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Construction on compressible saturated subsoils with the use of non-woven strips as vertical drains

Construction sur sol mou avec drainage vertical au moyen de bandes de non-tissé.

L'un des moyens utilisés pour reduire la durée de tassement consiste à raccourcir le chemin d'écoulement des eaux sousterraines. A cette fin, on applique depuis 1930 des drains verticaux placés à une faible distance les uns des autres dans le sous-sol et se présentant soit sous forme de pieux de sable soit sous forme de bandelettes de carton.
En 1972, le principe tel qu'appliqué par l'ingénieur suédois Kjellman pour le drainage par bandelettes de carton a été repris par Akzo Research Laboratories à Arnhem parce que cette technique offrait des possibilités intéressantes à un drain nouveau à base de bandes de non-tissé. L'étude effectuée dans ce cadre s'est déroulée comme suit.

En collaboration avec la société Visser & Smit,membre du Koninklijke Adriaan Volker Groep, des bandes drainantes d'une largeur de 30 cm, c'est-à-dire de trois fois celle des bandelettes en carton, ont été lancées dans des couches de terre compressibles et peu perméables. Les résultats obtenus avec des remblais expérimenttaux confirment que, pour un espacement des drains par mailles de 2,5 m, l'effet d'une bande drainante de 30 cm de largeur correspond à celui d'un drain de sable ayant 25 cm de diamètre.
Signalons à ce propos les résultats d'une série d'essais de drainage vertical réalisés sur plusieurs sections de l'autoroute A 19, à proximité de Delft, lesquels résultats se trouvent notamment traités dans la contribution fournie par MM. de Jager et Termaat.

L'application combinée d'un nouveau matériau (la fibre polyester) et de notre procédé pour la fabrication des non-tissés permet de produire des bandes drainantes très solides et durables dont la mise en place ne pose aucun problème particulier. La construction des remblais expérimentaux avait été précédée d'essais de laboratoire en vue de trouver la meilleure combinaison de caractéristiques mécaniques et hydrauliques,qui soit compatible avec notre procédé de fabrication.

Depuis son autorisation aux Pays-Bas en 1975, le système A.V.-COLBOND a été mis en pratique avec succès dans une dizaine de projets de drainage vertical, utilisant au total plus d'un demi-million de drain. Dans un certain nombre des ouvrages réalisés, le matériau se trouve en outre soumis à des contraintes mécaniques très élévées.

1. INTRODUCTION

When fill is used on a large scale, for instance in the construction of motorways, industrial estates or new residental districts and the subsoil consists of cohesive layers of soil, these layers will consolidate under the influence of the fill. This consolidation may sometimes take years with different degrees of settlement and shear occuring during the process. The result may be the subsidence of dwellings, offices or roads and paved surfaces.

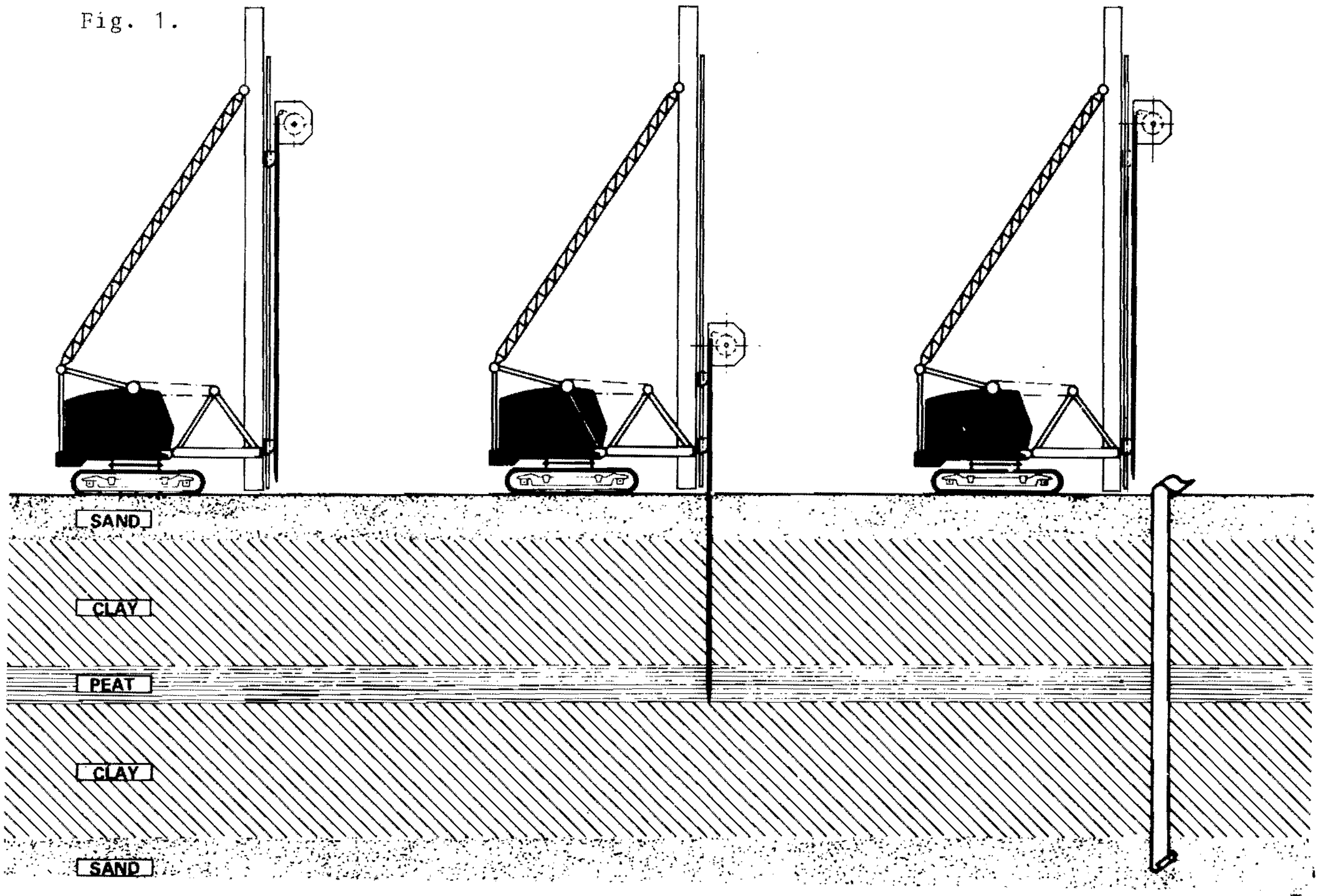
By shortening consolidation time, building activities can be started sooner without any risk.
A new drainage system has now been developed in the Netherlands by which approx. 80 % of full settlement is attained within a few months.

2. BUILDING ON SOFT SOIL BY THE USE OF VERTICAL DRAINS

Large -scale fill must be stable both during and after construction. Problems are encountered when the soil consists of cohesive layers with a considerable water content, like clay, sludge, peat or loam.In that case the additional load will cause settlement in soft soil.
The extent of settlement depends on the nature of the soil: water content, compactness, structure and thickness of the layers, and also on the nature of the loads.

Quick filling causes excess pressure in the soil, notably excess water pressure in cohesive layers and a greater effective pressure in non-cohesive layers.

Fig. 1.



As the water is forced out of the cohesive layers of soil, the excess water pressure decreases and settlements occur. These are usually of such an irregular nature that difficulties may be caused for any structures on that soil, such as dwellings, offices, sheds, sewage systems, roads and paved surfaces.

Once the excess water pressure has entirely disappeared, final settlement has been reached. The soil is then fully consolidated.

The consolidation process may take a considerable time in cohesive layers of great thickness, since in this case a larger quantity of water enclosed in the pores has to travel over a greater distance.

A means of reducing the time of settlement is to shorten the path that the water under excess pressure has to travel. For this purpose use is made of vertical drains close together in the soil. Since 1930 they have taken the form of sand drains or strips of paper.

In this field the A.V.-COLBOND drain system has now been developed by Visser & Smit, Soil Mechanics and Foundation Engineering Division, in collaboration with Colbond BV, the non-woven product group of Enka Glanzstoff, Arnhem. This new system is likewise based on the principle of vertical drainage, but instead of the sand drains or the 10 cm wide paper drains applied up to now, use is made of the polyester non-woven fabric COLBOND KF650 in 30-cm strips. (see Fig. 1).

3. <u>DEVELOPMENT OF THE NEW DRAIN</u>

Since 1972 Kjellman's concept of using narrow strips of paper instead of sand drains for vertical drainage had been further pursued within the Akzo Research Laboratories Arnhem. The investigations were based on the fact that new possibilities for the design of drains had presented themselves:

- Stripdrains could be made considerably wider. Calculations (according to Kjellman) showed that a stripdrain having a cross-section of 300x4 sq.mm is equivalent to a sand drain with a diameter of 25-30 cm. This has meanwhile been verified in an experimental section in 1973.
- New raw materials (polyester fibre) permitted the production of stripdrains of non-woven fabric which proved to be less vulnerable during insertion into the soil, and more reliable in use.

The synthetic drain as described in this article is one of the results of the activities at Akzo Research Laboratories relating to the use of synthetic non-woven and woven fabrics in soil stabilisation. Besides a qualitative exploration of the functions that can be performed by these materials in this field, model experiments are simultaneously made on laboratory scale. Thus the product can be optimized for a specific function, while also various parameters can be determined. Below a description is given of the set-up for testing strip drains and the results thus obtained.

3.1 LABORATORY TESTS

For a preliminary investigation a number of different strips of non-woven material, 5 cm wide, were incorporated in the centre of poorly permeable sand/clay cylinders (20% by wt of clay). having a diameter of 5 cm (see Fig.2). By maintaining a constant excess water pressure over the whole circumference of the sand/clay cylinders, the "yield" of the various drains could be compared. In this model non-woven strips could be replaced by sand drains having a diameter of 3 cm and also by blanks, i.e. undrained models. In this set-up several experimental versions were tried out, the length of the trials varying from 2 to 6 months

The results of a series of these trials are given in Fig. 3.

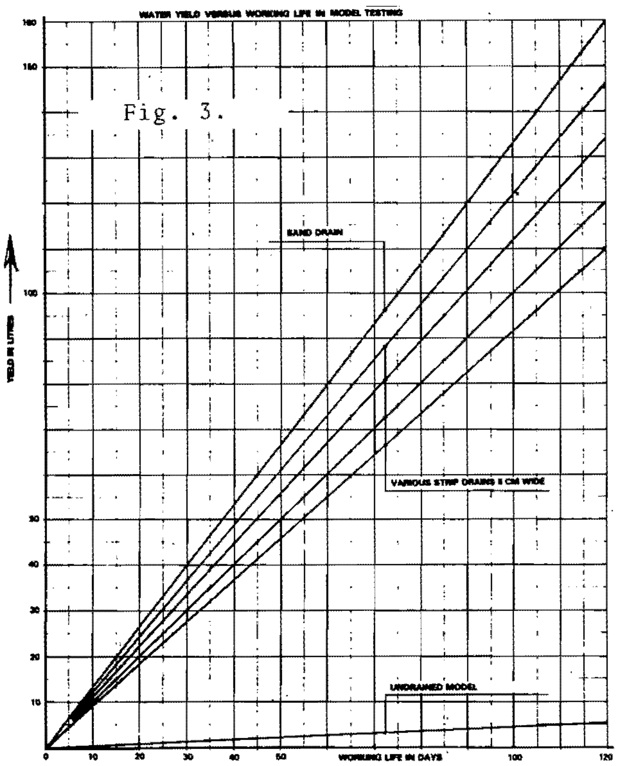


Fig. 3.

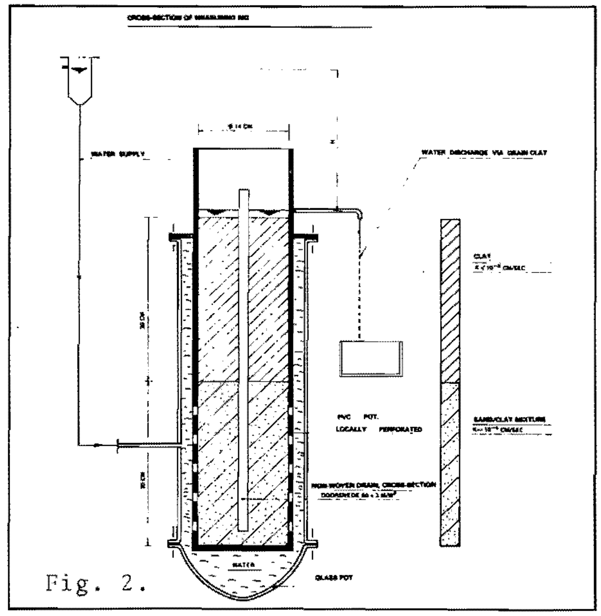


Fig. 2.

The information thus obtained was the sum of many parameters and was therefore in the first place of a qualitative nature. Nevertheless, sufficient knowledge was obtained to choose the non-woven strips used in a full-scale trial section (1973-1974).

In order to gain a better insight into the separate parameters determining the performance of a non-woven strip drain a second test rig was devised (Fig.4), which, like the rig sketched in Fig.2, is still in operation.

In this apparatus one or more circular non-woven fabric specimens are clamped between flat stainless steel plates. Water at a certain pre-pressure is then poured through these specimens from the centre. With this method the permeability of a non-woven specimen in its own plane (Kt value) can be determined as a function of:

- the type of non-woven fabric;
- the compression of the material (Fig.5);
- the kind of water, i.e. the influence of the surface tension, gas content, occurence of certain minerals, acidity etc.;

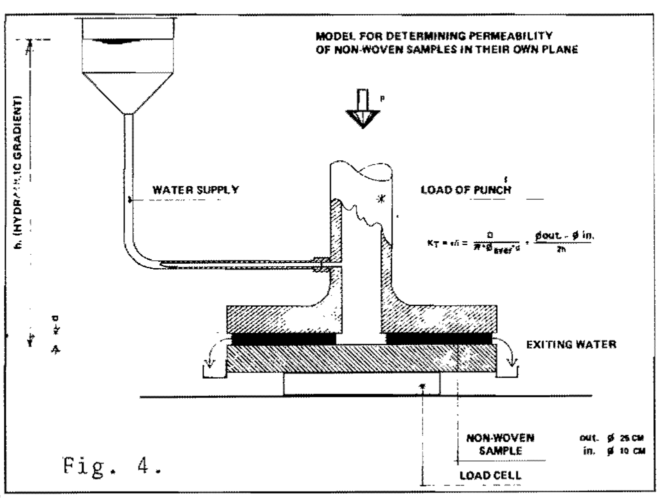


Fig. 4.

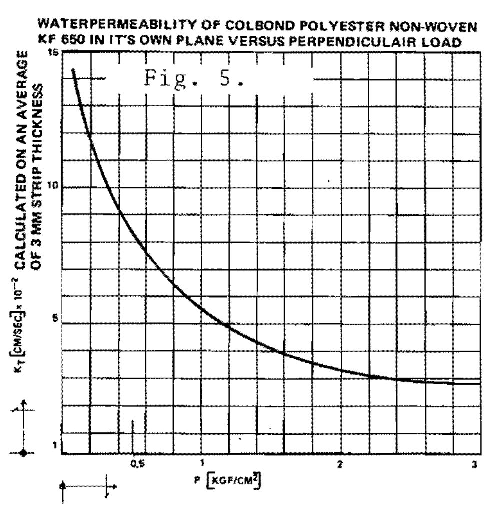


Fig. 5.

3.2 FULL-SCALE TRIALS

3.2.1 Test site Delfzijl

In 1973 a trial field of 15 x 80 m2 was laid out on a subsoil consisting of clay and peat down to 5.5 m below ground level (see Fig.1). This trial was made under the supervision of the Soil Mechanics Laboratory - Delft.

Scope

The purpose of the investigation was to compare two types of vertical drainage systems in identical subsoil layers. To this end 30-cm wide strips of synthetic, non-woven fabric were introduced into the ground in three of the trial sections by means of a purpose-built machine (see Fig.6 and 7). The spacing between the strips and strip thickness varied from section to section.

In the fourth trial section conventional sand pile drainage was applied.

Set-up

The trial field was divided lengthwise into four sections. In three of these sections, different types of A.V.-COLBOND drains having a width of 30 cm were placed at mutual spacings of 2.5 m (or 1.86 m in one of these sections).
For comparison the fourth trial section was provided with sand drains, also at spacings of 2.5 m. The drains formed a pattern built up of equilateral triangles.

After a priliminary investigation of the uniformity in thickness and structure of the compressible upper layers had been made, a 3-m high mound of sand was raised on the four trial sections containing the various kinds of vertical drains.

By observing the settlement of the mound and the water pressures in the soft compressible layers under the mound, an impression was gained of the rate of settlement and outflow of the pore water under excess pressure.
Both phenomena are functions of the rate of consolidation, which is governed on the one hand by thickness and permeability of the compressible layers and on the other by the drainage possibilities below, above and in the layer.

For 500 days the excess pressure of the water in the ground was measured by means of pore water pressure gauges installed under the mound of sand (four per trial section).
In the longitudinal direction of the mound 40 settlement markers had been placed, by which settlements were measured for approx. 600 days. Below is a summary of the results and conclusions, which have been confirmed by the Soil Mechanics Laboratory.

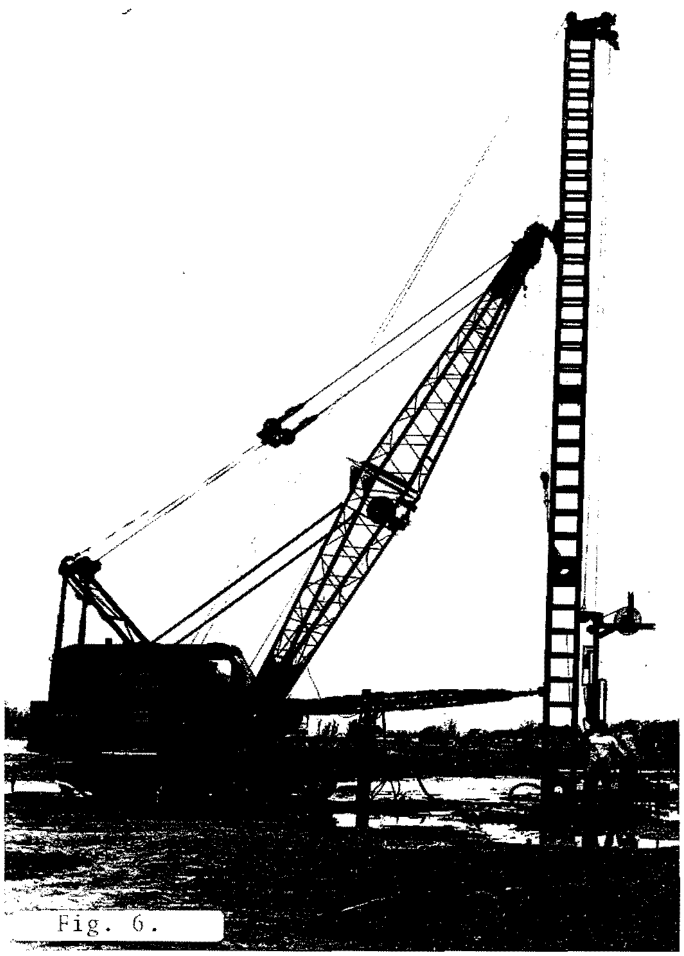


Fig. 6.

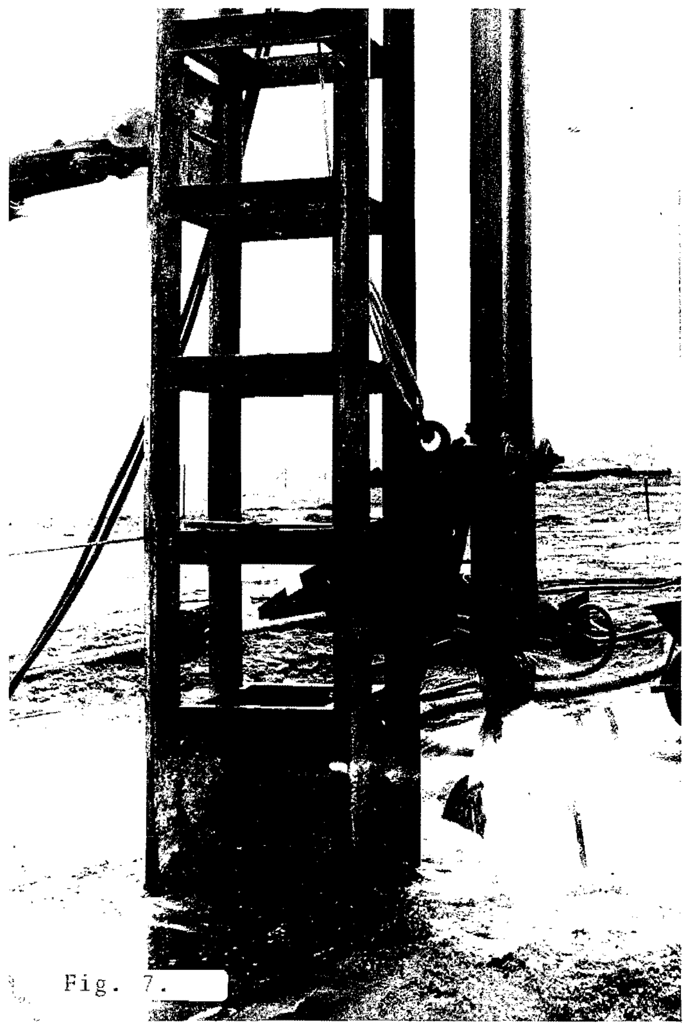


Fig. 7.

Results

1. The results of the settlement measurements showed that the sizes of the average settlements per section hardly differed from one another during the whole period of measurement. At the end of the measurement the measured values showed deviations not exceeding 10%.

   It could not be ascertained whether these minor deviations were due to differences in the rate of drainage or to differences in the nature and structure of the layers of clay and peat, or to a combination of both factors.

2. The results of the pore water pressure measurements were in agreement with the trends of the settlement measurements. Irregularities in the results of the observation had to be ascribed to fluctuations in the water levels. The absolute and relative values of the recorded excess water pressure were probably strongly influenced by differences in the distance between gauges and drains.

3. The measured trends of the settlement agreed reasonable well with the calculated values for all sections. The agreement is particulary good for the section with the sand drains, to which the calculation applied in principle.

   The calculations were made with the aid of Terzaghi-Buisman's settlement equation and the outflow calculation method for sand pile drainage according to Kjellman. The required coefficients of volume compressibility and permeability were derived from tests undisturbed samples performed in the laboratory.

   The Kjellman method was also used for the outflow calculations for the three sections with the non-woven drains.

   The settlements measured are probably influenced to a slight extent (at most a few centimetres) by the consolidation of the mound itself, so that the settlements of the soft layers may be less than measured.

4. In the same way as described under 2 and 3, the settlement behaviour of a similar mound of sand without any vertical drainage was calculated, using the same data from soil survey and the laboratory investigation. This behaviour clearly deviated from the measured and calculated situation with drains. For much of the period of measurement the settlement was calculated to be about 10 cm less. Relatively speaking, after approx. 200 days for instance, this means approx. 30% less settlement than for the sections with drains.

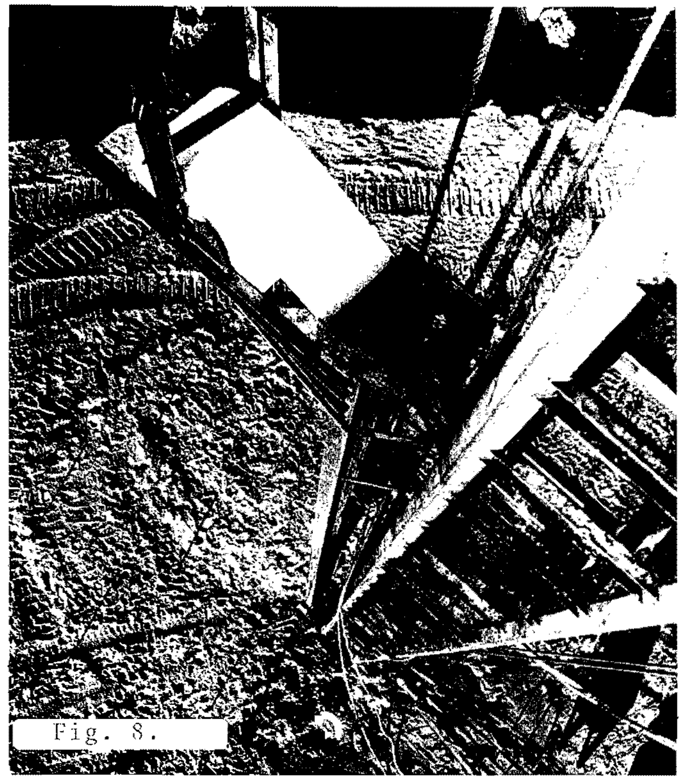


Fig. 8.

Conclusions

- The overall behaviour of the subsoil observed via settlements and pore water pressures was practically identical in the four sections.
- The use of the especially developed non-woven strips having a width of 30 cm certainly has as much effect as the conventional sand drains with respect to shortening the period of consolidation under the given circumstances.
- The letter conclusion is in agreement with the results of the laboratory tests performed by Akzo Research Laboratories Arnhem.

SOME TECHNICAL ASPECTS OF THE NON-WOVEN DRAIN STRIPS

- Roll length 200 meters, strip width 30 cm, thickness 4 mm, i.e. water inlet perimeter 60 cm.
- Pore volume 80%.
- Made from high grade polyester fibre: unaffected by weather conditions and resistant to chemicals and bacteria in soil.
- High resistance to compression: drain capacity remains sufficient up to 30 meters depth.
- High initial modulus (200 kgf at 5% elongation) combined with a tear stregth of 750 kgf, thus permitting different techniques for insertion, and garanteeing functioning under subsoil deformations.
- Water inlet surface (filterlining) adapted to specific soil conditions.

4. VERTICAL DRAINAGE PROJECTS AND TEST SITES 1975-1976

4.1 Test areas in State Highway no.19 at Schipluiden (NL); See Proc.International Conference "Soils and Fabrics", Paris 1977.

4.2 Project "Puttershoek" (NL)

Installation of 25,000 m' drain at 15-21 m.depth at 1.50 m spacing, by a vibrator-driven lance (see Fig.9). Installation time 6 weeks with 2 lance units.
(Description from the Annual Report 1975 of the Soil Mechanics Laboratory - Delft).
West of Puttershoek, on the outside of the dike along the Oude Maas, the sugar factory Puttershoek has adapted some fields as a depot for the earth that is released during the washing of sugar beets. This earth, which contains many fine constituents (clay), is discharged into the depot during the sugar beet campaign.
A few months after the 1974 campaign, deformations of the bottom were observed before the toe of the water-retaining dike, which also served as a quay to discharge the sludge. As these deformations had undesirable consequences for some structures there, the Soil Mechanics Laboratory was asked for assistance in order to prevent similar phenomena for adjacent depots to be filled during subsequent campaigns.

First an investigation was made into the cause of the deformations that had already occured. To this end the Laboratory carried out some soundings and continuous drillings and placed some electric water pressure gauges at different levels. With the data thus obtained stability calculations were made, which showed that at the highest sludge level in the depot the safety factor dropped below 1.
The conclusion was that at the given stability situation the excess water pressures had risen after a few months to such an extent that noticeable deformations occured at weak spots in the embankments. (e.g. the ditch present there).
Therefore, efforts were made to find a solution for the other sludge depot by providing the soil before the dike with a protection against excess water pressures.
After carrying out sounding and continuous soils drillings in these fields, installing water pressure gauges and making stability calculations, the Soil Mechanics Laboratory advised to introduce vertical drains in a strip of land just before the dike (on the side of the depot),as shown in Fig.9.
For these vertical drains use was made of synthetic strips which could be inserted into the ground without water jetting.
During the sludge discharge in the 1975 campaign and thereafter the water pressure gauges were regularly read. It was found that the water pressures before the drained strip of land hardly increased, so that the sludge discharge could be continued.

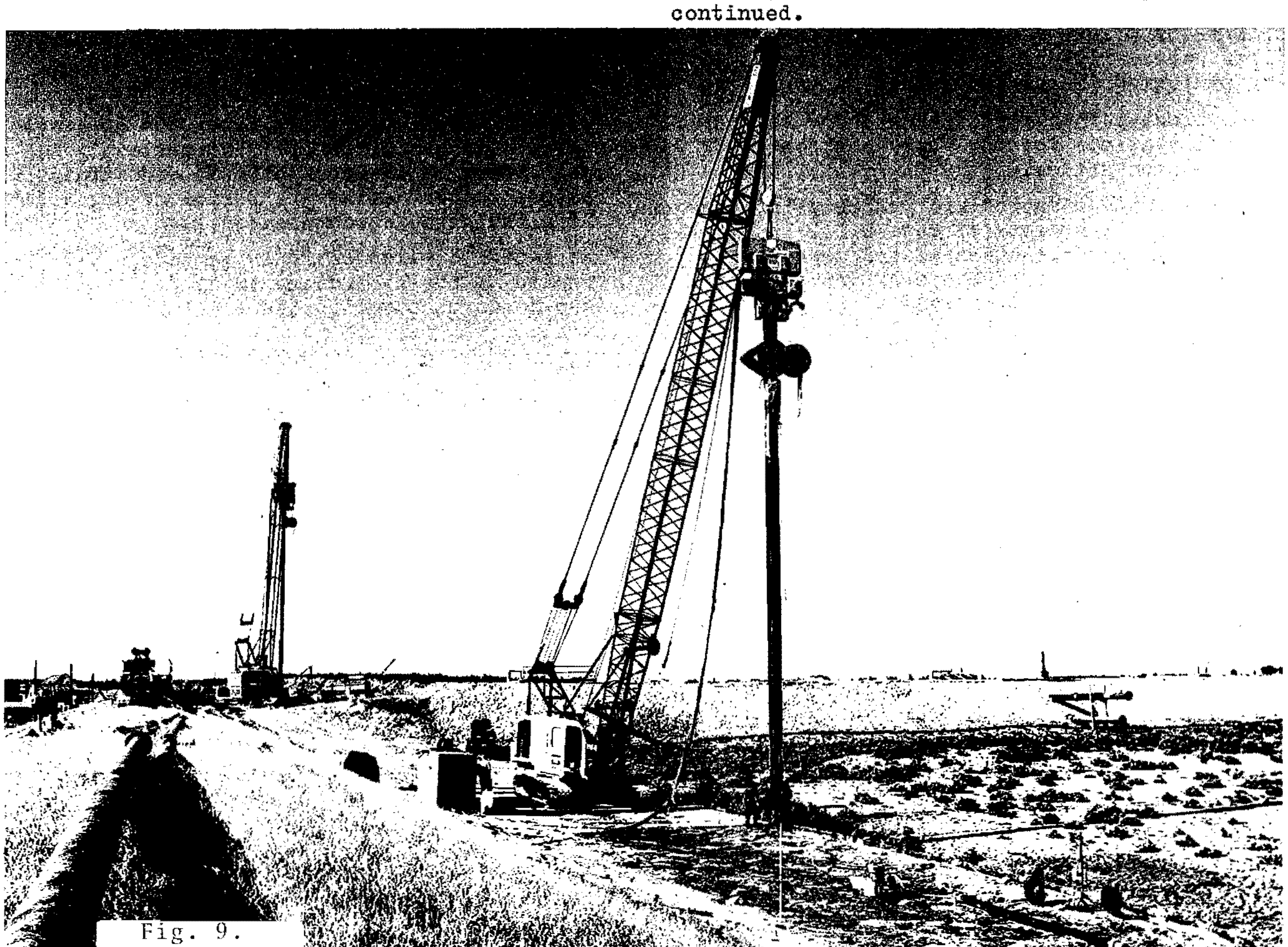


Fig. 9.

4.3 Project Delfzijl (NL)

Installation of 4000 m^1 drain at 7 m depth by jetting at 3.40 m. spacing, to accelerate consolidation time for the foundation of the storage tanks. Installation time 1 week with 1 lance unit.

4.4 Railway project and test site Amsterdam

4.4.1 Installation of 180000 m^1 drain at 8-30 m depth (see Fig.10), at 2 and 3 metres spacing by jetting, to accelerate consolidation time for a railway embankment. Installation time 12 weeks with 2 lance units.

4.4.2 Construction of a test-site (part of the railway project) covering 40 x 50 m2 of soil. This test-site is divided in two sections. In one section drains are inserted at 30 m. depth with a cross section of 300 x 4 sq.mm; i.e. water inlet perimeter 60 cm. In the other section drains are inserted with a modified cross section of 150 x 8 sq. mm. Spacing in both sections 3 m.

Scope

The purpose of this site is to study the efficiency of the two types of non-woven drains at a given spacing of 3 m.,
- in accelerating consolidation time,
- in decreasing the excess water pressure with time.

In this case under an overload of approx. 8 m sand fill.
Results will be available in 1977.

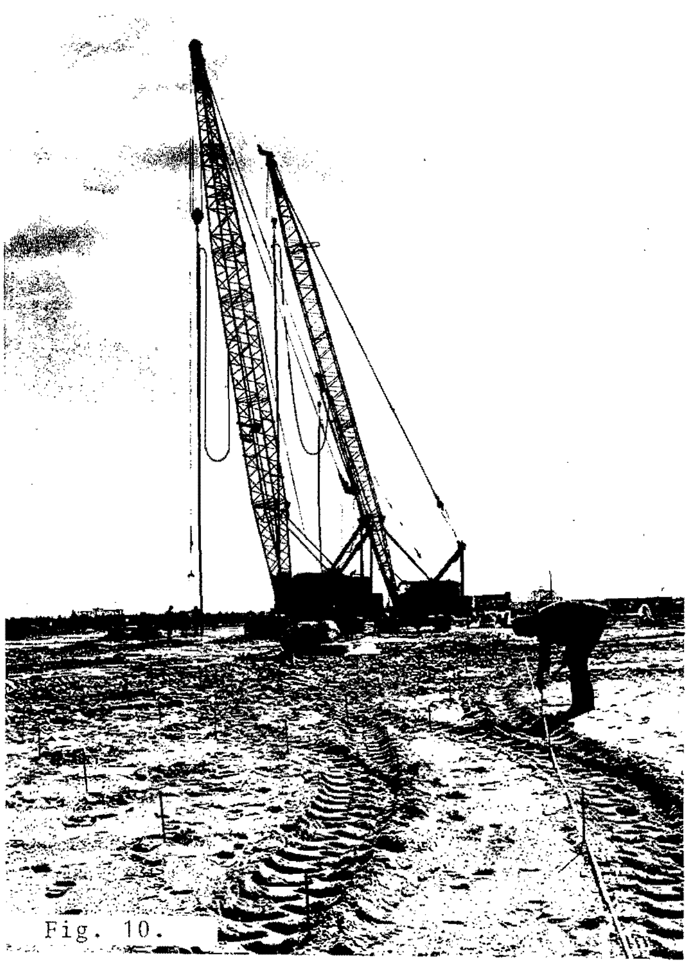


Fig. 10.

4.5 Project Bruinisse (NL)

Installation of 4000 m^1 drain at 8 m depth, spacing 2.50 m to allow avanced sea dike reinforcement. In this case by decreasing the excess water pressure in the soft subsoil at the adjacent inland side. Installation time 1 week with 1 lance unit.

4.6 Project Ridderkerk (NL)

Installation of 2000 m^1 drain at 6-12 m. depth by jetting, spacing 3 m., to allow advanced dike reinforcement on top of low-bearing soil. Installation time 1 week with 1 lance unit.

4.7 Road embankment Botlek Tunnel Rotterdam

Installation of 63,000 m^1 drain at 9-25 m depth by jetting, spacing 1.50-2.50 m. Installation time 6 weeks with 2 lance units.
In this situation the road embankment already under construction - sand fill approx. 5 m high -, started to slide thus rupturing the previously installed sand pile drains strips along the slip circle. Since non-woven strips have proved continued operation under lateral subsoil deformations this system was chosen by the Rotterdam Authorities as the best replacement.

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