# Improvement of Soft Clay for 50000 M$^3$ Oil Storage Tank

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SYNOPSIS A design of soil improvement for building a petroleum storage tank with a capacity of 50000 $M^3$, and its construction are presented in this paper. Mono—axis deep mixing technique was applied for this project. Laboratory and in-situ test on cemented soil both for static and dynamic properties were conducted, based on which analysis of strength for static and seismic loadings can be used for the practice of the project.

## INTRODUCTION

It is one of the key techniques for building huge petroleum storage tanks on soft clay to strengthen the subgrade, which will affect the cost and its normal service in service life during which it may encounter earthquakes and other disasters.

If there are any carelessness in improvement of the subsoil, tilt of the slab, crack and leakage will occur. Subsoil will be liquified and amplitude of ground motion will be amplified caused by earthquake loading, resulting in damage of the super—structure. On the other hand, storage tank, a bulk and flexible structure compared with normal ones, is sensitive to difference of settlement, therefore it should be safe under seismic loading.

A series of laboratory and in—situ tests were carried out both for obtaining static and dynamic properties of the soil, according to the requirement of soil improvement for 50000 $M^3$ storage tank and its construction. Analysis for evaluating the effectness of subsoil improvement both for static and dynamic loadings were conducted, some parameters and data such as excess pore water pressure, settlements at certain depths, were mornitered, to meet the needs of analysis and verify the results.

## BRIEFING OF THE PROJECT

The project is located in south bank of Yangtze River, Nanjing, Jiangsu Province. Soil profile is shown in Table 1. Ground water table was found at the depth of 0. 5m below ground surface. The elevation of ground surface is even lower than the water level of Yangtze River. Therefore, the ground level should be raised up 3. 5 meters by filling before construction.

Table 1. Soil Profile

| | D | ρ | W | e | E | P |
|---|---|---|---|---|---|---|
| Fill | 1.0 | 18.5 | | | | |
| Clay | 1.2 | 18.2 | 35.5 | 1.00 | 4.7 | 100 |
| Mucky Clay | 13.3 | 17.2 | 47.3 | 1.34 | 2.8 | 70 |
| Mucky Clay with Silt Lens | 1.5 | 17.5 | 42.7 | 1.18 | 3.9 | 80 |
| Silt | 14.2 | 18.3 | 29.8 | 0.91 | 14.7 | 15.0 |
| Silty clay with Gravel | 3.3 | 19.8 | 25.7 | 0.73 | 9.2 | 15.0 |
| Gravel with silty Clay | 5.0 | | | | | 200 |
| Weathered Base Rock | | | | | | |

D: Average Thickness (m) ρ: Unit Weight ($KN/m^3$)
W: Water Content e: Void Ratio $E_s$: Compression Modulus $E_{s(1-2)}$ (MPa) P: Bearing Capacity (kPa)

Design earthquake intensity for the project is 7 degree. The tank, with diameter of 60 meters, 20 meters height, has a capacity of 50000 $M^3$ and a floating top.

There are several points might be taken into consideration in the design of soil improvement: (1)the thickness of soft layer is about 15 meters, and the ground should be stable under a load of 300Kpa, uneven settlement, that is, the ratio of difference of settlement at the center and at the periphery, $\Delta S$, to the diameter, D, $\Delta S/D < 0.015$; (2) Sub—layer of silt soil would not be liquified during earthquake with intensity of 7 degrees and the amplified ground motion of the site would be controlled within a certain value; (3) It is necessary to have a fill with height of 3.5 meters before construction, which is an additional load to the soft clay at sub—layers, and also can be used for dispersing the surcharge load to deep layers; (4)The tank to be built is located very close to the existing tanks, only 20 meters away, technique to be applied would not affect daily operation of these tanks.

## DESIGN OF SOIL IMPROVEMENT AND CONSTRUCTION

Following effects should be under consideration in selecting design for strengthening the soft clay supporting huge petroleum storage tank: (1)foundation of the tank; (2) man—made subgrade below the foundation; (3)soft layers. They interact together. There exists a rational relationship of rigidities, so that the improvement results in good performance and costs less.

The design of improvement of soft sub—layers is shown in Fig. 1. Mono—axis deep mixing technique is employed for the project, with each column 15 meters depth and 550 mm diameter. Within the area of a circle having a diameter 68 meters, square pattern, 1.05M×1.05M, was selected, with replacement ratio, 21.5%. There are total 3249 columns in the site, the formular for the deep mixing technique as following: 15%, # 525 ordinary silicate cement over total weight of column of soil to be mixed with cement; 2%, plaster stone, over total weight of cement used; 0.2%, dewatering agent, over tatal weight of cement, ratio of water to cement, 0.5. In order to increase rigidity of the whole foundation, double—piece geotextile underlayer was used spreading over the treated horizontal area of subsoil.

Four deep—mixers wre employed for the project with total 50 working days, for each column, mixing 4 times up and down, with vertical lifting velocity, 1 m/sec., mixing angular velocity, 60 circle/min.

## LOAD TEST

It is necessary to know the strength of mixture of soil and ce-

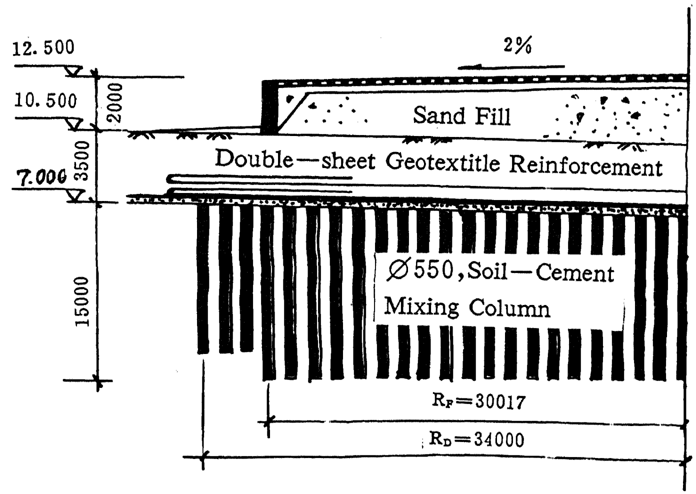



Fig. 1 Cross—section of Improvement of Sub—soil by Deep Mixing Technique for 50000 $M^3$ petroleum storage Tank.

ment with time during construction and its ultimate strength. Unconfined compression laboratory tests of mixture with various ratis of cement to soil were conducted. The test data show that the strength of mixture increases with increasing of curing time, and generally, the strength with 90 days curing is referred to as long—term, or ultimate strength. The ratio of cement to soil employed for the project was decided based on the lab test, 15%, ultimate strength, $q_u = 2000$Kpa, shearing strength, $c_u = 1000$ Kpa, deformation modulus, $E_{s0} = 300$Mpa.

In—situ load tests are to be performed before deep—mixing technique is employed for the project to confirm the bearing capacity meeting the needs of actual load. The test programme consisted of two single—column tests, one double—column test with concrete pad 1.0m×2.0m and four—column load test with concrete pad 2.0m×2.0m. The test results are shown in Table 2. Finally, allowable bearing capacity of single column is taken to be 220 KN, and allowable bearing capacity of composite subgrade is taken to be 270 Kpa. Based on the parameters mentioned above, the safety factor for stability of the foundation reaches about 2.0, the maximum deformation, 0.3 meters, and uneven settlement is controlled within the allowable value.

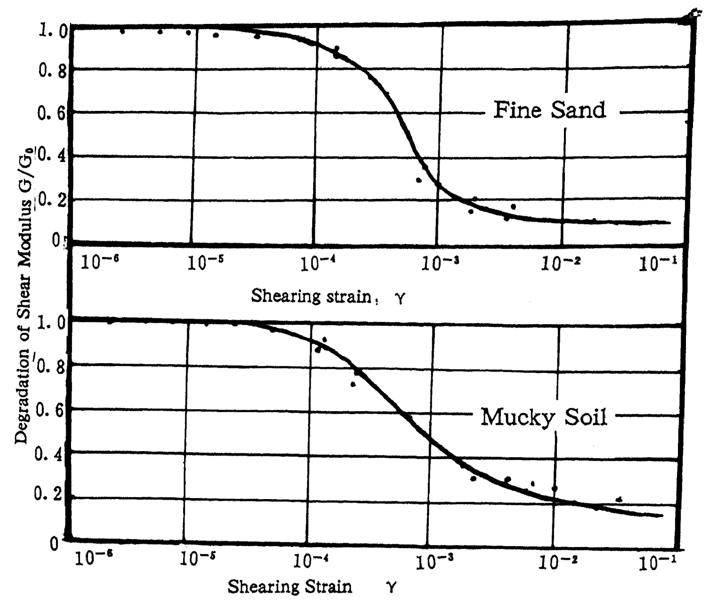
## DYNAMIC TEST AND ANALYSIS

Cross—hole tests and SPT in—situ, and resonant column tests and simple shear tests in laboratory were performed for obtaining dynamic properties of the soil involved. Shear wave velocities of mucky clay and silt were 140m/s and 210 m/s, corresponding shear moduli, 34Mpa and 82Mpa, respectively, from field tests. Blow count of SPT for silt, $N_{63.5}=13\sim31$, with an average, 22. The relationships of $G/G_0$. vs. $\gamma$ and D vs. $\gamma$, from resonant column and simple shear tests, are shown in Fig. 2

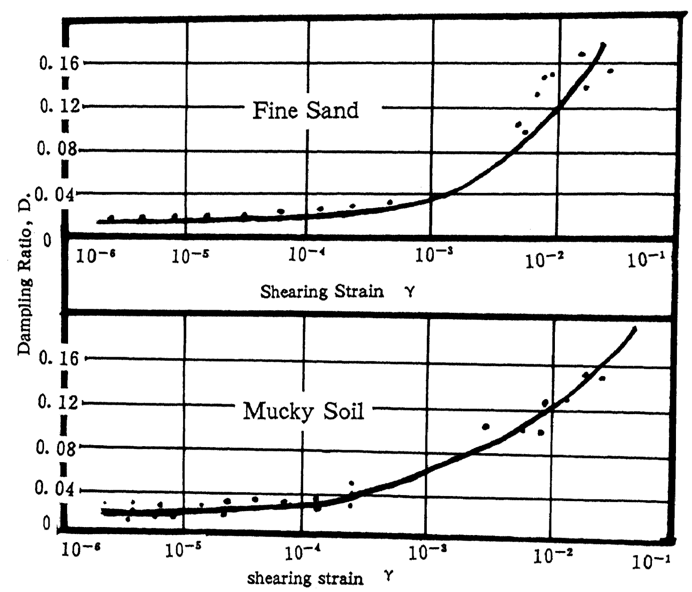
Table 2 Results of Load Tests

| | Single Column | | | Compoiste Foundation With Concrete Pad | | |
|---|---|---|---|---|---|---|
| | #1 | #2 | Average | 1m×2m Double Column | 2m×2m Four—column | Average |
| Ultimate Bearing Capacity (KN,KPa) | 488 | 46.1 | 475 | 585 | 445 | 515 |
| Settlement (cm) | 1.93 | 2.1 | | 2.8 | 6.2 | |
| Allowable Bearing Capacity (KN,KPa) | 244 | 231 | 238 | 290 | 263 | 277 |
| Settlement (cm) | 0.2 | 0.3 | | 0.4 | 1.4 | |

The results of resonant column tests on samples of soil—cement mixture are shown in Fig. 3. It can be seen that initial shear modulus of clay increases from 34Mpa up to 620 Mpa by ending 15% of cement , which is about 18 times as much as the previous value. Degradation of shear modulus also increases with shearing strain, which loses about 2/3, as shearing strain increases from $10^{6}$ to $10^{-4}$, in contrast to undisturbed clay sample, it essentially remains unchanged in the same shearing strain range.




(a) Shear Modulus vs. Shearing Strain




(b) Damping Ratio vs. Shearing strain

Fig. 2 Results of Dynamic Tests in Laboratory

Liquefaction potential of silt layers can be classified by wave velocity method and SPT, critical shear wave velocity for silt under earthquake with intensity 7 degrees, is about $V_{scr}=229m/s$, critical blow count, $N_{cr}=16\sim21$. The silt tested shows slightly liquefaction under earthquake with intensity 7 degrees, on the other hand, the large area of load of fill on the ground surface will improve to a certain extent.

Effects of amplification of ground motion was analyzed by means of shear beam method, with input base rock motion shown in Fig. 4, records of Loma Prieta earthquake, USA, 1989, $a_{max}=0.656m/s^2$, predominant period = 0.65 Sec. duration of time = 12 sec. The results show that the amplification factor is about 2.3, that is, ground motion is about 2.3 times as large as that of base motion. Maximum acceleration is amplified about 1.8 times as seismic wave propagating up through soft layers. Therefore, amplification effects should be taken into account seriously, specifically on soft layers.

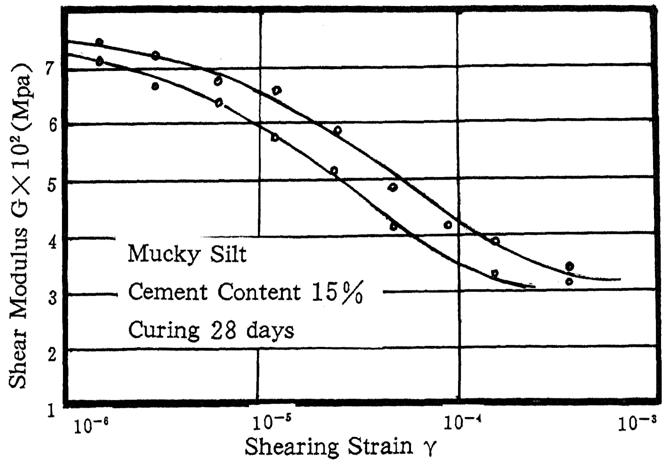



Fig. 3. Results of Resonant Column Tests on Soil—Cement Mixture

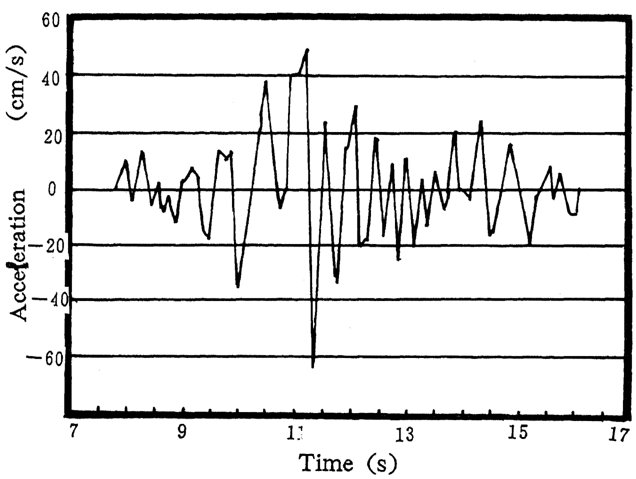



Fig. 4 Records of Lama Prieta Earthquake, USA, 1989

From laboratory tests, shear modulus of mucky clay increased dramatically by mixing certain amount of cement. For confirmation of these effects exist prototype, SASW (Spectral Analysis of Surface Wave) technique was applied to measure the shear wave velocity, obtaining the velocity for composite foundation 320m/s. The corresponding dynamic amplification factor was evaluated, 1. 3, for the site after improvement. The amplification factor of through mucky clay layer decreases down to 1. 1.

A double—sheet geotextile layer was placed between foundation and strengthened sub—layer of soft soil, in order to disperse heavy load of storage tank and absorb the energy transmitting upward from underlying layers.

## CONCLUSIONS

For the reason of transportation, large petroleum storage tanks are usually built along coast and bank of river, where soft soil spreads over widely. Because of heavy load, controlled uneven settlement and anti—seismic requirement, it needs special consideration for selecting the technique to improve the soft soil layers underneath. From the case studied herein, deep—mixing technique is the one with following advantages:

1. It is satisfactory to bear large static load, raising the bearing capacity from 80KPa for untreated natural deposit up to 270 KPa, and total settlement decreases from 2. 30m down to 0. 3m.
2. It improves the anti—seismic behavior of the subgrade dramatically, shear modulus raising 18 times by mixing 15% weight of cement, resulting in decreasing of amplification factor of earthquake motion remarkablelly.
3. There are no vibration and noice environmental polution during the operation of deep—mixing construction which is rather simple compare to the other methods.
4. It is of the advantage of low cost, which is about one half of that of pre—cast concrete pile.

## REFERENCE

De —Alba, P., Elastic—Wave Velocities and Liquefaction Potential, Geotechnical Testing Journal, Vol. 7, No. 2, 1984.

Code of Anli—Seismic Design, People's Republic of China, GBJ, 11—89. 1989.

Chen, Y. M., Wu, S. M., Spectral Analysis of Surface Wave Technique and It's Applications, Journal of Geotechnical Engineering (in Chinese) Vol. 14, No. 2, 1992.