COMPACTION SAND PILES FOR SOIL IMPROVEMENT

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Colonnes de Sable Compacté pour l'Amélioration des Sols

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SYNOPSIS At the site of a steam power plant in the southern part of Taiwan, the top 6 m of the subsoil is a loose fine sand deposit which has high liquefaction potential. Since the power plant is located in a seismic active zone, it is necessary to improve the subsoil condition by densification. Compaction sand piles of 45 cm diameter, 7.5 m long placed at 1.8 m center to center spacing in a triangular pattern distribution were used. The area being improved in the first stage of construction is 3,500 sq m. For the evaluation of the effectiveness of the improvement, soil sampling and Standard Penetration Tests were performed at random locations both prior to and after the improvement. The test results indicate that the improvement is successful, with 100% samples giving over the required 65% relative density, and 92% samples with more than 75% relative density. Standard Penetration Tests were found to be an effective way for the field control work. Correlation between the SPT values and relative density was established.

INTRODUCTION

The island of Taiwan is located in the active seismic zone of the Pacific Ocean and has experienced over thousand earthquakes every year. For any major construction project, the potential problem of seismic effect must be carefully evaluated. At the site of a thermal power plant which is under construction now in the south-western part of Taiwan, there exists a layer of saturated loose sand near the ground surface. This layer of sand was found to be susceptible to liquefaction during earthquakes (Woo, Moh and Ou, 1980). In order to alleviate this problem, some improvement work had to be carried out to densify the loose deposit and thereby to increase the factor of safety against liquefaction. Various methods of soil improvement were evaluated. Compaction sand pile method was adopted for the soil densification work for its simplicity, local availability, and lower cost.

For evaluation of the effectiveness of the soil improvement work, field monitoring including soil sampling, standard penetration tests, piezometer readings, lateral displacements and lateral load tests, was carried out. This paper describes the monitoring results on the use of compaction sand piles for soil improvement in the area where the first two units of power generating units were constructed.

SITE AND SUBSOIL CONDITIONS

The plant site which is about 1 sq km in total area is situated on an alluvial beach parallel to the coastline. The topography of the site before construction varied from El + 5.5 cm to El + 0.3 cm above mean sea level. To bring the site to the required design elevation, a 4 m thick hydraulic fill has to be placed over major part of the site.

The subsoils at the site can be divided into the following strata.

(1) Silty Sand Layer — From the ground surface to a depth of approximately 3 m, the soil is a layer of grey silty sand, loose to medium dense with Standard Penetration Resistance (SPT) N values varying from 3 to 16. The mean grain size (D_{50}) ranges from 0.19 to 0.32 mm. The amount of fines, i.e. minus No. 200 sieve, is about 12%. Liquefaction potential is found to be high in this layer.

(2) Silty Clay Layer — Underlying the silty sand is a layer of gray silty clay of about 14 cm thick. The silty clay is of very soft consistency with Liquidity Index of about 1.0 or larger. Thin layers of silty sand with varying compactiveness from loose to dense were found interstratified in the clay layer.

(3) Silty Sand Layer — Immediately below the silty clay is a thick layer of gray silty sand extending to the bottom of boring, which was 50 m below the existing ground surface. The silty sand is of medium dense to very dense with N values varying from 20 to 80 and increasing with depth. The D_{50} size ranges from 0.075 to 0.180 mm, and the fines content is about 20%.

since the site is located right beside the sea, the groundwater table as measured during the exploration period was at about El + 0.00 m to El + 0.50 m.

LIQUEFACTION ANALYSES AND REMEDIAL MEASURES

As described by Woo, Moh and Ou (1980), liquefaction potential of the soil deposit at the site was evaluated by using a number of different approaches including empirical methods based on SPT results,analytical methods employing dynamic cyclic soil testing results and effective stress model analysis. The results of evaluation indicate that the factors of safety against liquefaction in the upper sand layer under a 4 m of fill are generally lower than 2. In view of the importance of the power plant and in order to avoid any possible damage due to unforeseen nonuniformity of the soil deposit, it was decided that some improvement work should be carried out to reduce the liquefaction potential. In addition, the hydraulic fill would also be in a loose condition which would also need further densification.

There are many methods which can be used for soil densification, such as vibroflotation, compaction sand piles, dynamic compaction and preloading. Each method has its advantages and limitations, depending greatly on the site condition and soil characteristics. Dynamic compaction is a relatively new method (although in principle, it is an ancient method) and very few case records are available. Preloading requires long period of time and large quantity of material. These two methods were therefore not considered. Careful comparison was made between vibroflotation and compaction sand piles in view of the soil properties, thickness of the sand to be densified, construction time required, local construction capability and cost.

The principal criterion of soil improvement at the site is to increase the unit weight of the natural sand deposit and the overlying hydraulic fill to a minimum relative density of 65% which is equivalent to a factor of safety against liquefaction of about 3.5 under a seismic acceleration equivalent to 0.13 g (Woo, Moh and Ou, 1980).

In general, vibroflotation method of soil densification is most effective for loose fine sand deposit below water table with less than 20% fine content (i.e. minus U.S. No. 200 sieve). It was found that the silty sand at the site concerned contains too much fines and its grain size distribution curve lies at the outer boundary of the desirable range. For this type of soil containing more than 20% of fines, fine gravels will have to be used as the fill material in order to achieve the required densification. The presence of fine gravels may affect the driving of foundation piles at later stage. Furthermore, at the present site the depth of densification is less than 10 m. Due to the nature of the vibroflotation process, the top few meters of the sand (hydraulic fill) will have to be recompacted by rollers after the vibroflotation. On the basis of this evaluation, compaction sand piles were adopted for densification of the in situ sand as well as the overlying hydraulic fill.

CONSTRUCTION MONITORING

Types of Monitoring Tests

For the first stage of construction, only that area for the units 1 and 2 of the power generating units was densified. The area involved is 3,500 sq m. For the purpose of evaluating the results of compaction sand piles, a number of monitoring tests was carried out. They include soil sampling and SPT before and after the installation of the compaction sand piles and laboratory relative density tests. In addition, piezometer and inclinometers were installed, in situ borehole lateral load tests and vane shear tests were carried out to determine the effect on soil characteristics due to placement of the compaction sand piles. Since the monitoring work performed in this stage I construction would be used as standards for later construction, relatively large number of tests was carried out.

Tests Run of Compaction Sand Piles

Prior to the full scale improvememt work, compaction sand piles placed in a trianglar pattern at three different spacings, i.e. 1.6 m, 1.8 m and 2.0 m, were tried at the site. On the basis of SPT results, piles of 45 cm at 1.8 m spacing and 7.5 m long were used. The size of the pile after installation is about 70 cm and the average amount of sand fill required for each of the pile was 5 cu m.

Relative Density Tests

ASTM D2049 method was initally used for determining the maximum and minimum density. However, it was found that the value of maximum density so determined appeared to be on the low side. This is possibly due to limitation of the mold size. The maximum density was further evaluated by using drop hammer compaction method ASTM D1577. It was found that for the top layer of silty sand deposit at the site, the average maximum density is 1.83 t/cm^3, minimum density is 1.33 t/cm^3, with a standard deviation of 0.03 and confidence limit of 96%.

For determining the relative density of the in situ soil both prior to and after improvement, split spoon sampler with brass lining and thin wall piston sampler were used to obtain the "undisturbed" samples. Neither of the two methods was completely satisfactory for obtaining good samples. However it was found that density determinations on split spoon samples gave results which appear to be more consistent as compare with the SPT results.

Relationship between SPT Value and Relative Density

Standard Penetration Test is the most convenient way to evaluate the in situ compactiveness of sandy soils. Gibbs and Holtz (1957) has suggested relationships between relative density of sands with SPT value. Since the SPT values are affected by the overburden pressure, particle size of the soil, etc., particular relationships should be established for each site. For the present study, densities determined from split spoon liner samples were used to correlate with the SPT values. As shown in Fig. 1, the coefficient of correlation for the best fitted curve is 0.72 with a confidence limit of 90%. This indicates that these relationships between the N value and relative density can be used as a convenient means for field control.

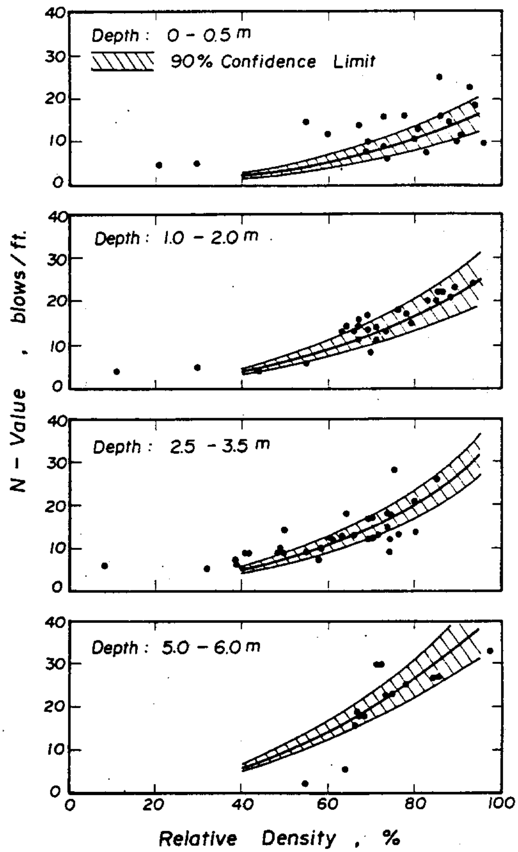

Fig.1 Relationships between Relative Density and SPT N-Value

RESULTS OF MONITORING

Effectiveness of Compaction Sand Piles

After installation of the compaction sand piles, the relative density of the sand layer was first estimated from the in situ N-values shown in Fig. 2 by using Fig. 1. Further checks were made by determination of the relative density of split-spoon liner samples obtained after soil improvement. Fig. 3 shows the frequency distribution curve of relative density of the sand layer after improvement. It can be seen from Fig. 4 that after the improvement work, all values of relative density exceed 65%, and 92% of the density values are more than 75%. This indicates that the improvement work is quite satisfactory.

Piezometric Pressure

To observe the variations of piezometric pressure in the subsoil layers due to installation of compaction sand piles, a total of 30 open-end hydraulic piezometers was installed at various depths. Observation records indicate that the piezometric pressure distribution in both the sand and the underlying clay layer was near static condition prior to any construction. Placement of compaction sand piles caused an obvious increase in the piezometric head in the sand layer, generally in excess of the height of the overburden. In the clay layer there were also increases in piezometric pressure. However, the sand piles had no effect on the lower sand stratum. The excess pore pressures normally took 3 to 4 weeks to dissipate.

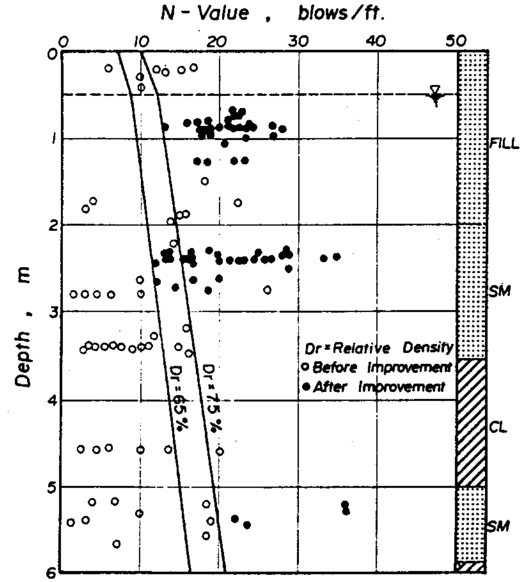

Fig.2 Variation of N-Values with Depth Before and After Soil Improvement

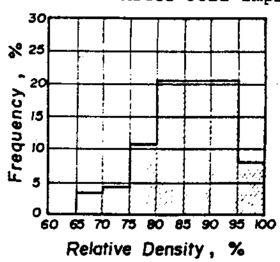

Fig.3 Frequency Distribution of Relative Density after Improvement

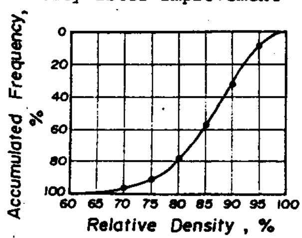

Fig.4 Accumulated Frequency of Relative Density after Improvement

Lateral Displacement

Installation of compaction sand piles definitely has effect on the lateral as well as vertical displacement of the surrounding soil layer. Two inclinometer tubings (SINCO type) were installed at the site. As illustrated by Fig. 5, the effect on lateral squeezing is limited within the top 15 m of the soil deposit with maximum displacement occurred between 5 m and 7.5 m depth.

Settlement occurred when the soil deposit was first affected by the compaction sand pile. At later stage, when more sand piles were placed, the soil layer actually moved upwards, i.e. heave.

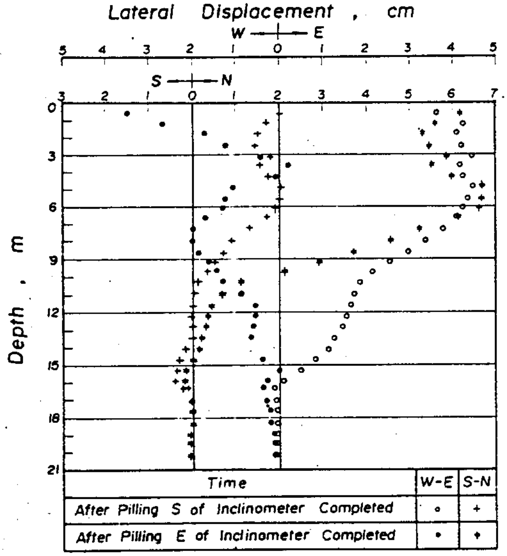

Fig.5 Lateral Displacement of Soil due to Compaction Sand Pile

In Situ Lateral Load Test and Vane Shear Test Results

In situ borehole lateral load tests were conducted to evaluate the coefficients of horizontal subgrade reaction which are to be used for designing the lateral resistance of piles. It was found that the coefficient of horizontal subgrade reaction of sandy soil increases with the N value. Soil improvement by compaction sand piles increases the relative density of the soil, therefore the N-value, and also its horizontal resistance.

As described in earlier section, there is a layer of soft clay underlying the top silty sand stratum. In situ vane shear tests were utilized to determine the effect of compaction sand pile. Although there was significant increase in the unit weight of the overburden material, the strength of the clay layer did not appear to be affected. It is possible that the strength may increase after some time due to consolidation of the soil under the additional overburden pressure. No data were available on this.

CONCLUSIONS

For the site concerned, compaction sand pile was found to be an economical and effective way to increase the relative density of the loose silty sand layer and its overlying hydraulic fill. Over 92% of the relative density test results after soil improvement exceeded 75% which indicated the effectiveness of the method. Liquefaction potential of the site is therefore greatly reduced.

Within the depth of improvement, both sand and clay layers developed excess pore pressure during installation of the compaction sand piles. These excess pressures took 3 to 4 weeks time to dissipate which is a factor to be considered in foundation design.

After improvement, the lateral resistance of sandy soils increases but there is no effect on cohesive soils.

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