Ground Improvement of Oil Storage Tanks Using Stone Columns

Modificación del Terreno para Tanques de Almacenamiento de Petróleo Utilizando Columnas de Piedra

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Abstract

This article describes the design, quality control and performance of vibroreplacement stone columns which were conducted for liquefaction mitigation and settlement control under the foundation of steel oil storage tanks in Poti Oil Terminal, Georgia. In the first phase of the project, four oil storage tanks with varying diameter ranging from 18.50 m to 28.50 m were constructed. The subsoil consists of 20 m thick loose to medium dense silty sand underlain by 15 m thick medium stiff to stiff clay. The groundwater table was located at 1.5 m depth. The recommended geotechnical design consisted of mitigating the liquefaction and reducing settlement using vibroreplacement technique. 1.0 m diameter stone columns down to 15 m depth were installed which corresponds to area replacement ratio of 12.5%-16.5%. Standart penetration tests were performed under each tank, prior to and after improvement of the soil. The results of preliminary and post improvement tests and observed settlements during hydrostatic tests were presented and discussed.

Resumen

Este artículo describe el diseño, control de calidad y funcionamiento de columnas de piedra instaladas por medio de vibro-sustitución, para la mitigación de la licuación y control del asentamiento bajo la cimentación de los tanques de acero para almacenamiento de petróleo en el Poti Oil Terminal, Georgia. En la primera fase del proyecto fueron construidos cuatro tanques de almacenamiento de petróleo con un diámetro variable entre 18,5 y 28,5 metros. El subsuelo consiste en arena gruesa limosa, suelta a media, de 20 metros de espesor que suprayace un estrato de 15 metros de espesor de arcilla media a rígida. El nivel freático fue localizado a una profundidad de 1,5 metros. El diseño geotécnico recomendó la instalación de columnas de piedra de un metro de diámetro y 15 metros de longitud construidas por vibro-sustitución, las cuales mitigarían la licuación y reducirían el asentamiento. Esta instalación corresponde a un cociente de reemplazo del área del 12,5 % al 16,5 %. Ensayos de penetración estándar fueron realizados bajo cada tanque, antes y después de la modificación del suelo. Se presentan y discuten los resultados de ensayos preliminares y post-mejoramiento y asentamientos observados durante ensayos hidrostáticos.

1 INTRODUCTION

The Port of Poti is located on the Eastern side of the Black Sea in Georgia. The port is the oldest and the most important gate of Georgia connecting Europe and Central Asia since 1858. The Port of Poti is one of the major ports for exporting Caucausus oil to world market. In January 2002, construction of a new oil terminal having 3.5 million ton annual capacity has started in the Port of Poti. The Client is Channel Energy Ltd. a joint venture between Channel Energy and Poti Sea Port. Civil and Mechanical Contractor is Ustay Construction Company. Kasktas Piling and Drilling Company has undertaken soil investigations and soil improvement works.

2 PROJECT DESCRIPTION

The project includes installation of 8 large diameter oil storage tanks and handling equipment for the on-shore storage facility to be built in two phases. In January 2002, construction of the first phase consisting of 4 tanks has been started. The first phase of the project have been in operation since August 2002. The second phase of the project is under construction since May 2002.

In this article, soil improvement works of the first phase of the project shall be presented.

Lay out plan of the oil storage tanks and structures constructed in the Phase-I is shown in Figure 1. Two of the tanks had a diameter of 28.50 m. The diameters of third and fourth tanks are 24.50 m and 18.50 m respectively. All the tanks had a height of 18 m which is the maximum allowable height for oil storage tanks specified by API 650 (1984).

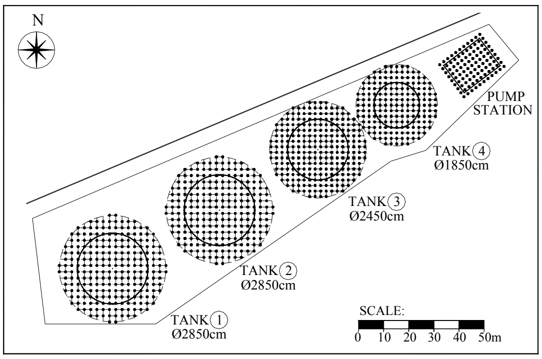

Figure 1 – Site Plan

3 SUBSOIL CONDITIONS

A total of 20 boreholes were carried out to a maximum depth of 35 m in order to determine the soil profile and engineering properties of soil layers. Supplementary soil investigation was completed by Kasktaş in March 2001. Four boreholes down to 35 m depth at the location of each tank were carried out with SPT in accordance with ASTM D-1586.

The site is situated on a river delta. The alluvium transported by the river streaming through the port till 1940's has formed the river delta formation. The geologic structure of the site consists of quaternary marine and terrestrial polygenetic sediments. According to existing data the depth of quaternary sediments exceeds 200 m in the city of Poti.

The subsoil conditions below the tank locations typically consists of 1.5 m fill overlying 20 m thick loose to medium dense silty sand. Silty sand is underlain by 15m thick medium stiff to stiff clay. Groundwater is encountered at a depth of 1.5 m.

Generalized soil profile is shown in Figure 2. The engineering properties of the soil layers are summarized in Table 1. Grain size distribution of the soil samples taken from silty sand layers is given in Figure 3.

Table 1. Engineering Properties of Soil Layers

Soil Classification		γ_n (kN/m^3)	w_n (%)	I_L (%)	N (average)	Deformation Modulus (MPa)
2	SP-SM	17.5	25	-	8	10
3 - 4	SP-SM	17.2	29	-	10	12
5 - 6	CL	17	40	75	12	15

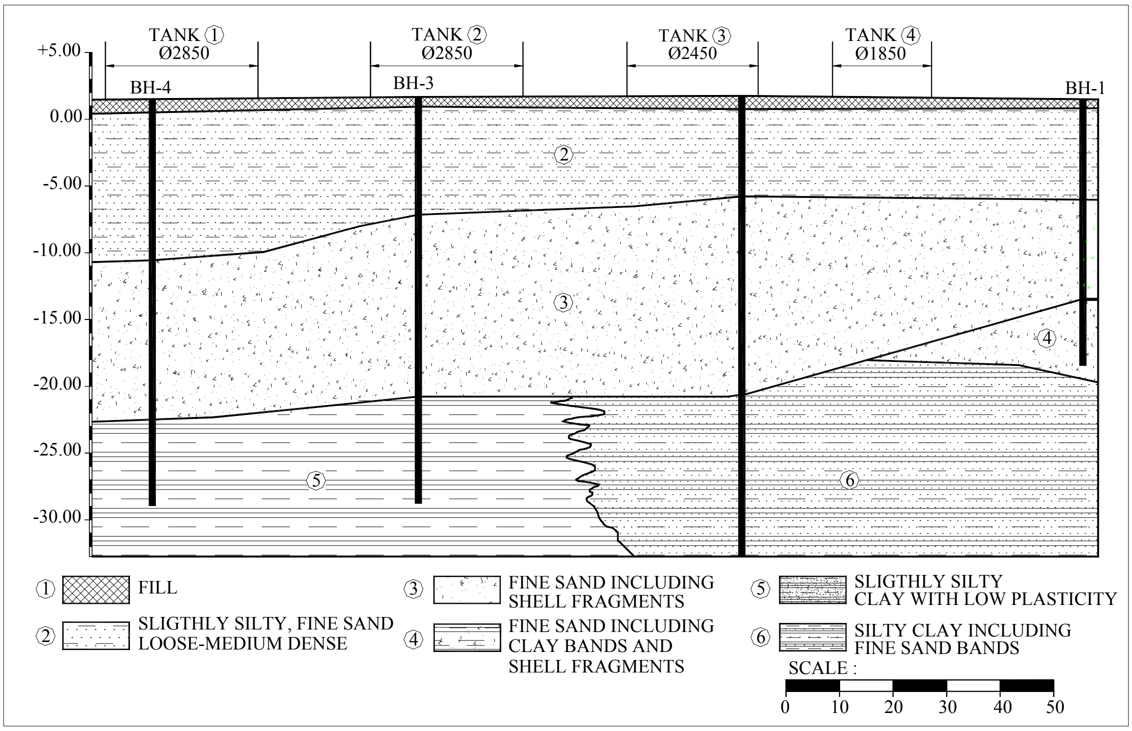

Figure 2 – Generalized Soil Profile

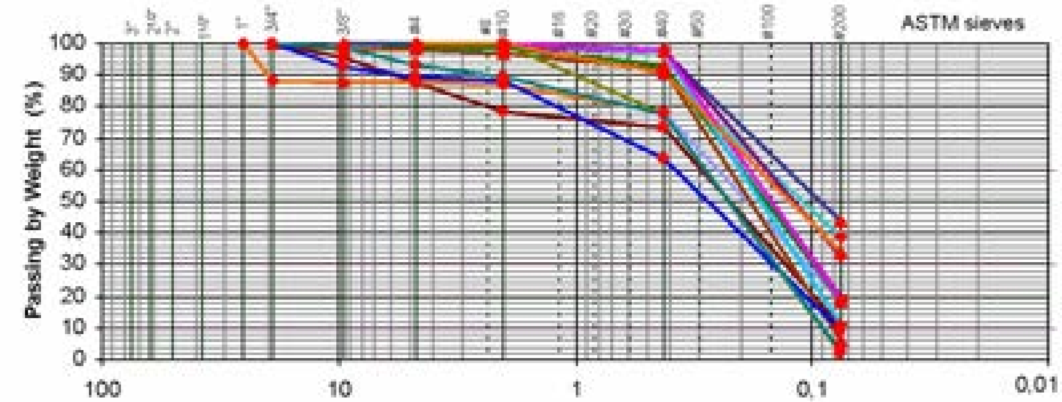

Figure 3 – Grain Size Curves (Between 1.50 - 15m)

4 FOUNDATION DESIGN

Maximum base pressures of oil tanks are determined as 153 kPa and 180 kPa at the time of operation and hydrostatic test.

A reinforced concrete ring wall with a combination of compacted granular fill made up the original foundation design.

4.1 Liquefaction

The magnitude of the expected earthquake for the region is given as 6.2 according the Richter scale (MSK intensity VIII). Maximum ground surface acceleration of a_{max}= 0.20 g is used in liquefaction analyses.

The liquefaction potential was evaluated using the method proposed by Seed and Idriss (1971) which utilize SPT data.

All tanks founded on silty sand strata were found to be susceptible to liquefaction under an earthquake magnitude of 6.2 and surface ground acceleration of 0.20 g.

4.2 Settlement

A settlement analysis was performed to predict the deformations and identify tanks susceptible to excessive settlement. The analysis included immediate and consolidation settlements. Janbu and finite element methods (Plaxis 7.2) were used to predict settlements. Settlement at the center and the edge of the tanks predicted by each method are summarized in Table 2.

Table 2. Predicted Settlements before improvement

Tank No.	At the center (mm)		At the edge (mm)	
	FEM	Janbu	FEM	Janbu
1	265	277	140	160
2	265	301	140	178
3	337	267	184	151
4	309	233	169	136

Settlement analysis yields a maximum value on the order of 337 mm. Though, there is not a rigid criterion limiting the total settlement of steel oil storage tanks, it is well known the fixed and floating roof oil tanks are susceptible to tilting. The allowable angular distortion of the steel tanks with fixed and floating top are given as 1/125 and 1/300-1/500 respectively (Settlement Analysis, 1994). Even though predicted settlement values summarized in Table 2 are within the tolerable limits, the specified distortion limits might be exceeded due to very loose silt pockets.

Based on the results of analysis summarized above, it was concluded that the subsurface soils underneath each tank to be improved. Several methods were proposed for soil improvement (Güler and Çetin, 2000). Jet grout columns, steel displacement piles and stone column alternatives were evaluated. Vibroreplacement method was found appropriate for ground improvement considering the local conditions.

4.3 Design of Stone Columns

Two approach's are basically available for the design of stone columns e.g. semi-empirical, analytical methods (Barksdale and Bachus, 1983) and finite element method. Pribe (1995) method and finite element method were utilized to predict settlements after soil improvement. Predicted settlements after stone column installation are given in Table 3.

Table 3. Predicted Settlements After Improvement

Tank No.	At the center (mm)		At the edge (mm)	
	Plaxis	Priebe	Plaxis	Priebe
1	161	214	95	129
2	161	245	95	151
3	153	195	98	111
4	121	161	81	97

Current liquefaction mitigation design approaches in the United States consider an increase in soil density only; the ability of the stone column to act as a drain and the stiffness of the stone column are not usually accounted for in the design approach. However, in Japan, stone columns that are installed without densification are designed to act as pore pressure dissipation sinks in the event of an earthquake (Elias et al, 1999). Design method proposed by Priebe, the stiffness and drainage properties of the columns are taken into account. According to Priebe, minimum SPT N values to be achieved after column installation are given in Figure 5.

Based on recent investigations conducted by Mitchell et al. (1995), a treatment width beyond the perimeter of a structure equal to the treatment depth is recommended. In Japan (Japanese Geotechnical Society, 1998) the recommended treatment width for oil tanks are summarized in Figure 4. The stone columns were extended 7 m lateral distance beyond the perimeter of the oil ta .

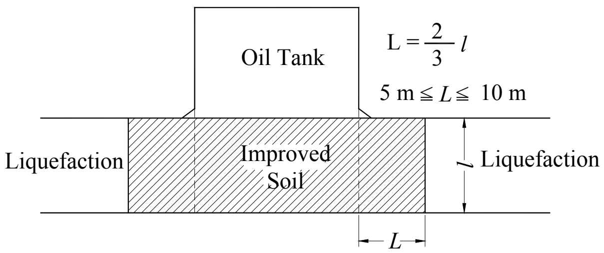

Figure 4 – Improvement Zone for Oil Tanks (Japanese Geotechnical Society, 1998)

5 CONSTRUCTION

A square pattern and 2.20 to 2.50 m spacing were selected for the foundation area which corresponds to area replacement ratio of 12.5% to 16.5%. The diameter of the completed columns was 1.0 m. A total of 11.000 m^3 of stone was used for 14.280 m of treatment. The backfill material used for stone columns was 20-100 mm.

The diameter of the 120 kW vibrator was 0.30 m. The vibroflot's motor force is provided by an electric motor rated at 120 kW with a frequency of 50 hertz at 3000 rpm.

6 CONSTRUCTION MONITORING AND QUALITY CONTROL

A digital data recording unit was used to monitor the stone columns. Depth vs. real time, depth vs. oil pressure and oil pressure vs. time plots were recorded for each stone column constructed. The amount of stone that were used for each column was also recorded to verify the column diameter.

In order to verify the degree of compaction 3 SPT's at 1.50 m intervals were performed after improvements. SPT results before and after the installation of stone columns for each tank are given in Figure 5. SPT 0 denotes the test before improvements and SPT 1, SPT 2, SPT 3 denote the tests after the completion of stone column installation. Uncorrected SPT N values were recorded as 2 – 20 and 18 – 30 before and after improvement respectively.

One plate loading test was carried out on stone columns for each tank. The results of loading tests are summarized in Table 4. The physical properties of the stone used in the production of columns were tested for each batch of 5000 m^3. Summary of laboratory test results are given in Table 5.

Table 4. Load Test Results

Tank No	Test Load (kN)	Displacement (mm) Total	Displacement (mm) Residual
1	409.6	15.71	13.48
2	256.0	6.65	4.07
3	409.6	6.30	4.15
4	153.6	5.41	2.92

Table 5. The properties of stone used in stone column installations

G_S	L A Abrasion (%)	Soundness (%)	γ_{dmax} (kN/m^3)	γ_{dmin} (kN/m^3)	Fine (%)
2,76	8.48	1	16.9	15.6	1

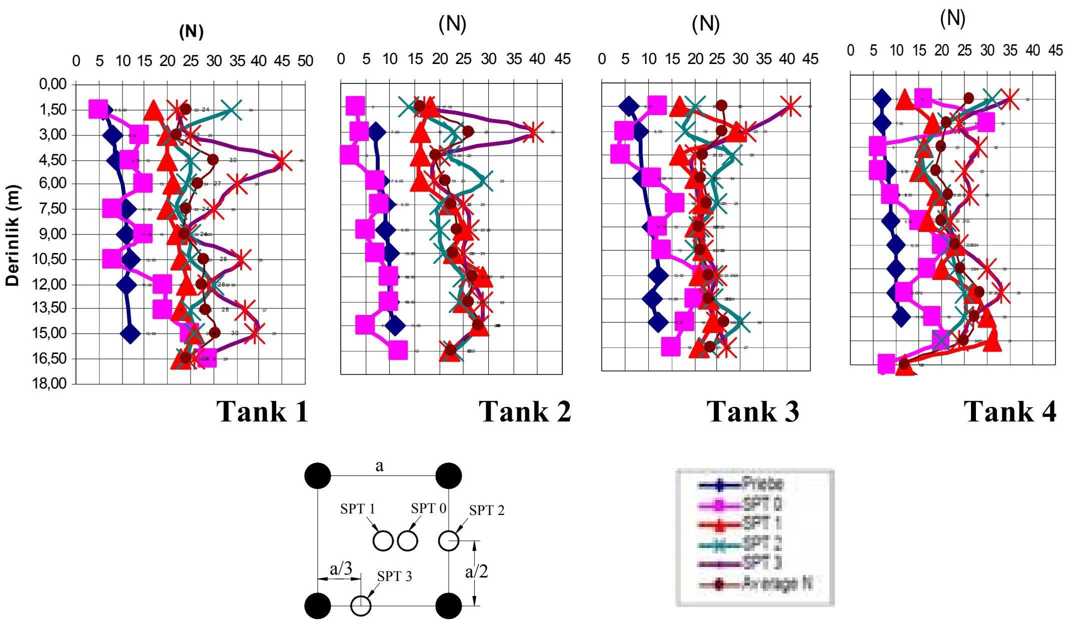

Figure 5 – SPT Results Before and After Improvent

7 SETTLEMENT OBSERVATIONS

The tanks were hydrostatically tested in accordance with the technical specification of the project. Tanks were filled with sea water. Each tank was filled in 4 filling increments with the following filling rates; 500 mm/hour up to 25% of the tank capacity, 300 mm/hour up to 50% of the tank capacity, 250 mm/hour up to 75% of the tank capacity, 200 mm/hour up to 100% of the tank capacity. Each filling increment was held for approximately 12 hours before adding the next increment. Settlement of tanks was measured using a series of survey points established on the ring walls prior to testing. 8 survey points were established for each tank.

The average settlement of the tanks recorded during hydrostatic testing are shown in Figure 6. The measured settlements at the edges of the tanks are presented in Figure 7. Measured peripheral settlements ranged from 133 mm to 152 mm for Tank 1. The maxium angular distortion values for tank 1 and tank 2 are measured as 1/1240 and 1/1860 respectively. These values are well below the specified limits for fixed top steel oil tanks, ie. 1/300-1/500 (Settlement Analysis, 1994)

Settlement measurements made at depth under ring shaped foundation in previous studies (Frank, 1991) showed that the deformations are concentrated in a zone having a height of 0.30 times its diameter. Long term settlement observations during the operation of tanks confirm above argument.

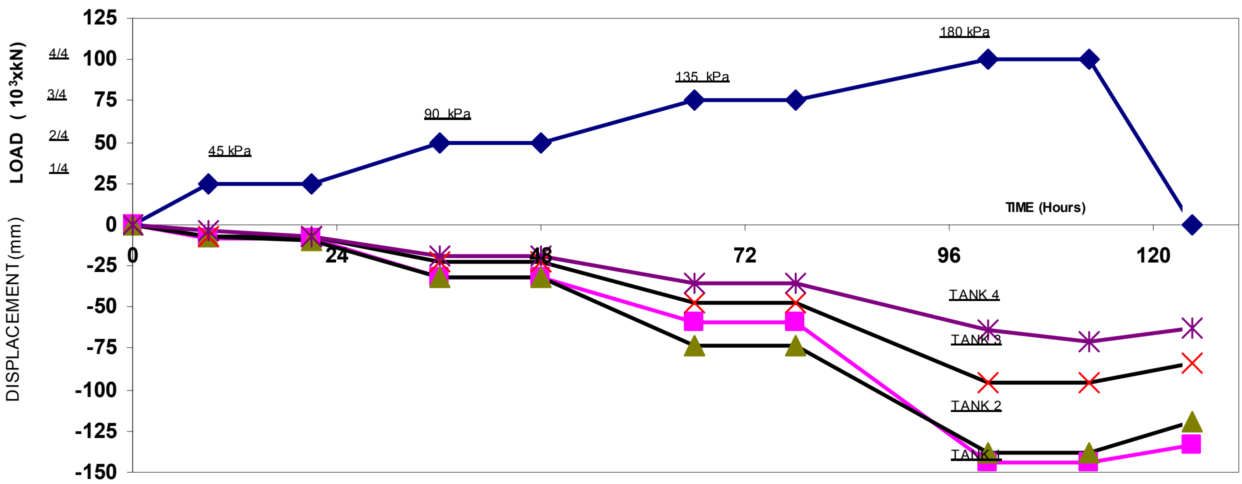

Figure 6 –Hydrostatic Load Test Results

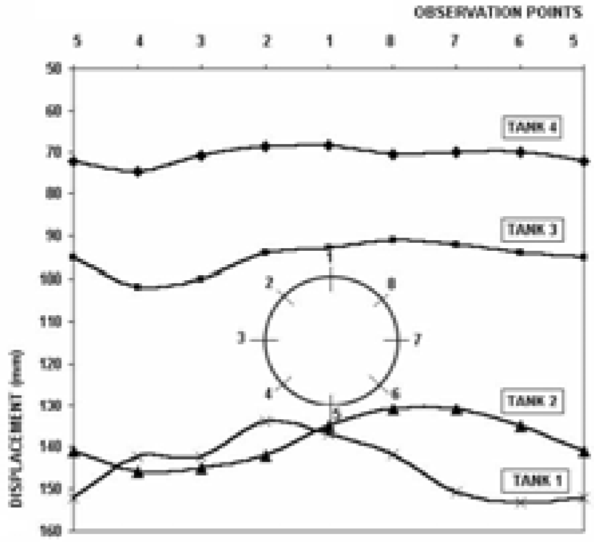

Figure 7 – Displacements at The Periphery of The Tanks

8 CONCLUSIONS

The following conclusions can be derived from this case history:

- Soil improvement of large diameter steel oil tanks was realized using vibroreplacement technique. A total of 988 stone columns were installed in the first phase of the Poti Port Oil Terminal project. Phase-1 of the project was completed before the planned schedule.
- Design of stone columns must be verified with in situ tests performed before and after improvement. Relative density derived from SPT, performed after the completion of stone columns varies with in the range of 70 – 75 %
- Observed settlements during hydrostatic testing fell within tolerable limits. Long term settlement observation during operation of the tanks has shown that the performed soil improvement serves efficiently.
- In general, the vibroreplacement technique proved to be an effective and economic means of improving compressibility characteristics and liquefaction potential of soils.

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The opinions expressed in this paper are solely of the author and are not necessarily consistent with the policy or opinions of Kasktas Co.

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