Construction Specifics of Oil Tanks with a Capacity of 20,000 m$^3$ on Large Strata of Collapsible Loess Soils

Mark Abelev, Dmitry Chunyuk and Olga Kopteva

Moscow State University of Civil Engineering, Yaroslavskoe shosse, 26, Moscow, 129337, Russia

E-mail: int207@mail.ru

Abstract. The article presents experience in compaction of a large stratum of collapsible loess soils (type II collapsibility) during the construction of 4 metal tanks with a capacity of 20,000 m$^3$.

1. Introduction

Modern metal tanks with a capacity of 20,000 m$^3$ are normally manufactured according to a standard design developed by ProektStalkonstruktsiya, LLC. These tanks are designed as a continuous tape of 12-18 meters wide rolled up around one carrier beam during transportation. When mounted, this roll unfolds, forming walls of a metal tank. A metal bottom made of welded sheets on a concrete or sand compacted base is arranged at the base of the tank. Such horizontal tanks usually have a diameter of 47 meters. After pouring oil products, a pontoon (float) is provided as fire prevention aids. The height of tanks is normally 12 meters, although metal tanks of this type have been recently manufactured 18 and 22 meters high.

Specifics of the arrangement of the base and foundations of such a tank is that according to requirements of designers of this project, the tank subsidence shall not exceed 30 cm. In case of large subsidence, there are cases of destruction of welds connecting steel sheets of walls of these tanks.

In cases where subsidence exceeds 30 cm, pile foundations are often used to completely go through a layer of soft and highly compressible soils and to rest with lower ends on slightly compressible soils that lie in lower layers of a geological section.

However, there are many cases when there are no strong layers below the layer of soft soils that could take up load transmitted by pile foundations. Such soil conditions are most often found near floodplain terraces of rivers and seashores, where transport lines are laid for the transshipment of produced oil from tanks into tankers.

For example, tank farms located in Iraq, Vietnam and in the south of China have soft water-saturated clay soils at their base with a thickness of up to 47 meters.

In many cases, large strata (of 20–50 meters deep) of collapsible loess soils lie at the base of tank farms located in China. In these cases, the use of pile foundations that would completely cut through a layer of soft collapsible soils is out of the question.
2. Overview

This article shares successful experience in the construction of a tank farm for storage of oil products composed of 4 metal tanks with floating pontoons located on a large stratum of collapsible loess soils.

According to data of engineering and geological surveys (wells are drilled to a depth of 25 meters) there are collapsible loess soils of type II collapsibility at the base of the site where the tank farm is located. Physical and mechanical properties of soils vary little in depth to 18-20 meters and are characterized as follows:

- bulk weight of the soil skeleton is 14.5 - 15.2 kN/m³
- natural humidity is 0.12 - 0.16

Collapsibility is characterized as follows:

- 0.014 - 0.016 at a pressure of 0.1 MPa
- 0.031 - 0.046 at a pressure of 0.2 MPa
- 0.048 - 0.066 at a pressure of 0.3 MPa

It is abundantly clear that at such a high degree of collapsibility, calculated values of subsidence are much higher than those accepted for this type of a metal tank.

It is worth mentioning that the composition of base loess soils includes a large number of highly soluble salts that would undoubtedly cause corrosion of concrete piles.

In connection with the above, the following pattern has been adopted to arrange the foundation of the farm tanks.

1. A ditch of 1.6 to 2.0 meters deep was dug at the base of each tank.
2. During engineering and geological surveys, many geological wells drilled to a depth of 25 meters were filled with fine sand, i.e. there were places at the base for penetration of water to great depths. Besides, additional wells were drilled on a 6*6-meter grid under the bottom of tanks and filled with sand as well.
3. Then, after drainage sand wells were arranged at the base of each tank, a sand cushion was made of coarse or medium sand (with a clay particle content below 3-7%).

After the arrangement of drainage wells and the sand cushion they began to supply water to all ditches under each tank.

To monitor subsidence around each tank, deep benchmarks were installed with their upper ends above the ground level. Their distortion allowed to judge about distortion at different points along the depth of the soil mass.

After water supply, the sand cushion demonstrated subsidence of base layers of collapsible loess soils in lower layers, i.e. at such depths, where the mass of the overlying stratum of the soil mass caused subsidence phenomena. Distortion was observed within 36-48 days.

It is worth mentioning that collapsible soils are compacted at pressures exceeding the initial subsidence pressure.

An embankment of 4.5 - 8.5 meter high was erected to cause subsidence of upper layers of the collapsible stratum at the location of each tank. The height of the embankment (set-on weight) was selected for the amount of pressure from the mass of this embankment on the sand cushion and underlying collapsible soils to exceed the pressure that occurs after the tank is put into operation.

So, for example, during the operation of an oil tank with a height of 12 meters, the pressure under the foundation bed amounted to 1.1 t/m², and the pressure at the base of the set-on weight embankment was 1.1 - 1.6 t/m², i.e. when there is the set-on weight embankment, the soil is compacted at greater pressure than during operation.

The analysis of subsidence monitoring results of installed depth benchmarks in the thickness of flooded collapsible soils rendered the following results:

1. By depth benchmarks after watering the tank site through the sand cushion prior to the erection of the set-on weight embankment, it was found out that the maximum subsidence of collapsible soils occurred from a depth of 16 meters and ranged from 8 to 42 cm. The subsidence was quite quick to develop and stabilized within 2 months.
2. After the erection of the set-on weight embankment, the subsidence of surface benchmarks increased dramatically and ranged from 14 to 27 cm due to compaction of the top layer of the collapsible soil. Subsidence stabilization lasted long and took from 2 to 6 months.

3. After the erection of the set-on weight embankment, during compaction of the soil mass, monitoring wells were drilled to sample water-bearing loess soils with the help of drilling-round sampling tools.

Studies were conducted in the laboratory of Spektr, LLC. Soil samples were analyzed to identify the following dependencies:

1. The degree of water saturation of soil samples was different and varied from 0.43 to 0.85. This is due to the heterogeneous structure of the soil mass.

2. Some soil samples rendered the value of relative subsidence to be as low as 0.02–0.03; the majority of samples turned out to be practically zero-collapsible.

3. Due to the fact that the operation technology of oil tanks involves an increase in the load when filling a tank, and a sharp decrease in the load when discharging oil products, in laboratory conditions, base soils were studied when loading a soil sample to a pressure of 1.3 t/m² with follow-up unloading to a pressure of 0.2 t/m². This loading/unloading pattern was applied to determine soil distortion performance and soil strength.

Subsidence values obtained by this laboratory research method are much better consistent with data of actually measured subsidence of tanks included in the tank farm.

Built on the basis of this technology, 4 metal tanks with a floating pontoon are successfully operated, although the maximum subsidence in 2 points of one tank was 36 cm. However, no cracks or damage to welds have developed.

Based on the foregoing, it can be concluded that during the construction of metal tanks with a capacity of 20,000 m³ on large strata of collapsible soils, the method of pre-watering the soil base with erection of the set-on weight embankment is a reliable way to build large tanks in difficult soil conditions.

In 1980, 2 metal tanks with a capacity of 20,000 m³ were built in the city of Grozny according to a project of ProektStalkonstruktisiya, LLC. When planning the location of 2 tanks with a capacity of 20,000 m³, a ditch of 0.5-1.3 m deep was dug to occupy a part of the site. According to data of engineering and geological surveys, collapsible soils lay at the base of this site to a depth of 16 meters. Those collapsible loess sandy loams and clay sand were underlain with a layer of non-collapsible semi-solid clay soils. The total covered thickness of that layer was 8 meters. Groundwater was not detected during the 1980 January-March survey. Studies of properties of loess soils were carried out in laboratory conditions, using consolidometers of the Gidroproekt design, as well as consolidometers and permeameters of the Nefteavtomatika (Oktyabrsky manufacturing enterprise) make. Studies were conducted using both the single-curve method at pressures of 1.0, 2.0 and 3.0 kgf/cm² and the double-curve method.

In addition, field investigations were carried out with the use of a pressuremeter of the Fundamentproekt design at a depth of 2.5 and 6.0 meters.

Besides, base soils were examined with stamping tools of S=600 cm² in wells at depths of 3, 5, 7 and 12 meters.

Results of those studies showed that collapsible loess sandy loams and clay sand underlying at the base are characterized by relative subsidence at a pressure of 3.0 kgf/cm² applied to a sample equal to 0.04-0.07.

Data obtained from soil studies in the pressuremeter were significantly different (by 8-12 times) from compressibility performance obtained at the base of stamping tools and results received in laboratory conditions with the use of consolidometers. That was explained by the fact that compressibility performance of loess soils of the base under study turned out to be different in vertical and horizontal directions (anisotropic properties).

According to results of engineering and geological surveys, a decision was made to arrange an artificial base under 2 tanks with a capacity of 20,000 m³ each. As suggested by Z. Z. Arsanukaev, a
soil cushion of local loess soil was arranged at the base of tanks. For that purpose, round ditches were dug to a depth of 4.0–4.5 meters at the location of each tank. Then, using an E-10011 cable excavator, soils were compacted over the entire ditch surface, dumping a heavy reinforced concrete rammer log weighing 7.0 tons from a height of 6.5-7.5 meters onto the base. The rammer log was dumped from 9 to 12 times for each track. With the last strokes of the rammer log, the lowering of the soil surface during ram molding did not exceed 1.0 cm (failure during ram molding).

After soils at the base of the open ditch were compacted with the heavy rammer log, additional engineering and geological surveys were carried out to select samples from the area compacted by the rammer log. Three prospect holes with a depth ranging from 1.8 to 2.6 meters were opened. Samples of the compacted loess soil were taken from walls of those prospect holes, using the cutting ring method. Those samples were studied in consolidometers to determine properties of compacted soils after ram molding.

The analysis of results of those tests showed that a compacted layer occurred after ram molding below the bottom of the ditch. The bulk weight of the compacted soil skeleton exceeded 1.65 t/m³ to a depth of 2.7 meters.

All samples from the layer under study turned out to be practically zero-collapsible at vertical pressures equal to 1.0 and 3.0 kgf/cm².

Below the area of 2.5 meters to a depth of 4 meters, collapsible soils were characterized by variable values of the bulk weight of the soil skeleton, ranging from 1.65 to 1.58 t/m³, i.e. the depth provided samples of soils with low subsidence (relative subsidence was 0.018-0.028).

The first layer of the compacted soil at the location of 2 tanks was followed up with a soil cushion made of local loess sandy loams and clay sand initially laid with rollers (with a layer thickness of 0.4-0.7 meters). After reaching a cushion thickness of 2.5 meters, recurrent compaction was carried out with a heavy rammer log previously used for the compaction of soils at the bottom of the ditch.

Despite the fact that the soil cushion filled in layers was compacted with rollers layer after layer, after reaching a total thickness of 2.5 meters, compaction of soils with a heavy rammer log led to noticeable compaction of soils in that layer. An average decrease in the soil surface of the compacted soil cushion after ram molding ranged from 20 to 35 cm.

The 2nd layer of the soil cushion to the bottom of the tank was arranged in a similar way. The total soil compaction at that site for 2 tanks took about 5 months.

When there were 6 meters of compacted loess soils at the base of the tank characterized by low values of the filtration coefficient, both tanks were mounted with a floating pontoon.

After putting the tanks into operation, geodesic benchmarks were provided along the perimeter of walls of each tank to monitor tank subsidence during operation.

Observations on operation of 2 tanks for 22 months showed that subsidence of geodesic benchmarks installed on walls of tanks varied from 4.0 cm to 14.0 cm. The subsidence was quickly stabilized during the first 6 months and did not change later.

3. Conclusion

The experience described above for the arrangement of bases for large storage tanks for oil products does not require the use of expensive and time-consuming pile foundations.

This is especially important when building in collapsible loess soils in earthquake-prone regions.
Reference

[1] Abelev M.Yu. Construction of industrial and civil structures on soft water-saturated soils. M., Stroyizdat 1983.
[2] Krutov V.I., Kovalev A.S., Kovalev V.A. Design and construction of bases in collapsible soils. M., ASB, 2013, 544 p.
[3] Tyapin A.G. Calculation of structures for seismic effects with a soil base. M., ASB, 2013, 392 p.
[4] M.Yu. Abelev, I.V. Averin. Determining the Deformability Characteristics of Sandy Soils at a Construction Base Using Field and Laboratory Techniques. Soil Mechanics and Foundation Engineering, 2019, Vol. 56, No 3, pp.7-11.
[5] N.F. Bulankin. Determination of the Pile Load Capacity of Collapsible Soils. Soil Mechanics and Foundation Engineering, 2020, Vol. 56, No 6, pp.15-18.
[6] A.A. Grigoryan. Some Design Characteristics of Foundations on Soils Prone to Slump-Type Settlement. Soil Mechanics and Foundation Engineering, 2015, Vol. 52, No 1, pp. 24-28.
[7] A.M. Dzagov, V.F. Sidorchuk. Settlements of cast-in-place piles subject to longitudinal wetting of soils prone to slump-type settlement. Soil Mechanics and Foundation Engineering, 2012, Vol. 49, No 5, pp. 12-18.
[8] M.N. Ibragimov, V.V. Semkin, A.V. Shaposhnikov. Soil Solidification by Micro-Cements. Soil Mechanics and Foundation Engineering, 2017, Vol. 53, No 6, pp. 26-31.
[9] Yu.N. Kozakov, N.F. Bulankin. Design of piles in soils prone to slump-type settlement. Soil Mechanics and Foundation Engineering, 2013, Vol. 50, No 3, pp. 10-13.
[10] V.P. Konовалов, S.G. Bezvolev, P.A. Konovalov. Preconstruction consolidation of weak saturated clayey soils by reinforcing limestone drains. Soil Mechanics and Foundation Engineering, 2012, Vol. 48, No 6, pp. 22-28.
[11] SP 24.13330.2011. Pile foundations.
[12] SP 45.13330.2017 "Earthworks, foundations and foundations".
[13] SP 47.13330.2016 Engineering surveys for construction.
[14] Filimonov E.A., Ustinov A.A. Special technologies for constructing the foundations of buildings in areas with water-saturated clay soils. Scientific, technical and production journal "Industrial and Civil Engineering" (PGS). 2011 No. 6. pp. 70-73.
[15] Chernov Yu.T., Kozmodemiansky V.G. Assessment of the parameters of ground vibrations excited by the movement of vehicles. Industrial and Civil Construction. 2009, No. 12. pp. 50-51.
[16] Chernov Yu.T., Kozmodemiansky V.G. Estimation of vibration parameters affecting soil properties. Industrial and Civil Engineering 2009, No. 11. pp. 54-55.
[17] Town planning code of the Russian Federation.
[18] Petrukhin V.P., Isaev O.N., Sharafutdinov R.F. Determination of the zone of influence of the construction of communication tunnels. Soil Mechanics and Foundations engineering. 2013. No. 4. pp. 24-27.
[19] Ponomarev A.B., Kaloshina S.V. Assessment of the influence of slab foundations being erected on the settlement of buildings in conditions of dense development. Soil Mechanics and Foundations engineering. 2013. No. 5. pp. 13-16.
[20] Minaev O. P. Development of dynamic methods for deep compaction of loosely bound foundation soils. Soil Mechanics and Foundations engineering. 2013. No. 6. pp. 21-23.
[21] Lavrov I.V., Ternovskaya V.T., Vinogradov Yu.A., Zharikov A.A., Agafonova O.V. Monitoring the condition of load-bearing structures, foundations and foundations of historical
buildings of the Moscow Kremlin. Soil Mechanics and Foundations engineering. 2014. No. 3. pp. 17-20.

[22] Ter-Martirosyan A.Z., Le Duc Anh, Manukyan A.V. Influence of soil liquefaction on the design bearing capacity of a single pile. Vestnik MGSU [Monthly Journal on Construction and Architecture]. 2020; 15(5):655-664. DOI:10.22227/1997-0935.2020.5.655-664 (rus.)