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ESTIMATION OF FUTURE SETTLEMENTS OF THE DIKES OF THE NORTH-EAST POLDER BASED ON OBSERVATION OF PAST SETTLEMENTS

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INTRODUCTION.

The dike enclosing the North-East Polder, is constructed during the years 1936 to 1940, as part of the scheme of partial reclamation of the former Zuidersea. (Situation, fig. 1) Soil conditions under the dike can be roughly characterized as follows:

The partial reclamation of the Zuydersea.

FIG.1

1) Sections, where the soil consists mainly of sand, interspersed with thin layers of clay or peat (up to 1 m thick).
2) Sections, where the layers of clay are thicker (up to 7 m thick).
3) A small section, where the soil consists of boulder clay.

To these soil conditions the method of foundation of the dike had to be adjusted.

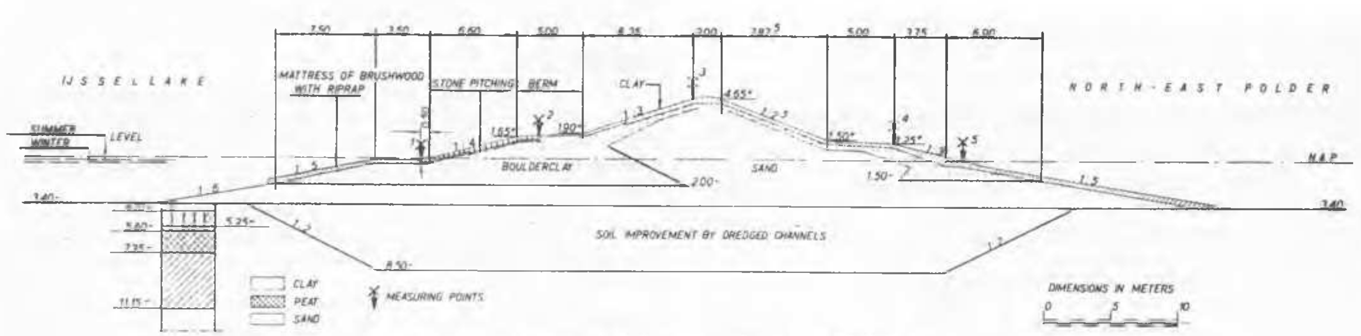
In the section 1) situated between Lemmer and the former Island of Urk (up to 8 Kilometers from the junction at Urk) and beyond Schokland, as well as in section 3) near the junction at Urk, no special staps have been taken and the dike has been constructed directly on the existing bottom of the sea.

In the section 2), where ever the soft layers were thicker than about 3,50 m, the soil has been improved by dredging a cutting with side slopes 1 to 2 to a depth of 1 to 2 m above the rigid sandmass and refilling this cutting with sand (fig.2). The remaining 1 to 2 m thick soft layers under this cutting have been left in order to prevent excessive seepage under the body of the dike.

Thereby stability during the construction period was improved and failures prevented, while the subsequent settlement due to consolidation of the subsoil could be made good by adding an overload height.

However, it seems preferable in future to lower somewhat the above mentioned limit of 3.50 m for the thickness of the soft layers because appreciable settlement has been observed in bordercases where no soil improvement by dredging and refilling has been carried out. Local raising of the dike was necessary, the cost of which exceeded sometimes the cost of the soil improvement.

With a view to the maintenance of the dikes and the determination of the overload height required for sections of the dike still to be constructed or to be strengthened, periodical settlement observations have been made at several points, viz. at the toes at waterlevel, at the outside berms, and at the crown. The work being carried out in the open sea, it was dificult to start settlement observations simultaneously with the commencement of the con-



Cross-section dike North-East Polder.

FIG.2

struction; a start was made as soon as the construction was sufficiently advanced for a reference point to be fixed on an emerging point.

In the following some examples will be discussed of the method, whereby future settlements were estimated from a record of the observations.

DETERMINATION OF THE EQUIVALENT TIME OF LOADING.

During the placing of the sandfill in the dredged cutting and the construction of the body of the dike, the load on the subsoil is gradually applied. Only after completion of the dike the load remains constant. It is obvious that the rate of settlement is influenced by the length of time of construction. In order to evaluate this influence in settlement computations, the late Prof. Ir. A.S. Keverling Buisman introduced the concept of Equivalent Time of Loading. This is the imaginary point of time at which the total load should have been applied in order to produce eventually the same rate of settlement as the actual, gradually applied, load. If the curve of fig. 3 represents an arbitrary rate of application of the load, where in time t the load increases to p, then the same settlement would be achieved by suddenly applying load p at a time T_u after the application of the first, gradually applied, load. Hence it follows that

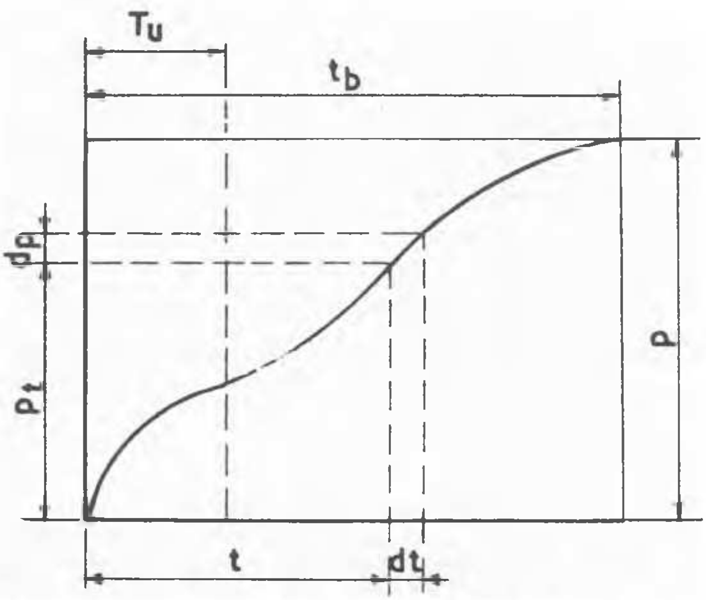
$$T_u \cdot p = \int_0^p t \cdot dp \quad \text{and} \quad T_u = \frac{\int_0^p t \cdot dp}{p}$$

For section 600, situated South of Urk and indicated on fig. 2, the time-load curve on the foundation soil is given on fig. 4. The various stages of construction are interconnected by straight lines.

By means of the formula mentioned, the Equivalent Times of Loading for the various reference points in the dike are computed and they are shown in fig. 4.

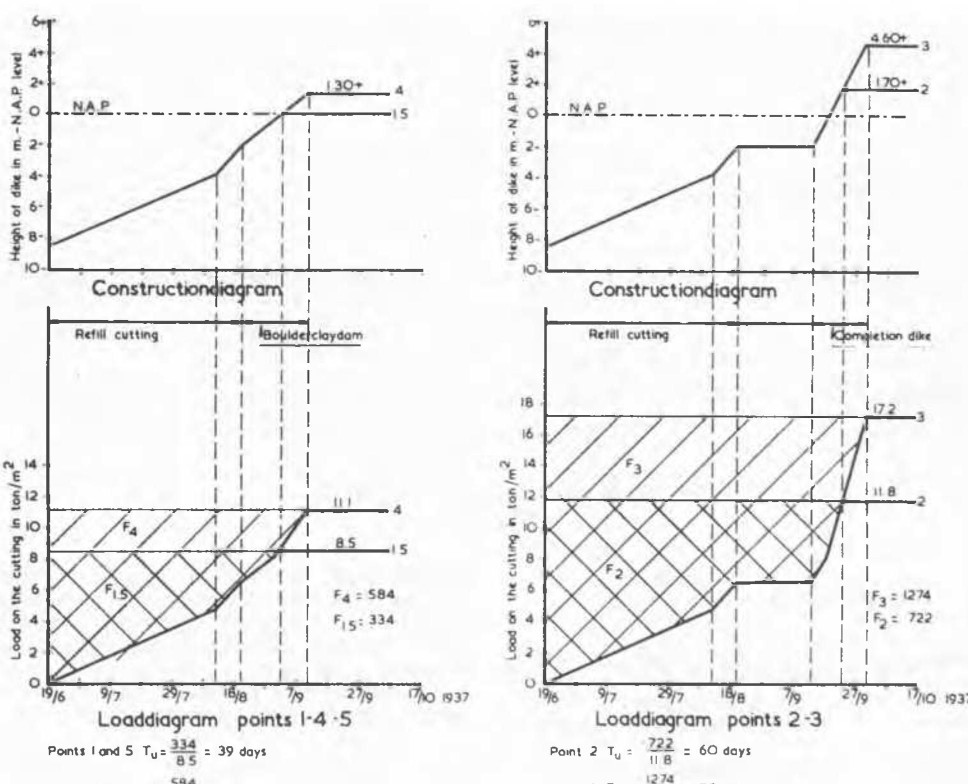
APPLICATION OF THE SETTLEMENT FORMULA TERZAGHI-BUISMAN.

The derivation of this formula is discussed in the article of ir. A.W. Koppejan. Using this formula, the settlement would be:



Determination of the equivalent time of loading

FIG.3



Determination of the equivalent time of loading for the various reference points of the dike

FIG.4

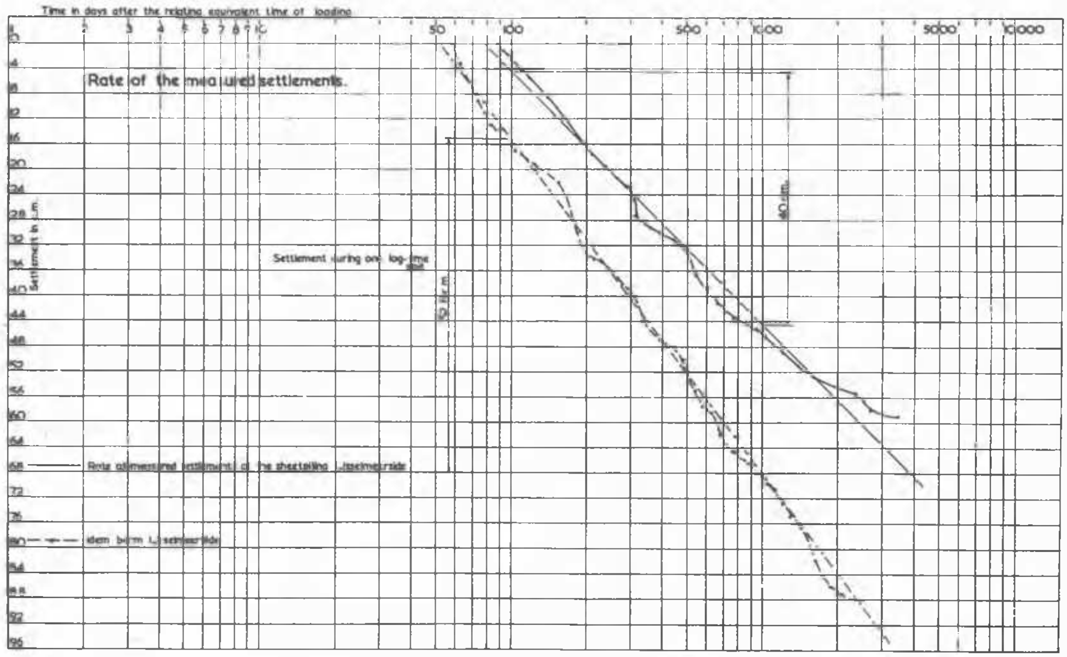
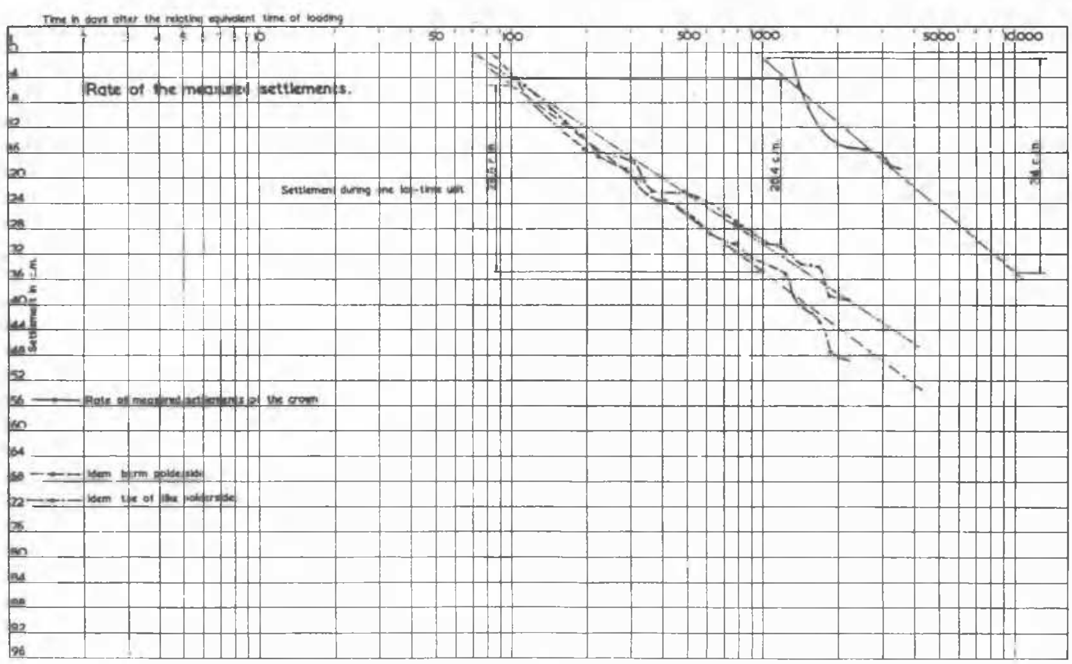


FIG.5



Rate of the measured settlements.

FIG.6

$$z_t = h\left(\frac{1}{C_p} + \frac{1}{C_s}\log t\right)\ln\frac{p_o + p}{p_o}$$

where: z_t = the settlement after t days

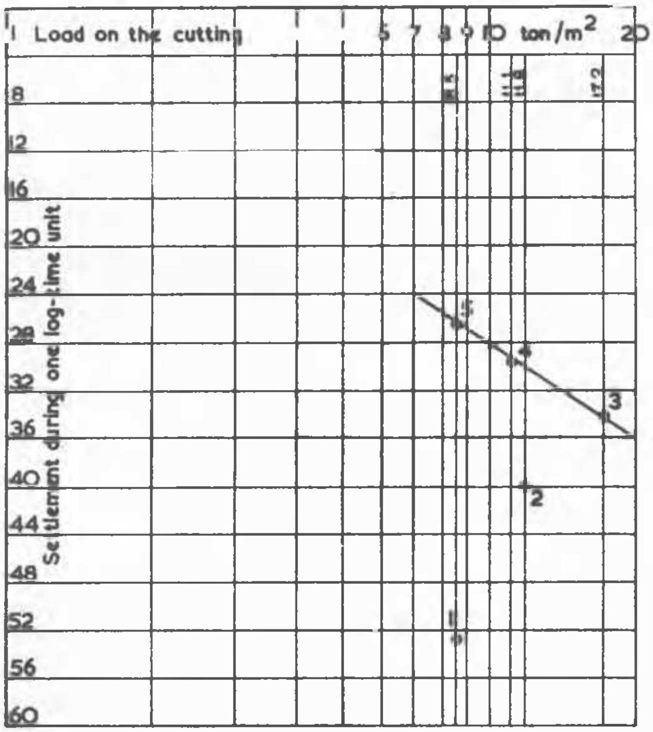
- h = the thickness of the layer
- t = time since the application of the load p
- p_o = initial effective pressure in the soil
- C_p and C_s = compression constants, dependent on the soil.

The intention being to determine from past settlement observations the expected settlement by extrapolation, and thereby to estimate the necessary overload height, it was decided to neglect C_p, representing the settlement shortly after the application of the load.

Hence the formula for the settlement observations after sometime can be approximated as

$$z_t = h\,\frac{1}{C_s}\cdot\log t.\ln\frac{p_o + p}{p_o}$$

Based on this formula a time-settlement diagram is constructed; on the Y-axis the logarithm of the time of observation is plotted, taken from the Equivalent Time of Loading, and



Settlement during one log-time unit as function of the load on the cutting.

FIG.7

on the X-as the recorded settlement since the first observation.

As an example it appears that for the point at the toe of the dike on the polder side the Equivalent Time of Loading occurs at 39 days after a start had been made with the sandfill of the cutting on 19/6-'37 and that the first settlement observation was made on 1o/11-'37.

Hence the starting point of the time-settlement curve is chosen at t = 144 (number of days from 19/6-'37 to 10/11-'37)- 39= 105 days.

The thus obtained time-settlement curves are plotted in fig. 5 and 6. It appears that on a semi logarithmic scale the curves approximate closely to straight lines.

On the diagrams these straight lines have been extrapolated, thus furnishing the date required to calculate the necessary overload height.

RESULTS.

If the foundation soil and the body of the dike are assumed to consist of homogeneous material and the influence of the spreading of the load under the body of the dike can be neglected, the same value for h/C_s would result for all reference points.

If z_t represents the settlement due to a load p at a time t, and z_{t1} the same after a time t_1, then:

$$z_{t_1} - z_t = \frac{h}{C_s} (\log t_1 - \log t) \qquad (4)$$

Fig. 7 shows the relationship between the logarithm of the increase of stress and the increase of settlement at the various reference points during the time interval of a logarithmic unit (e.g. 100 to 1000 days). It appears that the curves traced through points taken from the settlement diagrams for the toe of the dike at the Polder side, the berm at the Polder side and the crown of the dike approximate closely to straight lines. This in contrest to the curves for the sheet piling and the berm at the IJsselmeer side.

It seems likely that these discrepancies are caused by the volume of the boulder clay in the body of the dike at the IJsselmeer side, which is considerable larger than the corresponding volume at the Polder-side.

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VI a 8 DETERMINATION OF EXPECTED SETTLEMENTS OF HYDRAULIC FILLS IN THE SPANGEN POLDER NEAR ROTTERDAM

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INTRODUCTION.

In planning the Spangen Polder near Rotterdam, of a total area of 200 hectares (500 acres), certain areas were set aside for the housing of industries (see fig. 1). The industries concerned were previously situated in the city but were largely obliterated by the bombing of Rotterdam in 1940. In the Reconstruction Plan it was decided to shift these industries to the periphery of the town.

In order to fit the site to its purpose the surface level had to be raised considerably, the existing surface in the Polder being at 2.00 to 2.50 m below Normal Amsterdam Datum (N.A.P.) and the desired surface at 0.35 m plus N.A.P., partly in view of the construction of inner harbour basins.These basins will be in open communication with the surrounding canals with water level at 0.40 - N.A.P. The raising of the surface level has been achieved by the hydraulic fill method.

Because of the complications expected when in future, after settling of the indus-