement of the ground particle "u" is proportional with the vertical load "q" at this point; this results in q = C u.
Coefficient "C" is called **coefficient of subgrade reaction**. We can say, in this situation, that the displacement of any point depends on loading of this point but there is no influence of the surrounding load. Winkler's subsoil is often associated with group of springs not connected to each other (Fig.1a)

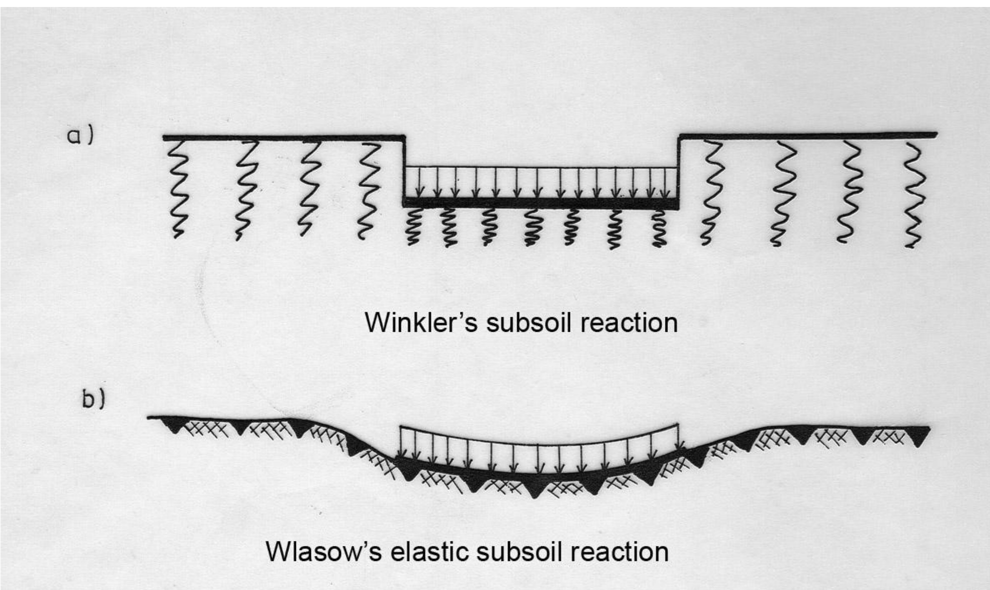

Fig. 1. Subsoil models development

Deficiencies of the linear subsoil reaction hypothesis are obvious because they do not consider subsoil characteristics and stiffness of a tank.

The Winkler's concept of subgrade reaction eliminates weaknesses of the first hypothesis. However, it also exhibits unrealistic model of the actual performance of subsoil. The coefficient of subgrade reaction "C" depends on physical characteristics of subsoil but do not consider shape of a tank and relations of an area of a tank base and its height. In addition soil settles down not only underneath a tank but around a tank what was seen with model experiments.

In structural analysis of circular tanks on subsoil below the ground water level we used to take evenly distributed subsoil reaction created by vertical forces along the edge of a tank slab. This approach leads up to calculation of large moments in the center of the slab as well as at the side wall connection with the tank slab what thickens the slab and the wall considerably. In the event the tank slab is above the ground water level one assumes that the base slab is on Winkler's subsoil. This assumption provokes internal forces concentration at the base slab around the point of applied load which are vanishing when we recede further away from the point of applied load. However, the numerical value of bending moments and normal forces are much smaller for the Winkler's model comparing with those calculated with assumption of uniform subsoil reaction.
In example of the circular tank with the diameter of 46 ft (14 m) and depth of the tank equal 16 ft (5 m), maximum tank slab bending moment at testing condition was about 80 % less than the same moment calculated with assumption of uniform subsoil reaction yet parallel force in the tank wall was around 40% smaller ([3] p.42). The effects of this specific subsoil model are pretty noticeable.

An elastic subsoil model is even more accurate when it takes into account physical characteristic of subsoil. Under the foundation of a tank in this model one has a homogeneous elastic body of deformable layer of soil with thickness "H", not restrained on sides. This model is suitable for the conditions of $H/R > 2.5$, where R stands for the radius of the base slab of a circular tank.
In practice we can simplify our calculations without sacrificing accuracy of the results if we assume that thickness of the soil stratum "H" is going to infinity. In conclusion we will get the subsoil model as a single half-space elastic space defined here as **two-parameter Wlasow's elastic subsoil**. The physical characteristics of subsoil in this model are defined by a modulus of subsoil reaction "E_o" and Poisson coefficient "υ_{gr}" which are independent from dimensions and a shape of the structure. The model of two-parameter Wlasow's elastic subsoil takes in effect shear forces in subsoil and vanishing vertical displacement (downwards) in the soil. The behavior of subsoil reaction is shown in Fig. 1b.

The solution obtained by support of references [8] and [2] and the results of model testing [1] which are compared with this work in [6]. <u>The results of this work were the basis for ZKM computer program elaborated in 1982</u> (program last updated in 2005). This computer program dimensions sections of the structure and reinforcement (authors of the program Marek Badowski and Roman Misiak). The program was demonstrated on Conferences [4] and [5] in 1985. The program became very popular in Poland and had been used to design a large number of tanks. <u>All the tanks built are in operation without any structural problems.</u>

In the example of a circular tank mentioned above [the radius of circular base slab is 46 ft (14 m) and depth of tank 16 ft (5 m)] we received big differences in forces calculated on the basis of Wlasow's subsoil and Winkler's subsoil models (Fig.2). Comparison of all internal forces indicates that the maximum parallel force in the tank wall on Winkler's subsoil is 14% greater than the same force taken from two-parameter Wlasow's elastic subsoil model but bending moments in the wall and the slab have opposite signs. Magnitude of extreme bending moments at wall received at the case of Winkler's subsoil are 76% greater but only 1% greater in the slab on two-parameter Wlasow's elastic subsoil.

Signs (plus, minus) difference in bending moments is provoked by assumption of Winkler's subsoil model where uniform loading of base slab (example – tank is filled up with a liquid) causes uniform settlement (all the assumed springs are cut short as in Fig.1a). In this model the edge of the slab does not rotate. Uniform loading of base slab on the whole area in a model of two-parameter Wlasow's elastic subsoil causes rotation of the edge of the slab (see Fig.3) what influences bending moment diagram in all elements of the circular tank and decreases parallel force in the wall.

The comparison described above lets us see benefits in using two-parameter Wlasow's elastic subsoil model when designing circular tanks. It indicates substantial savings in structural material as well as <u>proper placement and distribution</u> reinforcement in case of concrete tanks.

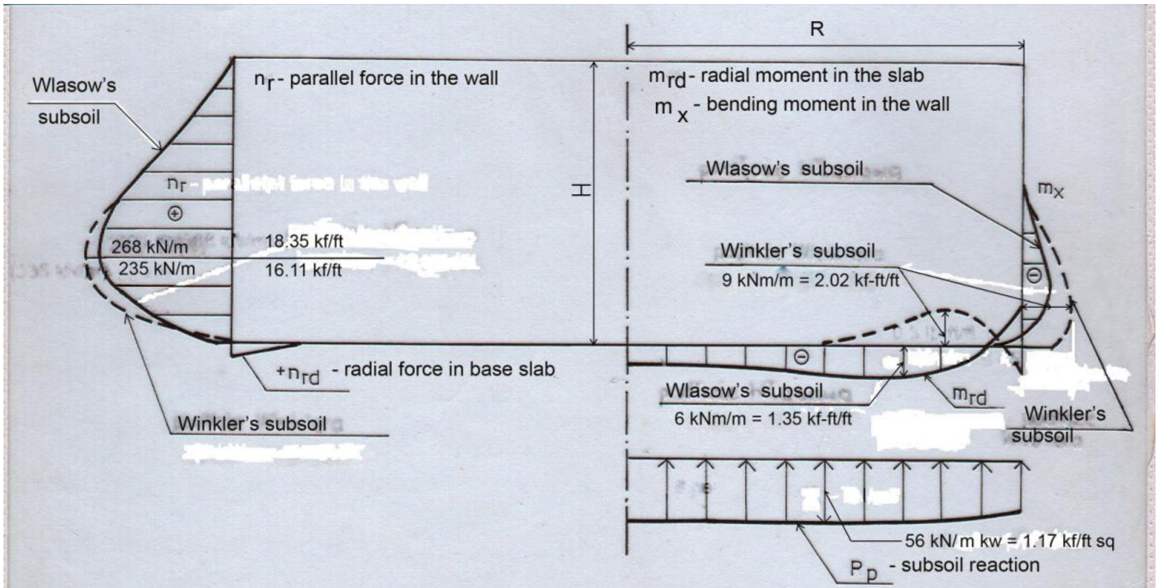

Fig. 2. Bending moments and force diagrams for circular tank [R=23' (7m), H=16' (5m)]

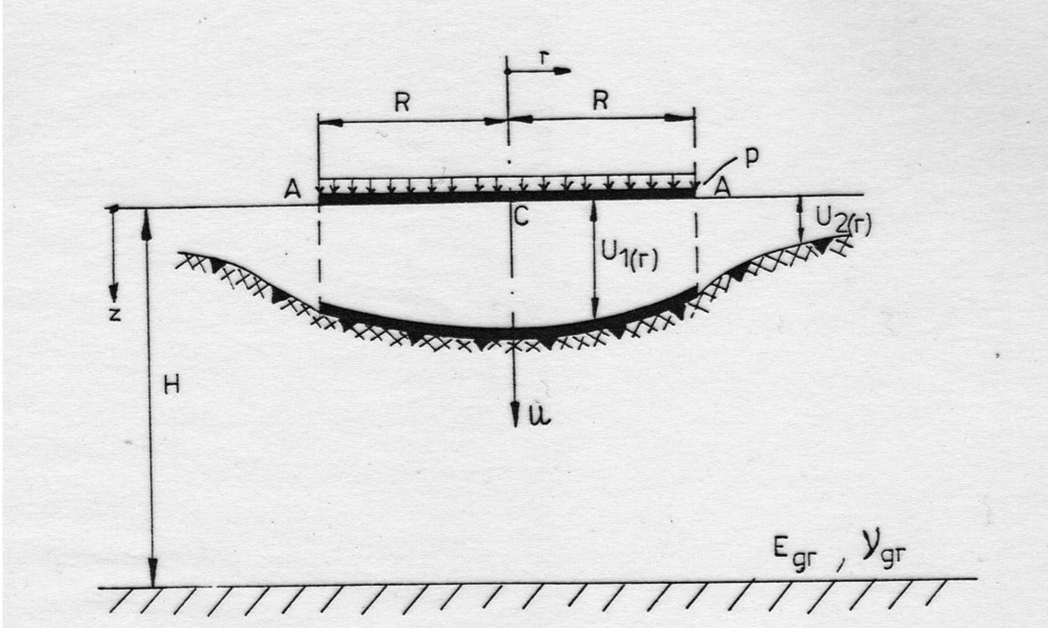

Fig. 3. Circular tank on two-parametr Wlasow's elastic subsoil

All above discussed issues are resolved in the work which can be seen on my website www.powlokiwybrane.pl in Polish and (some parts) in English. Solutions are presented with formulas adapted to the computer program where all internal forces, in any required section, can be found. Majority of static schemes used in practice for circular uncovered tanks are also solved in my work. The contents and references used in this work are listed below.

<u>Contents of my publication</u>

7. Examples of calculation

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