Drainage and Filters
6 B/2

Third International Conference on Geotextiles, 1986, Vienna, Austria

RISSEEUW, P., Enka Industrial Systems, Netherlands
VOLDERS, R., Ballast Nedam Dredging, Netherlands
TEUNISSEN, H., Delft Soil Mechanics Laboratory, Netherlands

SOIL IMPROVEMENT BY PRELOADING AND VERTICAL DRAINS, PORT KELANG POWER STATION, MALAYSIA

CONSOLIDATION DES SOLS PAR DRAINS VERTICAUX ET PRECHARGEMENT

BODENKONSOLIDIERUNG DURCH VERTIKALDRAINAGEN UND VORBELASTUNG

The demand for a coal storage yard (250 m x 1,000 m) and rehandling facilities of Port Kelang Power Station on the west coast of Malaysia called for special measures to improve the overall bearing capacity of the subsoil. The claimed "price-performance" of soil improvement by installing over 3 million lin.m vertical synthetic strip drains, 10 cm wide, to a depth of 20 metres at close spacings, combined with extensive preloading, was found to be better than that of a foundation on piles. The handing-over criteria, i.e. an accelerated settlement of approx. 3.1 m, combined with a corresponding increase in shear strength, were to be met in one year.
Extensive soil investigations and laboratory tests were carried out. Also an axial symmetrical finite element computer program to predict the behaviour of the multi-layered subsoil was developed. During preloading the actual behaviour of the subsoil was continuously monitored.

1. INTRODUCTION

1.1 In the late seventies the National Electricity Board of the States of Malaysia decided to build a new multi based thermal power station on the mangrove covered foreshore of the Malacca Straits in the state Selangor. Phase II of the construction of the Power Station concerns a coal-fired plant. This paper will discuss the results of subsoil improvement for the coal storage yard, which measures 250 m x 1,000 m, and will provide a storage capacity of 760,000 tons of coal, in mounds of 13 m height. To rehandle the coal, three stacker reclaimers are planned, each exerting a live load of 528 tf. (Fig. 1).

1.2 The initial design showed a piled foundation for said reclaimers (Fig. 2). The piles should reach to a depth of approx. 50 m. The subsoil under the actual stock area had to be consolidated by the coal itself with the help of vertical drains, down to 11 m depth. This would cause settlements in the order of 3 m over the years.

It is clear, however, that in view of these large vertical settlements, also large horizontal forces will act on piles, which are likely to inflict damage.

1.3 Ballast-Percon JV, a joint venture of Ballast-Nedam/Holland and Pernas Construction/Malaysia, proposed an alternative design comprising extensive preloading in combination with vertical drains to a larger depth, so as to realize a solid foundation for the stacker reclaimers by soil improvement in advance. This design bypassed any piling operation and the reclaimers would run on a normal ballast/sleeper bed (Fig. 3).

Für das Steinkohlenlager (250 m x 1.000 m) mit Verladeeinrichtungen des Port Kelang-Kraftwerks an der Westküste Malaysias waren Spezialmassnahmen erforderlich, um die Tragfähigkeit des Untergrunds zu verbessern. Die Annahme, dass das Preis/Leistungsverhältnis einer Bodenverbesserung durch den Einbau von vertikalen, synthetischen, 10 cm breiten Dräns bis zu 20 m Tiefe in engem Raster in Verbindung mit hoher Vorbelastung günstiger sei als das einer Pfahlgründung, erwies sich als richtig.
Die Abnahmekriterien, d.h. eine beschleunigte Setzung von ca. 3,1 m in Verbindung mit einer entsprechenden Zunahme der Scherfestigkeit, mussten innerhalb eines Jahres erfüllt werden. Dazu wurden umfassende Bodenuntersuchungen und Laborprüfungen durchgeführt.
Ferne wurde ein achsensymmetrisches "FE"-Computerprogramm zur Vorhersage des Verhaltens des mehrschichtigen Untergrunds entwickelt.
Das Verhalten des Untergrunds während der Vorbelastungsvorgangs wurde am Monitor verfolgt.

- capacity 800 ton / hour
- rail span 8 m
- wheel load (in operation)
  vertical load 22 ton/wheel*6 wheels*4=528 ton
  horizontal load 2.2 ton/wheel*6 wheels*4=52.8 ton
- other load (belt conveyor etc.) 0.50 ton/m2

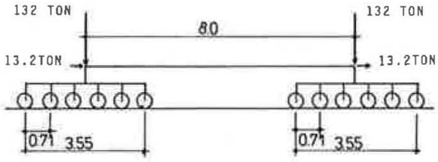


Figure 1

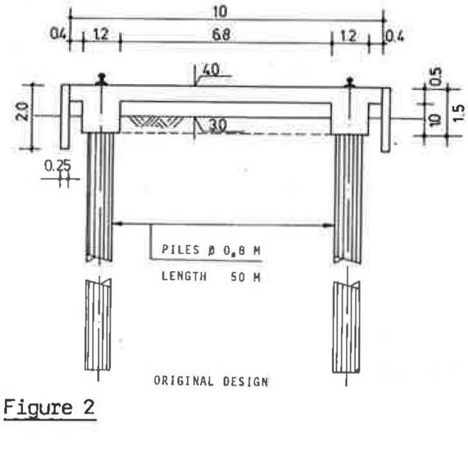


Figure 2

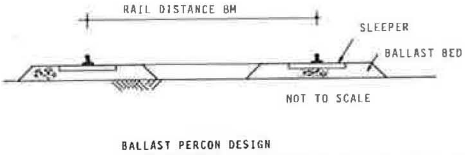


Figure 3

This design approach offered a more rapid delivery to the client and better price-performance.
The work commenced in March 1984.

2. GEOLOGY

The proposed site is situated on one of the alluvial planes along the west coast of Malaysia facing the Straits of Malacca. It is commonly understood that the seawater level in this area was more than 100 m below the present level about 20,000 years ago.
The surrounding hills and mountains were severely eroded during this period and as a result numerous valleys were formed. With the gradual rise of the seawater level, the eroded sandy materials were deposited in shallow water, while the eroded clayey materials were transported to deeper water.
About 6,000 years ago the rise of the seawater ceased at a level of about 5 m above the present level.
So a marine clay layer started to accumulate in the site area and the water near the shore became very shallow due to the continuous sedimentation.

3. SOIL CONDITIONS AND PRELIMINARY DESIGN

3.1 Soil Conditions

As early as 1982 a soil investigation was performed for tender purposes, i.e. information was collected from 9 boreholes within the boundaries of the future coal storage yard. The test results showed a large variation and did not include information on horizontal permeability and secondary consolidation. Ballast/Percon decided to execute additional soil investigations which included continuous sampling. From the results obtained a theoretical soil profile was constructed (Fig. 4).
Below 34 m alternating stiff to very stiff silt and clay layers were found and at approx. 75 m below OGL dense sand was encountered. The properties of these layers were such that no influence was to be expected on the consolidation process and the stability of the preload.

3.2 Design

Based on this information, Ballast-Percon proposed preloading and vertical drains down to 21 m depth, in a triangular pattern of 1.41 m spacings.
This required the installation of over 3 million linear metres of drain. It was calculated that on top of the existing 2.5 m sand layer an additional 7.5 m sand (preload) had to be placed. The handing-over criteria were then determined to be:

- an average of 91% consolidation of the undrained clay layers underneath in approx. 1 year, viz. approx. 3.1 m of settlement;
- a corresponding increase in shear strength.

Subsequently, about 5 m of sand surplus had to be excavated, which could be used for preloading of adjacent areas.

Given the importance of this basic design, the client agreed to let the contractor construct a fully instrumented test area, 120 m x 153 m, at the south end of the planned coal yard, to collect data in order to:

- optimize the design by back calculations, based on the monitoring results;
- establish the performance of two types of 10 cm wide strip drains (Colbond CX-1000 drains and Castleboard) that had been prequalified and select one of them to be used in this project.

Depth (m)	Soil profile	$C_c/1+e_o$	$C_\alpha/1+e_o$	C_v (m^2/y)	C_h (m^2/y)	γ_t (t/m^3)	P_o (tf/m^2)	P_c/P_o	S_u corrected acc. to Bjerrum
+2.5 0	hydraulic fill								
4	GWT	0.25	$13x10^{-3}$	18	72	1.7	2.4	1	0.94
				2.7	10.8	1.56	4.64	1	1.28
7 10.5	grey soft to very soft marine clay	0.38	$26x10^{-3}$	0.7	2.8	1.43	6.23	1	1.13
14							7.74	1	1.63
17							9.14	1	1.73
18.5						1.46	10.13	1	2.15
20			$12x10^{-3}$	0.7	2.8	1.46	10.82	1	2.16
23	grey soft to stiff marine clay					1.51	11.93	1.15	2.58
26						1.56	13.53	1.45	2.90
31		0.25	-	10	40	1.63	15.95	1.75	3.15
34						1.70	18.22	1.95	2.98

Figure 4 : Soil Profile

LEGEND
Cc = compression index
C_α = secondary compression index
eo = initial void ratio
Cv = coefficient of consolidation for vertical pore water flow
Ch = coefficient of consolidation for horizontal pore water flow
γt = unit weight of saturated soil
po = initial effective vertical stress
pc = preconsolidation stress
Su = undrained shear strength (corrected for anisotropy, strain rate, etc. according to Bjerrum).

4. PLANNING AND CONSTRUCTION OF THE TEST AREA

4.1 Figs. 5 and 6 show the lay-out of the test area, i.e. its geometry, where the additional soil investigations were performed, and the 29 locations for all types of measuring devices. The most critical item during construction was the stability of the fill, i.e. the speed at which this preload could be raised up to 10 m + OGL. The rate of filling is directly related to the increase of shear strength of the subsoil, which value depends again on the rate of consolidation during construction.
Hence, the performance of the vertical drains was decisive from the very beginning.

4.2 Drain Performance Calculation Program

Since most calculation methods assume a homogeneous subsoil and neglect the decrease of effective load due to subsidence, it was decided by Ballast-Percon to develop in co-operation with Delft Soil Mechanics Laboratory a finite element computer program to predict the consolidation process for a multi-layer system. This program is based on linear deformations and flow. The required input parameters have to be calculated from the traditional parameters such as C_c, e_0, C_v, C_h, etc. Lay-out and results are presented in Figs. 7 and 8.
To calculate the preload and the drain configuration following boundary conditions have to be known:

* design load as a function of depth;
* time available for preloading and consolidation;
* performance of the drain, i.e. discharge capacity, permeability of the filter lining etc., during its service life;
* allowable post construction differential settlements;
* increase in shear strength together with decrease in pore pressure.

The outcome of these calculations also supplied the safe rate of hydraulic filling for the preload. These data and back calculations based on continuous monitoring led to filling in 5 stages at a slope 1:4, maintaining a factor of safety of more than 1.1.

4.3 Calculated Primary Consolidation

Under the future design load, i.e. stacker reclaimers, coal stock and remaining fill, the total settlement due to both primary and secondary consolidation, during a service life of 30 years, was calculated to be approx. 3.0 m. For the preloading scheme applied (5 stages) a total primary consolidation settlement of the drained layers was calculated to be approx. 3.4 m (Fig. 8).
At 91% consolidation of these drained layers the settlement is 3.1 m. During the service life, a small deformation in the order of 0.30 m can be expected due to recompression and minor secondary consolidation of the drained layers and primary consolidation of the undrained layers.

4.4 Choice of Vertical Drain Type

The total available construction time did not allow long term monitoring of the behaviour of the test area with regards to the selection of the drain type. Therefore within the test area, two smaller test embankments (25 x 25 m) were constructed. Based on the short term performance such as settlements of the embankments and water discharge capacity of the drains, it was decided to use Colbond CX-1000 drains for this project. Subsequently about 3 million lin.m drains were installed within approx. 7 months.

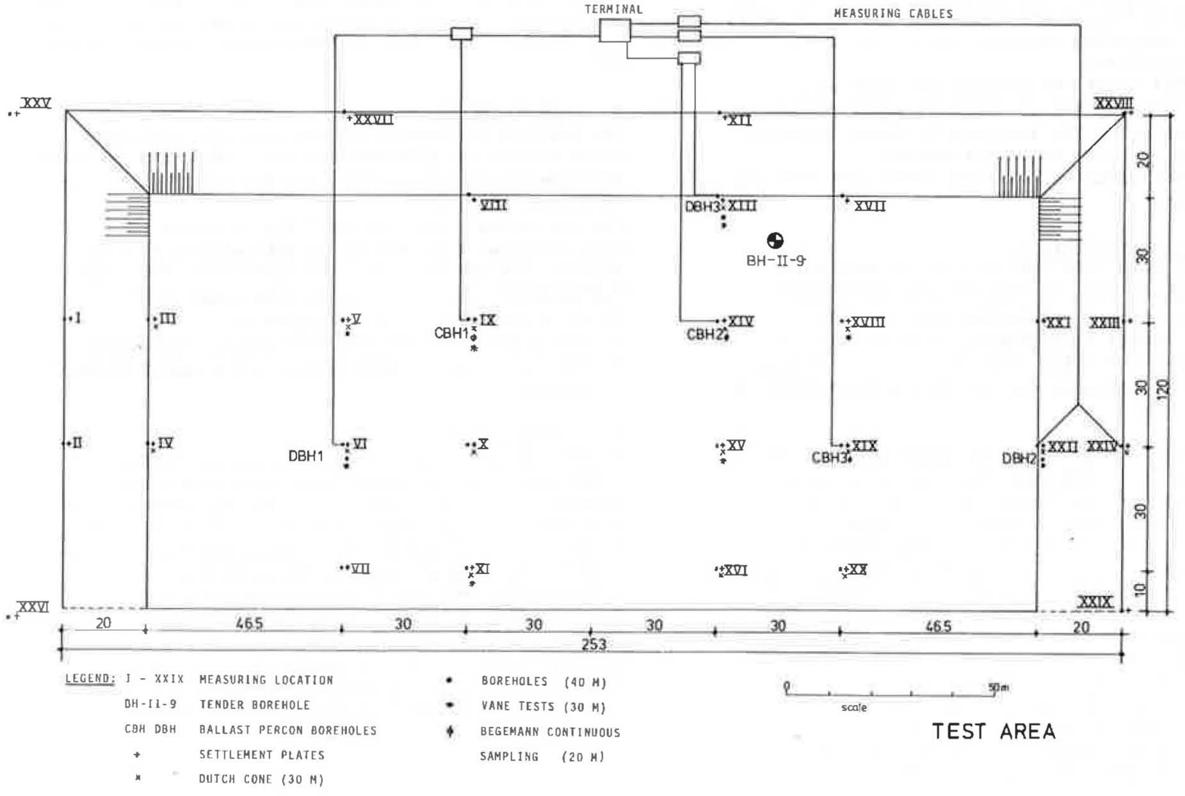


Figure 5

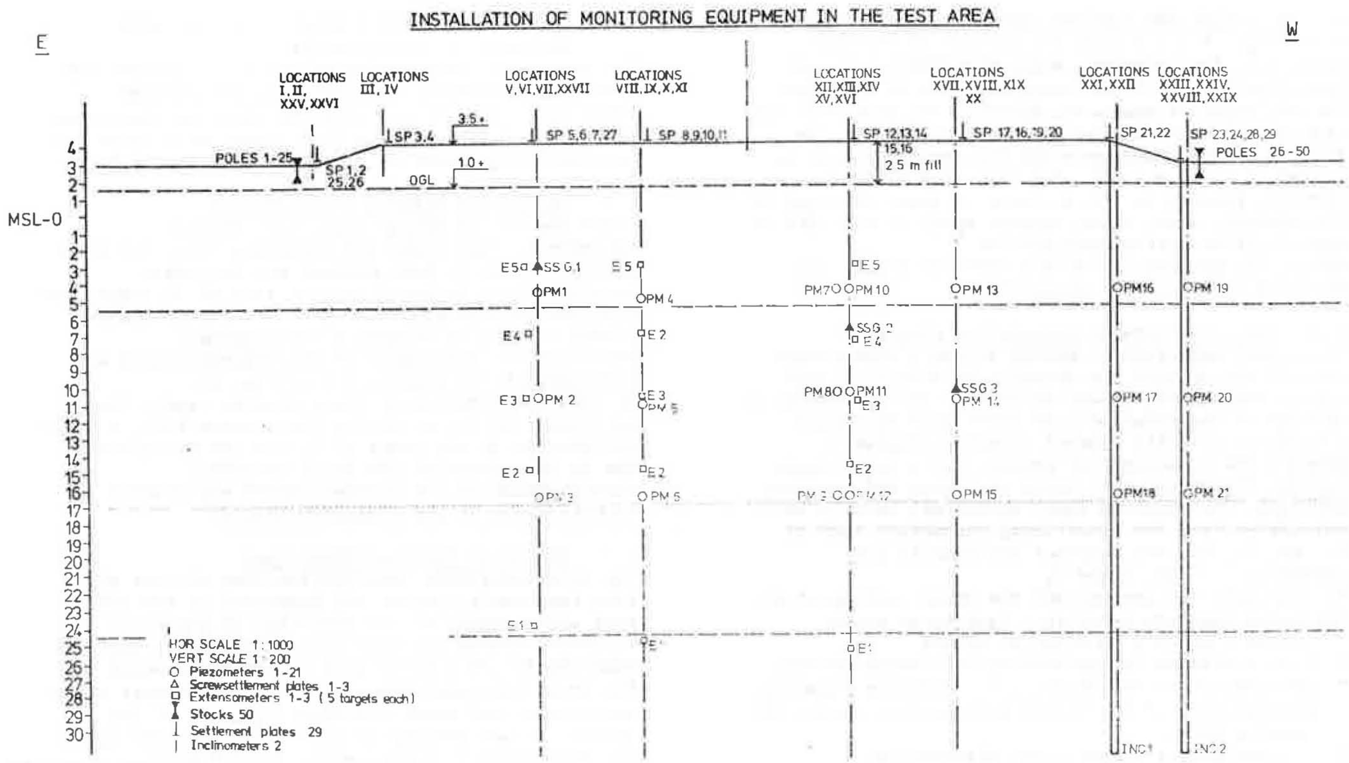


Figure 6

5. PREDICTED AND MONITORED RESULTS IN THE TEST AREA

5.1 As shown in Fig. 6, the test area was extensively equipped with measuring devices, which have been continuously monitored.
Since the stability of the preload was critical, especially during filling of the last layer of sand (stage 5), monitoring the increase in shear strength was considered to be of major importance.
For this purpose almost continuous field vane testing was carried out.

5.2 Shear Strength Profile
The results of more than 800 initial in situ vane tests are shown in Fig. 9. The initial measurements showed a shear strength effective stress ratio (Su/p) of 0.3 almost consistently up to a depth of 27 m. Below 27 m the ratio seems to be considerably higher, which is probably due to the overconsolidated state of the clay.

5.3 During filling and when the surcharge was at full height, another 200 vane tests were performed. From the results of the latest two series it can be concluded that the shear strength increased considerably in the top layers. In the lower drained layers the improvement is less pronounced. Although deformation measurements indicate a high degree of consolidation, the shear strength development shows a delay. Pore pressure measurements in the lower layers show a similar feature. Hansbo et al (Ref. 4) reported that delayed excess pore pressure dissipation or even the lack of it, which is in contrast with other deformations gained from a monitoring program, cannot be explained at the present stage of the author's knowledge.
The authors of this paper share this statement. This phenomenon has been encountered in several projects, e.g. Prai-Penang (Ref. 2) and Changi Singapore (Ref. 3).

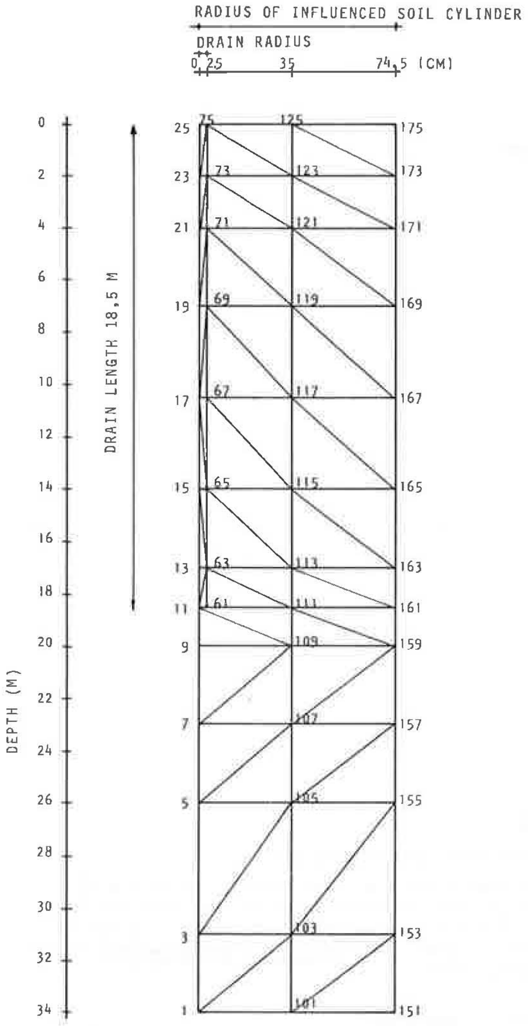
6. SETTLEMENTS

The surface settlement of the test area has been monitored by 29 settlement plates (SP). The recorded settlements in the centre part are reported on the next page (Fig. 10).
For the actual location see Figs. 5 and 6.
Fig. 10 shows that the final settlements will be approx. 10% larger than calculated with the Drain Performance Computer Program (see under 4.2).
This difference can be explained by:

- the scatter in the compressibility ($C_c/1+e_o$);
- the secondary consolidation in the upper drained layers.

7. CONCLUSIONS

At the present stage of the project preliminary conclusions can be drawn from the interpreted monitoring results, the predicted settlements have been reached and shear strength is still improving. So it can be said that the overall performance was satisfactory, which was confirmed by the client. Subsequently removal of the preload was started.
The alternative design of Ballast-Percon JV including Colbond CX-1000 vertical drains and extensive preloading, has led to a comparatively cheap foundation for the rehandling facilities of the coal storage yard of the Port Kelang Power Station.



1 - 175 Nodes of Model
Figure 7

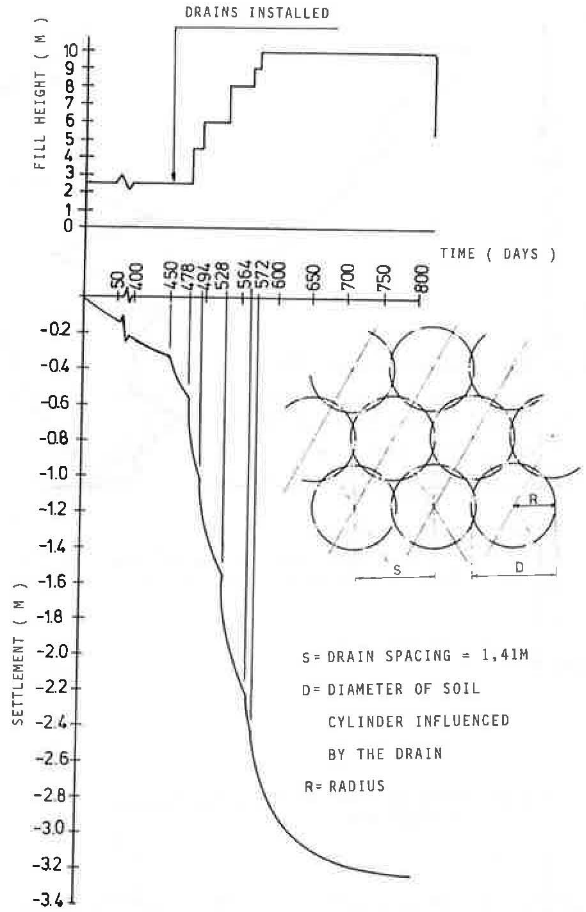
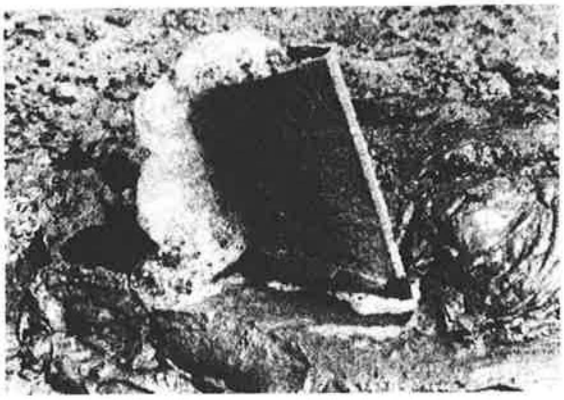


Figure 8



Colbond CX-1000 drain installed at Port Kelang Power Station Project

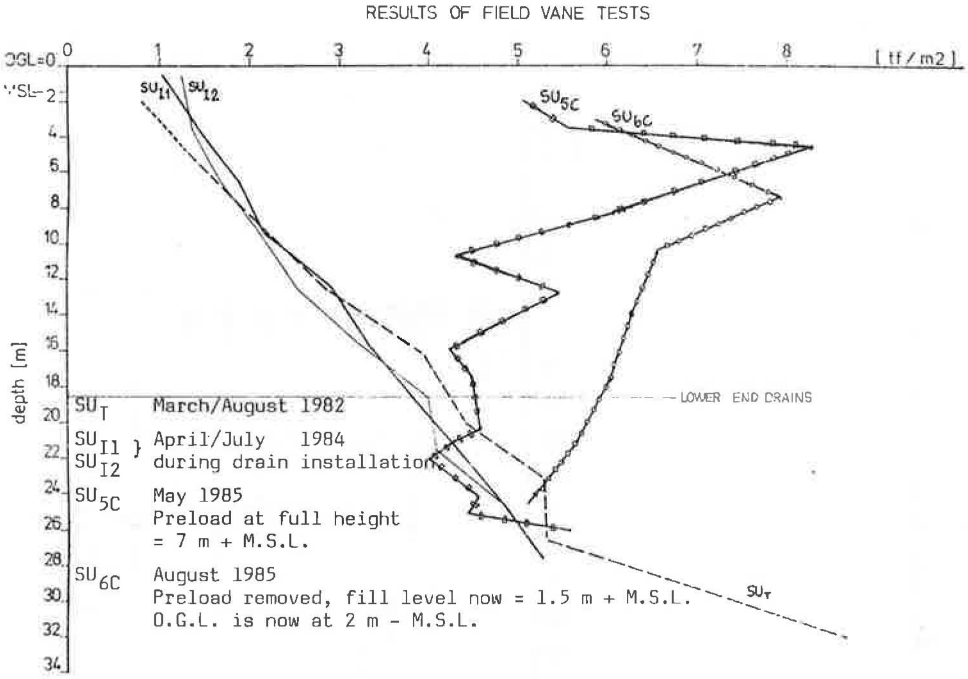


Figure 9

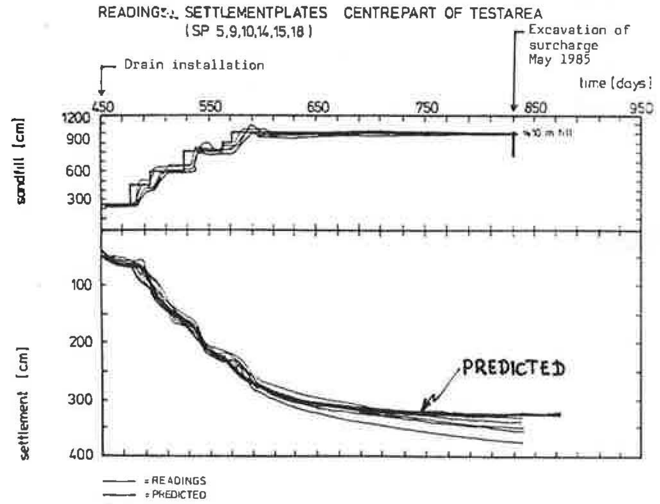


Figure 10

REFERENCES

(1) Volders R.H. and Risseeuw P.
"Soil improvement by preloading and vertical drainage for the foundation of the coal storage facilities of the Port Kelang Power Station in Malaysia, 1984-1985", Ballast Dredging-ENKA report, Holland, 1985.

(2) Adachi K. and Todo H.
"Case study on settlement of soft clay in Penang". Proc. 6th Asian Reg. Conf. on Soil Mechanics and Foundation Engineering, Singapore, 1979.

(3) Choa V. et al
"Drain performance in Changi marine clay", Proc. X ICSMFE, Stockholm, 1981.

(4) Hansbo, S. et al
"Consolidation by vertical drains", Geotechnique, vol. XXXI, No. 1, Paris, 1981.