Site Improvement by Preloading with Sand Drains

L'Amélioration du Site par le Chargement Préliminaire avec le Drain en Sable

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SYNOPSIS Sand drains and compacted sand piles with preloading were used to improve a previously reclaimed tidal marshland. Subsurface soil data prior to and after the treatment, and data of an instrumentation program were evaluated to asses the effectiveness of the site improvement. The improved site is presently used as a raw ore material storage yard which is capable of carring a maximum loading of 350 kPa without soil failures.

INTRODUCTION

A 30-hectare previously reclaimed tidal marshland was to be developed into a raw material storage yard of China Steel Mill in Kaohsiung, Taiwan. Two quay walls were also to be built along the northwestern corner of the site for material unloading and product loading facilities, as shown in Figure 1.

The subsoil conditions were too weak to support the planned heavy material and equipment loadings. Stability and settlement were the two major concerns. Various site improvement techniques were therefore investigated, and the most feasible methods were implemented at the project site.

SITE CONDITIONS

The site was originally a maritime area which was occupied by many fish ponds. The land was later reclaimed by placing, hydraulically, 1 to 2 meters of loose fine sands on a layer of 5 to 8 meters of compressible, normally to slightly over-consolidated, soft to medium stiff silty clays which is underlain by dense alluvial deposits. Prior to the site improvement, the silty clays had an unconfined compressive strength of 20 to 50 kPa, compression index of 0.2 to 0.40, vertical coefficient of consolidation of 0.4 to 0.7 x 10^{-6} m^2/sec, and horizontal coefficient of consolidation of 0.6 to 1.1 x 10^{-6} m^2/sec.

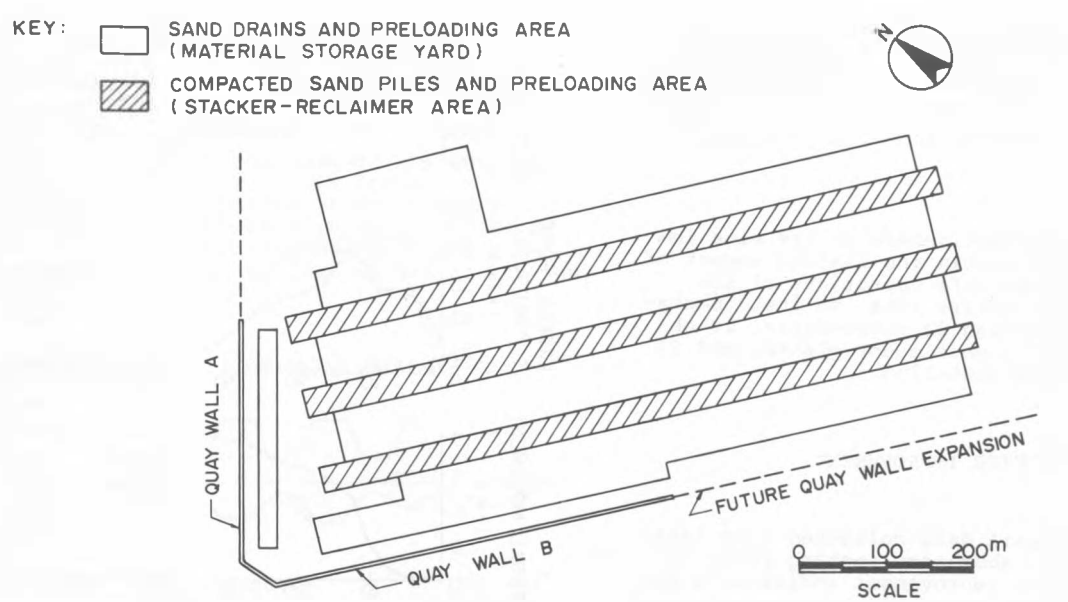

Fig. 1 Site Plan

SITE IMPROVEMENT

Potential ground failures in the heavily loaded areas and slope instability along the water-front facilities were the primary concerns because of the weak subsoil conditions. In addition, estimated settlements under the equipment and material storage loads were about 1 to 3 meters. Large amount of settlement and differential settlement would have adverse effects on safety and operation of some facilities, such as stacker-reclaimers.

In order to alleviate the potential severe stability and settlement problems, different site improvement techniques including soil replacement, drainage, preloading, vibro-compaction, electro-osmosis and chemical stabilization were evaluated. Sand drains with preloading were considered to be the most feasible methods for improving the general area, whereas compacted sand piles with preloading were used in the stacker-reclaimer areas to meet a heavier loading and more stringent settlement and differential settlement requirements.

The upper loose fine sands were first blended with coarser material and compacted to a dry density not less than 19.5 kN/m^3.

Site conditions, loading and settlement requirements in different areas were considered in the design of sand drains and compacted sand piles, using theories developed by Barron (1948) and Terzaghi (1943). A total of 160,000 linear meters of sand drains with 40 centimeters in diameter, spaced 2.1 to 3.4 meters on centers, and 120,000 linear meters of compacted sand piles with 70 to 80 centimeters in diameter, spaced 2.1 to 3.0 meters, were installed. Estimated amount of sand needed for preloading the entire site simultaneously would be about 1.7 million cubic meters. By a careful planning, only 0.7 million cubic meters of sand was used to preload different areas at different times.

The entire site improvement program was started in August, 1974, and completed in March, 1976.

INSTRUMENTATION

To evaluate the effectiveness of the site improvement program within the limited amount of time, and to assure safe operations of the facilities in the entire area, an instrumentation program including 34 piezometers, 10 observation wells, 32 settlement plates, and 27 inclinometers were installed.

EFFECTIVENESS OF SITE IMPROVEMENT

Strength

A comparison of soil data collected from field explorations and laboratory testing prior to and after the site improvement indicated a decrease in natural water content and substantial increases in both N-value and shear strength. Typical data are shown in Figure 2. Increase in shear strength ranged from 2 to 5 times, and the bearing capacity was therefore sufficient to carry the maximum anticipated loading.

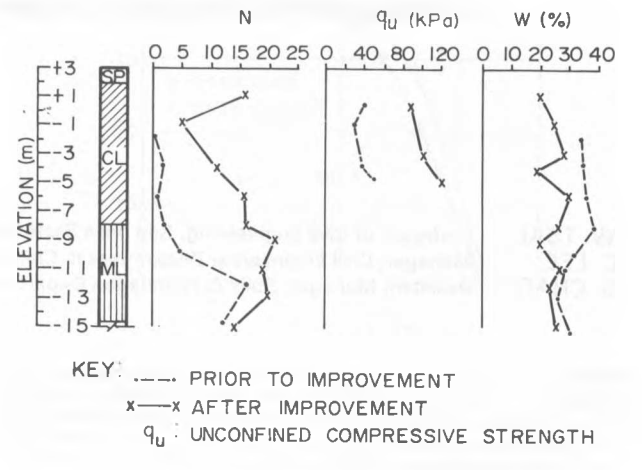

Fig. 2 Soil Properties Prior to and after Improvement

Stability

Excess pore pressure was completely dissipated in about 2 months after preloading, and up to 8 centimeters of lateral movements were measured in the storage area, as shown in Figure 3. The lateral movements were leveled off after one month of preloading. No ground failures were observed.

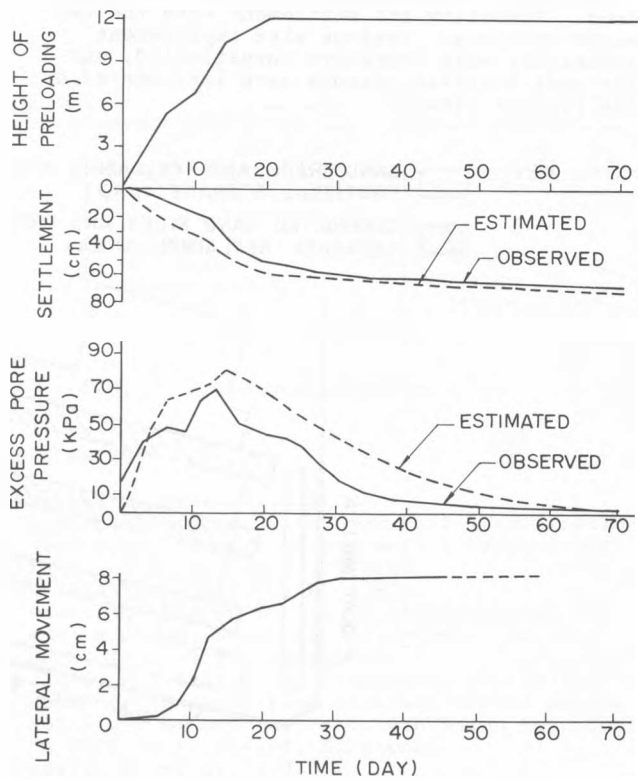

Fig. 3 Estimated Versus Observed Data in Preloaded Area

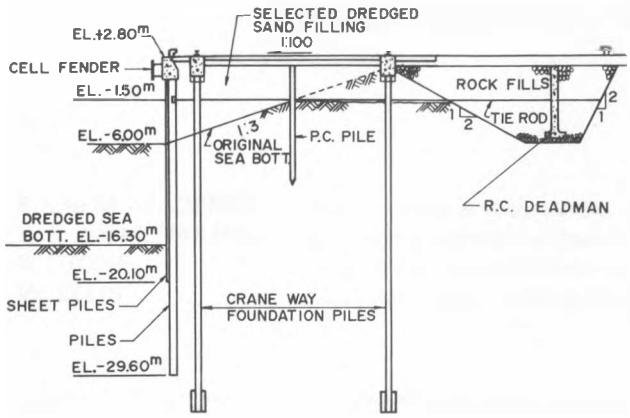

Fig. 4 Quay Wall

Construction of the two quay walls, as shown in Figure 4, required dredging of 10 meters on the waterside. Potential instability and mud waves induced by heavy loading in the storage areas were among the considerations in the design. Readings of the inclinometers, adjacent to the quay walls, taken in January, 1978, about 2 years after completion of the preloading, indicated a maximum lateral deflection of 3 centimeters. This movement was considered to be acceptable and no signs of instability were observed. Inclinometers will be read periodically to detect any sign of movement which may be caused by natural forces, such as earthquakes, or human errors, such as overloading during operation.

Settlement

settlements were accelerated by the site improvement program as anticipated in the design. Typical comparison of estimated versus observed settlements are shown in Figures 3 and 5. Settlements observed after the preloading and estimated settlements due to full operation loading are compared in Figure 6.

No appreciable future settlements are anticipated in the stacker-reclaimer areas. Estimated remaining settlements in the material storage areas ranged from 0 to about 30 centimeters, and these were considered in the site regrading to minimize the loss in use of storage materials.

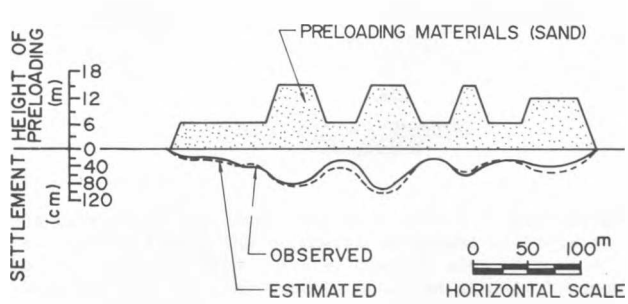

Fig. 5 Settlements Profiles

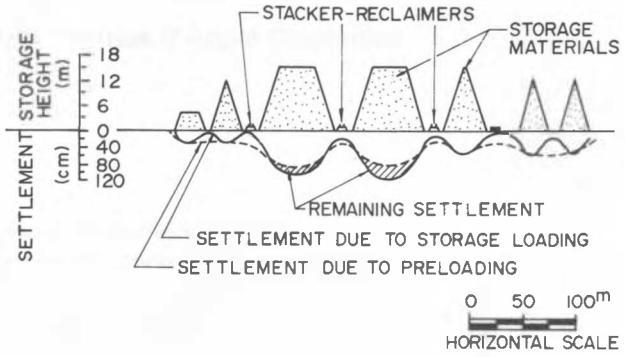

Fig. 6 Remaining Settlements

CONCLUSIONS

With proper design and installation of sand drains and compacted sand piles with preloading, a previously reclaimed marshland was improved substantially to be able to carry up to 350 kPa of heavy storage material loading. Remaining settlements were reduced to insignificant values. No soil failures occurred. Facilities in the storage yard and along the quay walls are functioning properly.

Data collected from the instrumentation program made it possible to evaluate the site conditions after improvement. This is a key to the safe, economical and successful construction and operation of the entire project.

REFERENCES

Barron, R.A. (1948). Consolidation of fine-grained soils by drain wells. ASCE Transactions 113, pp.718-754.

Terzaghi, K. (1943). Theoretical Soil Mechanics pp.239-240. John Willey & Sons, New York.