Geosynthetics - 7th ICG - Delmas, Gourc & Girard (eds) © 2002 Swets & Zeitlinger, Lisse ISBN 90 5809 523 1

Analysis of Improved soft ground under oil tank with GSC cushion

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ABSTRACT: In Nanjing, China, crushed stone reinforced by geosynthetic is used in improving soft subgrade under oil tanks, in conjunction with drainage consolidation. 5 oil tanks of 20,000 m^3 in volume have been constructed and they have been in good conditions since put into operation 10 yeas ago. This paper will discuss functions of geosynthetic stone cushion (GSC) in improving soft subgrade of the oil tanks, according to the observed in situ settlement, base pressure, pore pressure and lateral displacement etc.

1 INTRODUCTION

In Nanjing, China, crushed stone reinforced by geosynthetic is used in improving soft subgrade under oil tanks, in conjunction with drainage consolidation. 5 oil tanks of 20,000 m^3 in volume have been constructed and they have been in good conditions since put into operation 10 yeas ago. This paper will discuss functions of geosynthetic stone cushion (GSC) in improving soft subgrade of the oil tanks, according to the observed in situ settlement, base pressure, pore pressure and lateral displacement etc, so as to promote its use in practice.

The oil tanks, each with 20,000 m^3 volume, 40.5 m inner radius and 15.80 m hight, are constructed on the south valley flat of Yangzi River that is low and inundated sometimes. Ring bases are 2 m high, with ground level of EL 9.80—10.2 m, which is 3 m or so higher than original ground level. Total load, including fill and GSC, is 288kN/m^2 on original ground. The soft layer is thick, mainly including 16m mucky clay and 11.5m mucky silt, with low strength and high compressibility, as shown in Table 1.

Table 1. The parameter of each soil layer

Layer	Clay	Mucky clay	Mucky loam	silt
unit weight(kN/m^3)	18.6	17.5	17.6	18.5
water content(%)	31	46	41	31
void ration e	0.91	1.32	1.10	0.88
compressibility Index Cc	0.21	0.37	0.32	0.21
consolidation co-efficient(cm^2/s)	4.8-6.0	4.8-6.0	—	—
undrain strength Cu(kPa)	25	17	20	—
effective friction angle(°)	29	29	30	32
thickness(m)	1.5	16	11.5	>10

Oil tank construction and operation issues a much stringent requirement on subgrade. In addition to that subgrade, under 288kN/m^2 pressure, must be stable, whole tank incline ($\Delta s/D$) must be controlled in less than 4‰ and different settlement on tank base sides ($\Delta s/\Delta L$) less than 2‰. It is a ticklish issue regarding to thick and high compressible subgrade.

Because of large load and stringent requirement of tank and its soft subgrade, considerable settlement and different settlement will develop and the tank will even overturn unless the subgrade is improved. Therefore, it is necessary to select a ground improvement plan, economical and secure in technique. After compared with many ground improvement methods, such as pile, deep agitating with cement, vibro replacement stone column, etc., the synthetic reinforced stone cushion (GSC), in conjunction with preload drainage consolidation with sand well, shorted as reinforced cushion and preload drainage (RCPD), as shown in Fig. 1, was selected to improve the tank subgrade.

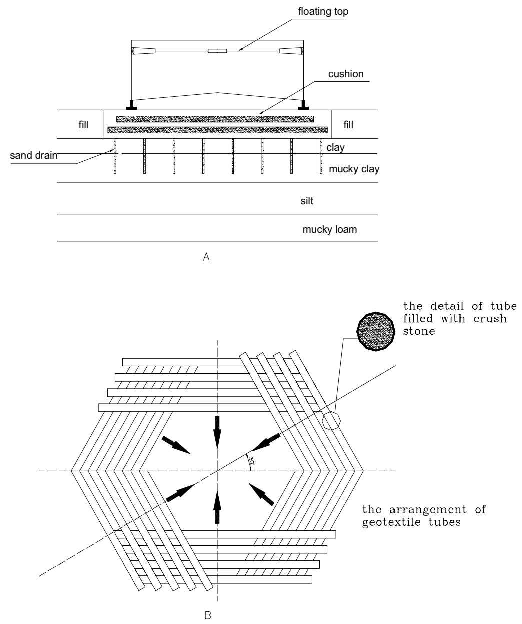


Figure 1.The profile of oil tank and the arrangement of geotextile tubes

The improvement plan I for the tank 5th consists of 4 m cushion, two layers (1 m high each) of long synthetic tube filled with stone and the other two layers (1 m high each) of stone layers, and sand drain of 16 m deep in subgrade. The synthetic tube layers and stone layers sandwiches each other, as shown in Fig. 1b. The synthetic tubes are made from polyprolene knitted fabric, with 2000 din, 300g/m^2, 2000—2500 N/5cm tensile strength, 35% ductility, 90625 kPa tensile modulus and 23° friction degree with sand. A synthetic tube layer consists of 3 sub-layers that, with 0.3 m radius, cross with 60° and sandwich some crushed stone, forming 1m thick geosynthetic tube layer. Sand wick (diameter is d_w = 70 mm) are laid in right triangle way, with 1.4 m distance. The wick are made of fabric tube compactly filled with sand whose permeability $k = 5\times10^{-2}$cm/s.

Different with the improvement plan I, the plan II uses geotextile to reinforce stone cushion, instead of geosynthetic tube filled with stone. The ground is natural one, instead of improved one.

Main ideas and purposes of the both improvement plans are:

(1) In order to solve the problem that the soft ground strength and bearing ability is not enough, the improvement

Table 2. Observation settlement under the oil tank 5

Items Location	GSC construction	Base con-struction	Settlement in Preloading 1st	2nd	3rd	Filling oil	Total settl.	In base bot-tom	Computed fi-nal settlement
In center/mm	264	315	1544	158	33	10	2324	1745	2477
In side/mm	178	201	1082	84	90	10	1645	1266	1780
Accum.diff. Settlement/mm			87	94	101	96			
Diff.settl. be-tween center & side	86	114	462	74	-57	0	679	479	667
Load/kN/m^2	80	130	296.6	279.1	279.0	253.8			
Lasting time/day	219	72	347 (147)	65 (41)	60 (0)	1 (1)			

Note: in ( ) is data during const. Preload with water; Total settl. is total settlement since GSC construction.

plans makes use of sand wick and preloading tank with water to make the subgrade consolidate and its strength increase so that the bearing capacity and stability would meet the requirement of tank load.

(2) Due to the large resisting capacity of tension cracking, strength and rigidity, the thick GSC would disperse load, make base pressure even, adjust different settlement and make large local settlement less so as to effectively control large settlement and different settlement of the tank base and base plane.

In order to guarantee the normal operation and to monitor changes during preloading, this project set up observation instruments, such as those for settlement, deep settlement, base pressure, lateral displacement and pore pressure, etc., and conducts long period of observation and study.

2 IN SITU OBSERVED RESULTS

2.1 Settlement

The settlement observation locations are under base, around base and under cushion. Settlement is measured with cup-settlement gauges and leveling gauges. The measured results during GSC and base construction and tank preloading are shown in Table 2 and Fig. 2.

According to the results, after the 3 times of preloading with water, tank base settlement gradually reached a stable value. The first oil filling produced only 10 mm settlement and 10 years since tank construction the settlement is less than 200 mm. Therefore, it is believed that the preloading consolidation has a good effect. The ratio of the different settlement between tank center and side (Δs) to the tank radius (ρ), $\Delta s/\rho = 0.97\% < 2.0\%$ (design standard); the ratio of the different settlement on ring base sides (Δs) to tank diameter (D), $\Delta s/D = 2.35‰ < 4‰$ (design standard); base inclination in a plane is $1.9‰ < 4‰$.

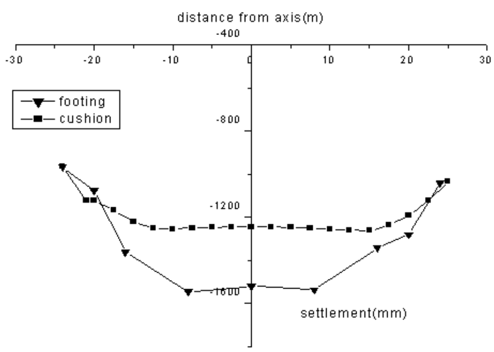


Figure 2. the settlement profile at the bottom of footing and at the bottom of cushion

All of above meet the tank design standard. As a result, tank base plane is basically level and no concavity, steep slop and punching occurs.

2.2 Base Pressure

Earth pressure cells are buried under base and GSCs to measure the base and cushion pressure during preloading. The observed results are shown in Fig. 3. In Fig. 3, upper, middle and bottom group curves are the observed pressure under base, the first GSC and the second GSC layer respectively, of different preloads. According to Fig. 3, the pressure distributes even and disperses gradually laterally as depth increases. The dispersion widths are 4 m and 8 m for the first and the second GSC, respectively, which is about twice the pertinent depth.

In order to analyze the pressure dispersion, the relationship between loads and the average of the pertinent observed pressure are shown in Fig. 4. The average of the base pressure is basically same as load, which means that the tank base is basically flexible. Load laterally disperses due to GSCs. The pressure under the first GSC is 77% load and that under the second GSC is 73%. Per as the observed pressure under the base and GSCs, stress dispersion agree α is 55° in the first GSC and 40° in the second GSC, which are larger than that usually used for sand cushion and means that GSC has a more obvious stress dispersion function.

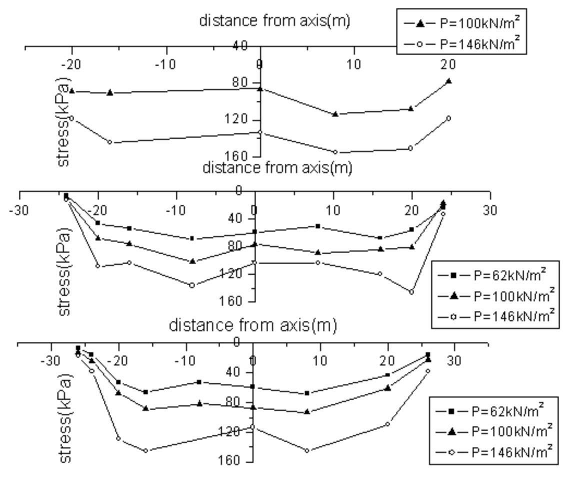


Figure 3. the pressure distributes with depth

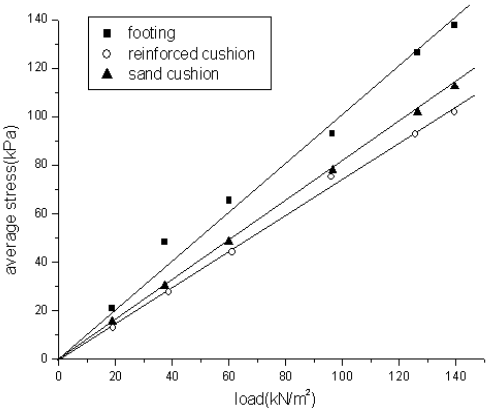


Figure 4. The average stress in different conditions

2.3 Lateral Deformation

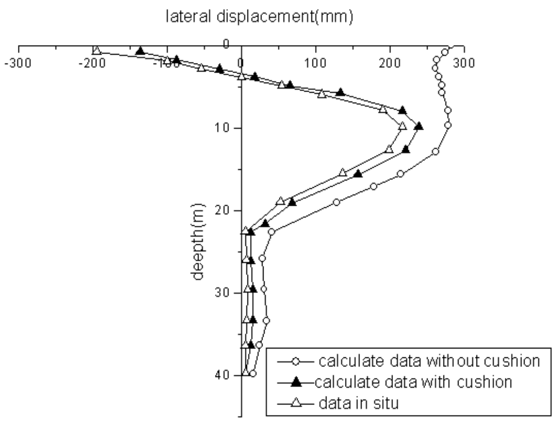


Figure 5. The lateral displacement in situ and calculated

Typical lateral deformation results are shown in Fig. 5, with following features: (i) lateral displacement increases as load increases. After and during the pertinent load is exerted, lateral deformation decreases, due to drainage consolidation; (ii) lateral deformation distribution is parabolic and dependent on soil property; (iii) the maximum lateral deformation occurs in the middle of pertinent soil layer; (iv) under the cushion and under but near the interface of soil layers negative lateral deformation, about 200 mm, occurs. Per as analysis, it is believed that it is because GSCs have large tensile strength and develop resistance to lateral deformation.

2.4 Pore Pressure

In tank subgrade, 24 piezometers are set up to monitor pore pressure changes due to preload and to analyze the subgrade consolidation and stability. Herein are some features of the consolidation and stability.

(1) The observed results show that as preload increases pore pressure increases quickly; during intermittent of preloading, pore pressure dissipates; after the third preloading, pore pressure dissipates to a very little value, consolidation degree U $\geqslant$ 90%.

(2) Accumulated preload ($\Sigma\Delta p$) and pertinent accumulated pore pressure ($\Sigma\Delta u$) can be got from the observed results. The curve of the accumulated preload with the pertinent accumulated pore pressure is linear and the ratio of the accumulated pore pressure to the accumulated preload, $K_u = \Sigma\Delta u/\Sigma\Delta p$, is constant. Per as theory and laboratory test, if K_u is a constant without sudden increase and nonlinear change, the soil nearby pertinent piezometer is belong to normally compressive deformation and no shear failure would occur. According to the monitored results, in most of the piezometers, K_us are constants (0.13—0.69). Therefore, it is believed that the tank subgrade is stable.

To summarize, according to the monitored pore pressure, the tank subgrade is stable during preloading, consolidate quickly and meet the requirement of the tank load.

3 GSC PROPERTY ANALYSIS

3.1 Analysis Methods

In order to study GSC property and its affection factors, this paper uses 3 analysis methods.

(1) Linear elastic finite element method (LEFE) takes GSC as a transverse isotropic composite material whose stress-stain relation can be got from test. LEFE can take consolidation into consideration, using Biot consolidation theory. LEFE can also conduct back-analysis of parameters, based on observed results. The GSC stress-strain relation, taking anisotropy and nonlinear into consideration, is

$$E_{vt} = \frac{3p^2(1-2\mu_{vt})}{A_{rs}[3p-q-(6p-q)\mu_{vt}]}(1-\frac{q}{p}B_{rs})^2 \tag{1}$$

$$E_{nt} = nE_{vt} \tag{2}$$

$$G_{vt} = mE_{vt} \tag{3}$$

in which $p=(\sigma_1' + \sigma_2' + \sigma_3')$, $q=(\sigma_1 - \sigma_3)/2$;

A_{rs}, B_{rs}—composite property parameters of cushion; m, n—parameters of anisotropy; E_{vt}, μ_{vt}—tangent modulus and Poisson's ratio. In analysis, laboratory test results of geosynthetic reinforced sand are used: A_{rs}= 0.004, B_{rs}= 0.3; μ_v= 0.3, μ_h= 0.33; m= 0.38, n= 0.9; coefficient of permeability k_r=k_z= 10^{-4}cm/s. For pure stone cushion, A'_{rs}= 0.007, B'_{rs}= 0.6.

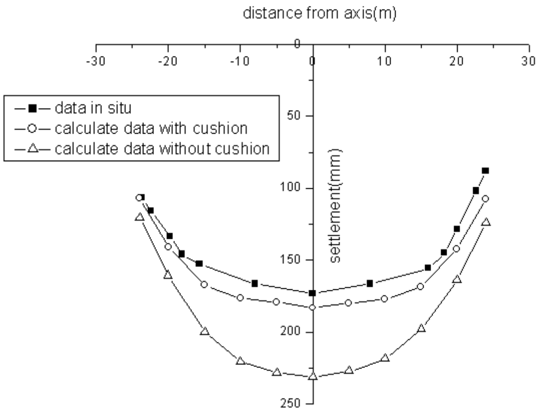
(2) Elastic-perfectly plastic finite element method (EPPFE) takes GSC as a linear elastic-perfectly plastic material and analyze problem using axial symmetry finite element program Plaxis that can take consolidation into consideration. In analysis, geotextile is taken as a very thin tension resistance material with tensile stiffness J = 600 kN/m, Yang modulus of GSC, 8×10^4kPa and composite modulus of GSC, 12×10^4kPa.

(3) Double parameter method (DP) takes GSC as an elastic plank undertaking horizontal tension under the tank load and takes ground as Winker material. DP resolves cushion bottom settlement (vertical displacement) and stress in cushion, using DP (K.T) methods in Poisson-Kitchhoff circle plank theory on elastic subgrade. In analysis, given GSC composition modulus and stone friction agree, in conjunction with settlement analysis, the parameters K and T and then cushion bottom settlement and pertinent stress can be solved out.

3.2 GSC Effect On Tank Bottom And Subgrade Deformation

Fig. 5 and Fig 6 show distribution of lateral deformation with depth and tank base bottom settlement, analyzing by LEFE, considering GSC cushion or only pure stone cushion. In analysis, according to observed results, model parameters are back-analyzed, considering GSC cushion or only pure stone cushion. Then compute tank base settlement and lateral deformation with GSC cushion or pure stone cushion and compare the results with the observed data, as shown in Fig. 5 and Fig. 6. From the Figures, it can be seen that the computed results are near to the observed data, which means that the used parameters are practical and reasonable. Comparing the conditions with GSC cushion or pure stone cushion, it is obvious that due to GSC cushion, tank center settlement decreases and tank base settlement is even, like a shallow sausage, which is benefit to oil tank project.

Figure 6. The tank base bottom settlement



Regarding to lateral deformation, pure stone cushion develops outward displacement that is the largest in shallow part. However, with GSC cushion, in shallow part of tank, ground lateral deformation is inward and negative displacement (200—300 mm or so) occurs, which means that GSC cushion, with large tensile strength, resists shallow subgrade lateral displacement and improves ground stress and strain field. This is benefit to tank stability and decreasing deformation.

3.3 Effect Of GSC Thick And Composition Modulus

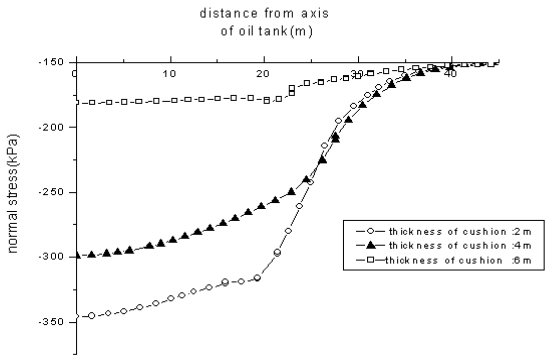


Figure 7.the effects of thickness

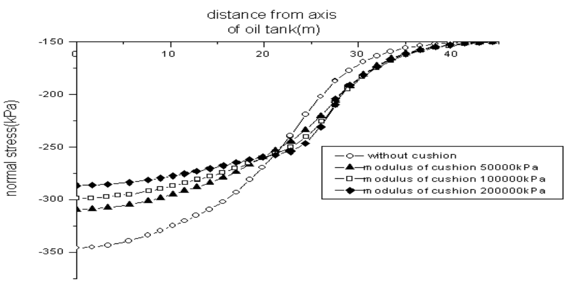


Figure 8. the effects of modulus

Fig. 7 and Fig. 8 are effects on tank base settlement of GSC thickness H and composition modulus E_b, analyzed with EPPFE. From the Figures, it can be seen:

(1) As the GSC thickness increases, tank base settlement decreases and gradually becomes even. Therefore, GSC plays a role on adjusting settlement.

(2) Increasing GSC composition modulus E_b can also reduce base settlement but not so obviously as the thickness does.

It is known, according to the analysis results with DP method, that the effect on base settlement of GSC thickness H and composition modulus E_b should not be independent. Contrarily, the effect should depend on the flexural rigidity (D) of whole GSC cushion that includes cushion thickness H and modulus E_b:

$$D = \frac{E_b H^3}{12(1-\mu^2)} \tag{4}$$

That means that GSC cushion should have enough thickness and tensile modulus E_b so that GSC can not been cracked by tension and no shear failure occurs. For only with whole uncracked GSC cushion, can it form flexural rigidity D, reduce base settlement and adjust uneven settlement. Analysis results with DP method also show that the thicker the GSC cushion, the more obvious its effect on base settlement adjustment. This is very useful in practice. In GSC cushion design, it must be required to use geosynthetic of high tensile strength and cushion material of high strength and to guarantee that whole GSC cushion is un-cracked and no shear failure occur.

4 CONCLUSION

1. Observation showed that it is reasonable to treat the soft foundation under the oil tanks with GSC cushion together with drainage consolidation. It is effective to adjust the differential settlements of the oil tank as well as improving the bearing capacity of the foundation.

2. The GSC cushion can increase the lateral tensile resistance of foundation, confine the lateral deformation and retain the completeness of the cushion. So it can change the displacement field of shallow subsoil below the cushion, as well as improve the bearing capacity of foundation. It also can diffuse the load, make stress even on subsoil, as well as adjust the deferential settlement of the tank.

3. Theoretical analysis and observed in situ results show that the effect of GSC cushions are mainly affected by the flexural rigidity $D = E_b.H^3/[12.(1-\mu^2)]$, including the cushion thickness *H*, the composite modulus E_b, the width of the cushion the number of layers, the reasonable layout of the reinforcements. Among all factors above, the depth H affects the effect the composite modulus at the greatest degree.

Reference:

Qian, J. H & Yin, Z.Z. 1996. Geotechnical mechanic and calculation. Beijing: the Water conservancy and waterpower Press.

The design and research of using reinforced cushion together with drained consolidation to treat soft clay subgrade. The civil engineering department of Zhejiang University. 1990.

Suzuki, O. 1988.The lateral flow of soil caused by banking on soft clay ground. Soils and Foundation 28(4): 1-184.

José Leitão Borges, António Silva Cardoso.2000. Structural behavior and parametric study of reinforced embankments on soft clays. Computer and Geotechnics 23: 209-233.