# PRECONSOLIDATION OF SOFT BANGKOK CLAY BY VACUUM LOADING COMBINED WITH NON-DISPLACEMENT SAND DRAINS

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*Reprinted from*
*Proceedings, XII Int'l Conf. on*
*Soil Mechanics and Foundation Engrg.*
*Vol. 2, pp. 1431-1434*
*Rio de Janeiro, 1989*

# Preconsolidation of soft Bangkok clay by vacuum loading combined with non-displacement sand drains

# Préconsolidation de l'argile molle de Bangkok par chargement par vide combiné avec des drains de sable sans déplacement

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SYNOPSIS: There are many soil improvement techniques for decreasing post-construction settlement of a site with soft clay deposit. In 1983, a geotechnical improvement study program for the proposed Second Bangkok International Airport Project, Thailand, was carried out. Soil improvement techniques by means of non-displacement sand drains with preloading by surcharge or vacuum or dewatering were tried in test sections to investigate their effectiveness. The paper describes the detailed method of using vacuum pressure. Due to air leakage through the top soil layer, an airtight plastic sheet was needed to cover the test section to achieve the required vacuum pressure. Full vacuum pressure could be applied in the drains to consolidate the soil rapidly. It accelerated the settlement rate of the test section similar to that with surcharge loading.

## 1 INTRODUCTION

The use of vertical sand drains with surcharge loading has been successfully applied to many soft soil improvement projects. A new form of surcharge loading is obtained by applying vacuum in the vertical drainage system. An underpressure of 0.8 - 0.9 bar (8-9 ton/sq m) can be applied immediately to the soil without any danger of stability loss along the edges.

This paper describes a pioneered fullscale study of soil preconsolidation by using this method. The work was carried out for the proposed Second Bangkok International Airport Project for the Department of Aviation of the Government of Thailand. The possible site selected for the proposed airport was at Nong Ngu Hao, a suburb at 25 km east of Bangkok Metropolis. The subsoil at Nong Ngu Hao is similar to the well-known Bangkok clay but it is generally softer at the top 8 m. Rapid preconsolidation of the soft layer is necessary for construction to overcome the large settlement problem of the proposed runways, aprons and other airport structures. As part of the soil improvement scheme study, three test sections were constructed and monitored to evaluate the effectiveness of non-displacement sand drains loaded with three different types of loadings, i.e. surcharge fill loading, vacuum loading and dewatering. The result of study for the test section by preloading with surcharge has been reported by Moh et al (1987).

## 2 DESIGN OF TEST SECTIONS

The subsoils at the project site are fairly uniform. Five different soil strata can be identified within the top 35 m zone. They are:

(a) weathered clay (0 - 1.5 m)
(b) very soft to soft clay (1.5 - 11 m)
(c) soft to medium clay (11 - 15 m)
(d) stiff clay (15 - 25 m)
(e) dense sand (below 25 m)

The typical soil profile and soil properties obtained from the site are shown in Fig. 1. The

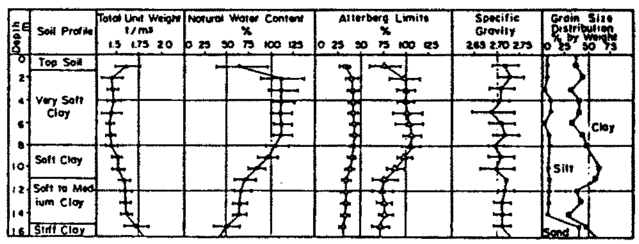


Figure 1. Typical soil profile and soil properties

40 m by 40 m test section had 460 sand drains installed in triangular pattern. With spacing of 2.0 x 1.75 m centres (or one drain per every 3.5 sq m of ground surface area). Each sand drain which was installed by jet-bailer method had a minimum nominal diameter of 26 cm and 14.5 m long. A 60 cm thick sand blanket was placed on the ground surface to provide a firm working platform.

During placement of sand in the drains, two filters were placed inside each sand drain at depths of 3 m and 11 m from the top of the sand blanket. These filters were connected by small diameter tubes with different subsidiary lines through manifolds. Each manifold had a control valve and usually was connected to 12 tubes from the filters. The top 1.3 m of the sand drains was sealed off over their cross-section with a cement-bentonite slurry plug. There were 40 manifolds connected to five subsidiary lines which was in turn linked with the main line from the vacuum pump.

The vacuum pump had a maximum capacity of 110 cu m of water and 130 cu m of air per hour and a maximum under pressure of 0.9 bar.

The test section was well instrumented with piezometers, settlement plates, inclinometers, sondex settlement gauges and hydrostatic profile gauges to monitor groundwater pressure, ground settlement and lateral soil movement.

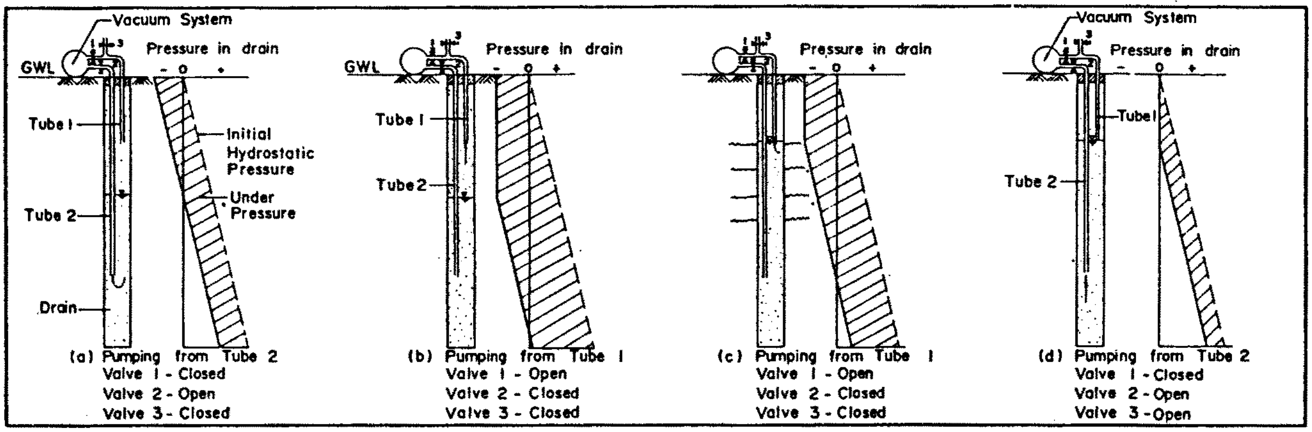


Figure 2. Operation of vacuum loading in sand drain

## 3 THEORETICAL CONCEPT OF PRELOADING BY VACUUM LOADING

The application of preloading by vacuum to consolidate soft clay was first proposed by Kjellmann (1952). However, his theory and practical applications were not widely discussed in publications ever since. Some new theoretical approaches have been discussed by Chen et al (1982) and Ter-martirosyan and Cherkasova (1982).

A successful application of preloading by vacuum was reported by Ye et al (1983). It was concluded that the vacuum system could consolidate the soft clay in a shorter time.

In principle, preloading by vacuum is to suck water and air from the airtight sand drains and create a pressure difference between the drains and the surrounding soil. The effective loading on the subsoil will be this pressure difference. With such a loading, the whole soil mass will be consolidated. The operation of preloading by vacuum in this study is shown in Fig. 2. The precedures are as follows:

(a) The top filter were closed, with application of vacuum,the suction in the lower filters emptied the drains by evacuating the water to a level of 6 to 8 m below the surface.

(b) Air in sand drains was pumped out from the top filters,higher underpressure was developed.

(c) Water from surrounding soil flowed into the sand drain, air-water interface in the sand drains rised to reach the top filters, water could then be pumped out from the drains.

(d) The top filters were then opened to air. There was then no underpressure in the sand drains, and dewatering of the sand drains were through the bottom filters. Water level in the sand drains dropped to a steady level.

(e) Repeat pumping cycle from (b) to (d).

The initial excess pore water pressures at the clay layer is given in Fig. 3. The dissipation of excess pore pressure can be estimated by assuming both vertical and horizontal flow of pore water as suggested by Barron (1948).

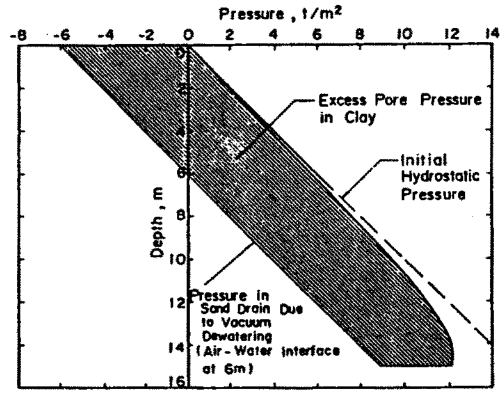


Figure 3. Excess pore pressure due to vacuum dewatering

## 4 PREFORMANCE OF TEST SECTIONS

### 4.1 Initial pumping

The planned full-scale pumping operation was started with all the top filters closed. An initial underpressure of 0.3 bar was gradually applied to bottom filters for 5 hrs. The underpressure was then gradually increased to 0.6 bar and maintained for 16 hrs. Thereafter, the maximum underpressure which could be attained was only 0.68 bar with full pump capacity. But as soon as pumping was applied to the top filters, the pressure dropped to a very low value indicating severe leakages somewhere. After intensive searching, leakage of air through voids in the top soil stratum was discovered. It was found from an excavated pit that there were numerous tiny holes which might be formed by grass-roots or earth worms. Atmospheric air could have passed via the sandy working platform, through these holes and reached the sand drains below the plugs.

### 4.2 Sealing of sand blanket

With the considerations of effectiveness, cost and durability, placement of a plastic sheeting on top of the working platform was selected for sealing. The sealed area was 12 m wide by 46 m long and it covered 132 sand drains. The four edges of the plastic sheet were buried 1 m deep in narrow trenches sealed with cement-bentonite mixture. Double gluing was applied to connect the plastic sheets. Special sealing arrangements were also made around those instruments protruding through the sheets.

4.3 Pumping operation

Only the sand drains in the sealed area were connected to the pump. It was possible to maintain an underpressure of 0.6 to 0.7 bar in the top filters. The pumping operation was continued for 2 months.

In the cyclic pumping process, it was observed during the first cycle that the water level in the drains took two days to reach the top filters from its lowest level. A two days period was therefore adopted as the cyclic time for subsequent cycles. Because of the limited time available for the project, the cyclic pumping operation was stopped after seven cycles.

## 5 EVALUATION OF RESULTS

### 5.1 Settlement rates

Plotted in Fig. 4 are the observed settlements at the centre of the test section with time. Periods during which the pumps were out of order and preparation of sealing have been taken out. The settlement rate can be separated into 3 stages, namely: dewatering (before sealing), vacuum loading and cyclic vacuum loading. It can be seen that the ground settled rapidly in the first 2 months after the start of dewatering, and then at nearly constant rate. The settlement rate increases from approximately 3.3 mm/day to 4.2 mm/day after changing from dewatering to vacuum loading; it increased further to 6.5 mm/day when cyclic vacuum loading was applied.

The settlement data from a similar test section which was preloaded with surcharge are also shown. The ground settled correspondingly to the various type of loadings indicating the effectiveness of sand drains installed.

### 5.2 Settlement profile

Variation of settlement across the centre of the test section was monitored. Assuming that the settlement under the centre of the test section is 100 per cent, the settlement profiles across the section can be expressed as given in Fig.5. The test section where vacuum loading had been applied, has a more uniform settlement profile as compare to that where surcharge loading was applied. It also shows an area of influence beyond the edge of the test section of about 5-10 m where the ground settled slightly.

The settlement at various depths is expressed in Fig. 6 as a percentage of the maximum settlement at ground surface. A similar relationship of settlement data of the test sections preloaded with vacuum and preloaded with surcharge indicating the the consolidation behavior of the compressible strata was identical irrespect of the method of loading. In the two test sections, the bottom 5 m of the soft clay contributed only about 15 per cent of the total settlement. More than 50 per cent of the settlement achieved was from compression of the soft clay layer at depth between 3 m and 7 m. Therefore, it can be concluded that use of sand drains at Nong Ngu Hao will be most beneficial for this depth range.

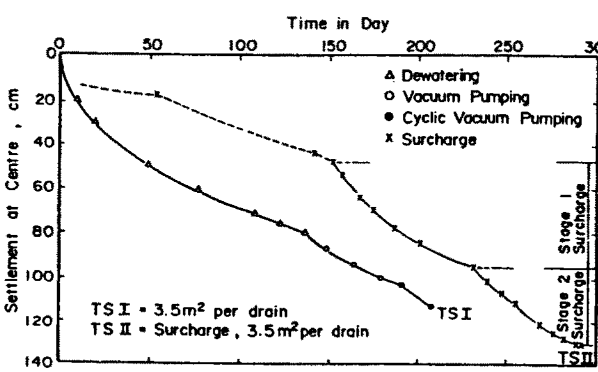


Figure 4. Observed settlement rates

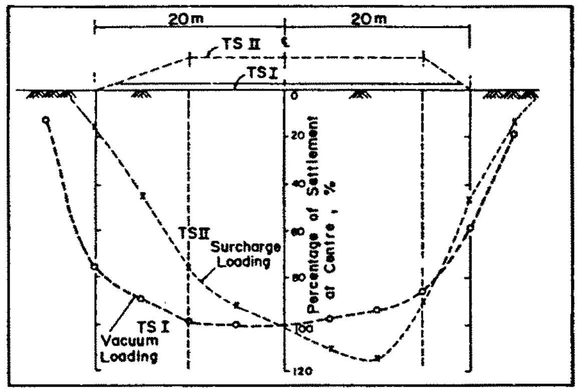


Figure 5. Settlement profile across centre of test section

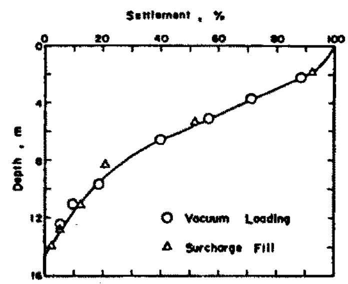


Figure 6. Percentage of settlement vs depth

### 5.3 Water content and cone resistance

Fig. 7 presents comparison of water contents in the soils before and after treatment. It shows that the soil water content decreased by about 20% in the very soft layer due to the application of vacuum loading through sand drains. It should be further pointed out that the time period for vacuum loading of the test section was very short. Better results, i.e. more decrease in water content, are anticipated with longer loading period. Fig. 8 shows that the cone resistance increased after preconsolidation.

### 5.4 Comparison of field results with theoretical analysis

A theoretical settlement analysis was carried out to compare with the field results. Based on results of field exploration and in situ probe tests, the entire compressible soil profile up to 15 m depth was divided into four major layers each bounded by two free drainage boundaries at the top and bottom. Compression indices of the various soil layers as obtained

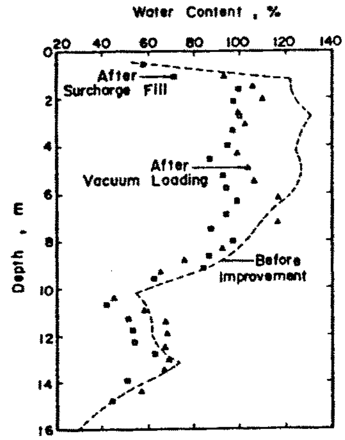


Figure 7. Water content before and after improvement

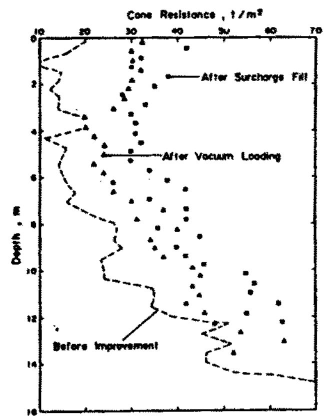


Figure 8. Cone resistance before and after improvement

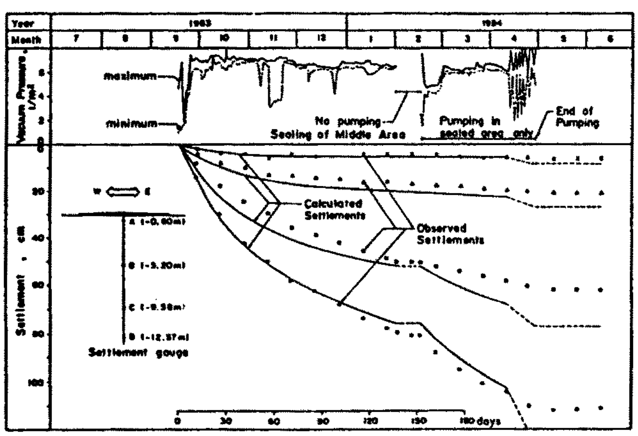


Figure 9. Calculated settlement vs observed settlement

from laboratory consolidation tests were used, and the horizontal coefficient of consolidation with horizontal drainage was taken as one-half of the value obtained from pore pressure dissipation test (Tortensson, 1982). As the monitoring period for the test section was relatively short, only immediate settlement and consolidation settlement were considered. The rates of consolidation settlement were calculated by considering the combined vertical and radial pore water flow into the drains.

Fig. 9 presents the consolidation settlement-time curves at various depths under the test section. In general, agreements of the results are good. Second stage of pumping (by vacuum after sealing ) appeared to change the rate of settlement only at 0.6 m and 5.2 m depths. It is because after pumping from both filters, only the top 6 m zone could show an increase in pressure difference.

Cyclic pumping tends to increase the settlement rate, unfortunately the pumping period was too short to give a meaningful comparison.

## 6 CONCLUSIONS AND RECOMMENDATIONS

The use of non-displacement sand drains with vacuum loading proved to be an acceptable method for improvement of the Bangkok clay. Vacuum system requires special pumping techniques and design features, e.g. an airtight sheeting and tubings. Field results from the test section show that the settlement rate and consolidation behavior of the subsoil were identical to the results preloaded by surcharge fill. However, full vacuum loading could be applied with no danger of stability failure. The performance of the test section could be analysed by conventional sand drain theory. For projects that need rapid preconsolidation, the possibility of combining vacuum load with low surcharge fill is worthy to be studied.

## ACKNOWLEDGEMENTS

The Authors wish to acknowledge the Dept of Aviation of the Ministry of Communications of Thailand for their kind permission for publishing the test data.

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