

Soil / cut-off wall interaction at Diemerzeedijk, Amsterdam

Leon A.M. Groenewegen
Hollandsche Beton- en Waterbouw bv

Hans Niemeijer
Arcadis Heidemij Advies bv

ABSTRACT: The land remediation project at Diemerzeedijk, Amsterdam, includes a series of land fill operations and the construction of a cement-bentonite cut-off wall in the slope of the embankment. PLAXIS has been used to analyse the effect of accelerated drainage of excess pore water pressures and the performance of the cut-off wall. The evaluation of this performance in terms of stress levels and the likelihood of crack development has been carried out as a separate analysis on the basis of the PLAXIS results.

1 INTRODUCTION

This paper presents results of a PLAXIS-calculation for the contaminated land remediation project at Diemerzeedijk, Amsterdam. The considered area is of approximately 0.6 km², with a circumference of about 4 km and is illustrated in figure 1 below.

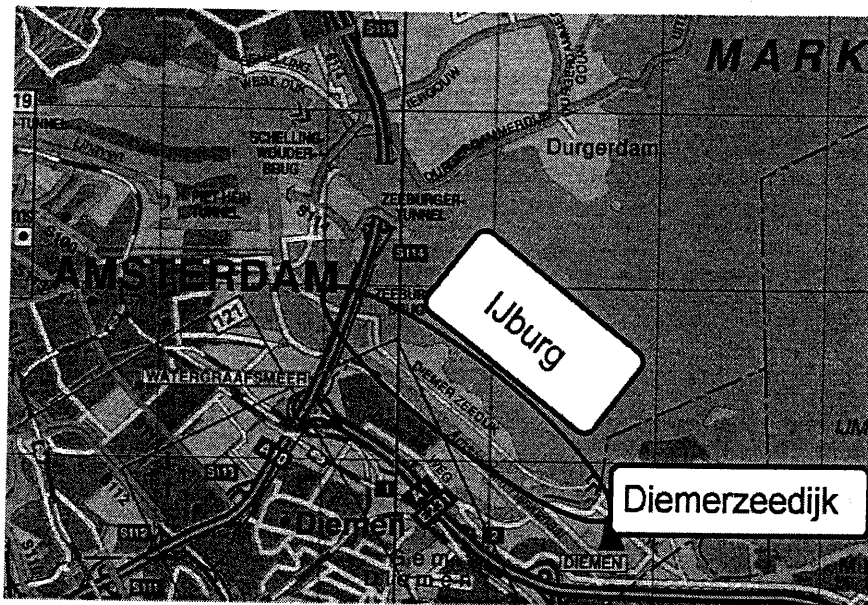


figure 1: Project location

The contamination was caused by continuous waste dumping during the 1960's and 70's, resulting in significant concentrations of benzenes, dioxins and other chemicals. Environmental awareness developed in the seventies eventually lead to a closure of this dump-site and the location was left unused throughout the eighties. Figures 2 and 3 give an impression of the site shortly before start of the construction activities.

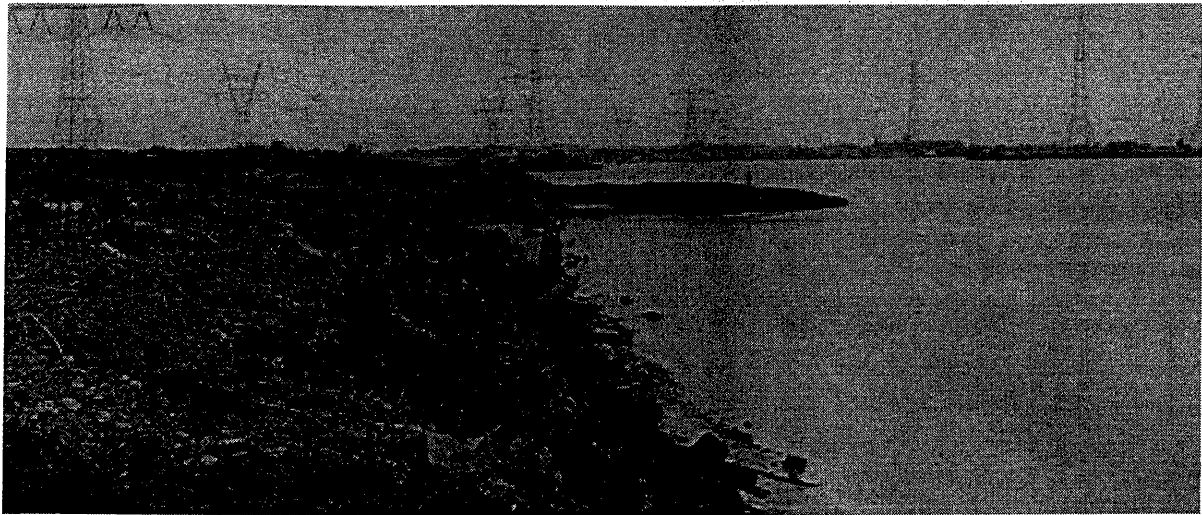


figure 2: IJmeer side after bush removal (North side)



figure 3: Dike at the site's Southern boundary

In 1997 Amsterdam's growing need for residential areas resulted in the decision to start a land reclamation project for the development IJburg, east of the city's centre and directly North of Diemerzeedijk. The IJburg project comprises primarily the construction of about 18000 houses and started in 1998. The presence of a former dump site at a close distance to IJburg was turned into a challenge to reshape Diemerzeedijk into a clean park with all kind of facilities for the future inhabitants of IJburg.

In view of the excessive costs of total soil replacement (order of billions Dutch guilders) an alternative method was developed to arrive at a safe solution. The selected concept is referred to as the IBC method, claiming isolation of the contaminated area and imposing a head by lowering the groundwater table within the contaminated area to prevent leakage. The extracted waste water is treated by a dedicated on-site installation before final discharge. The concept is illustrated in figure 4.

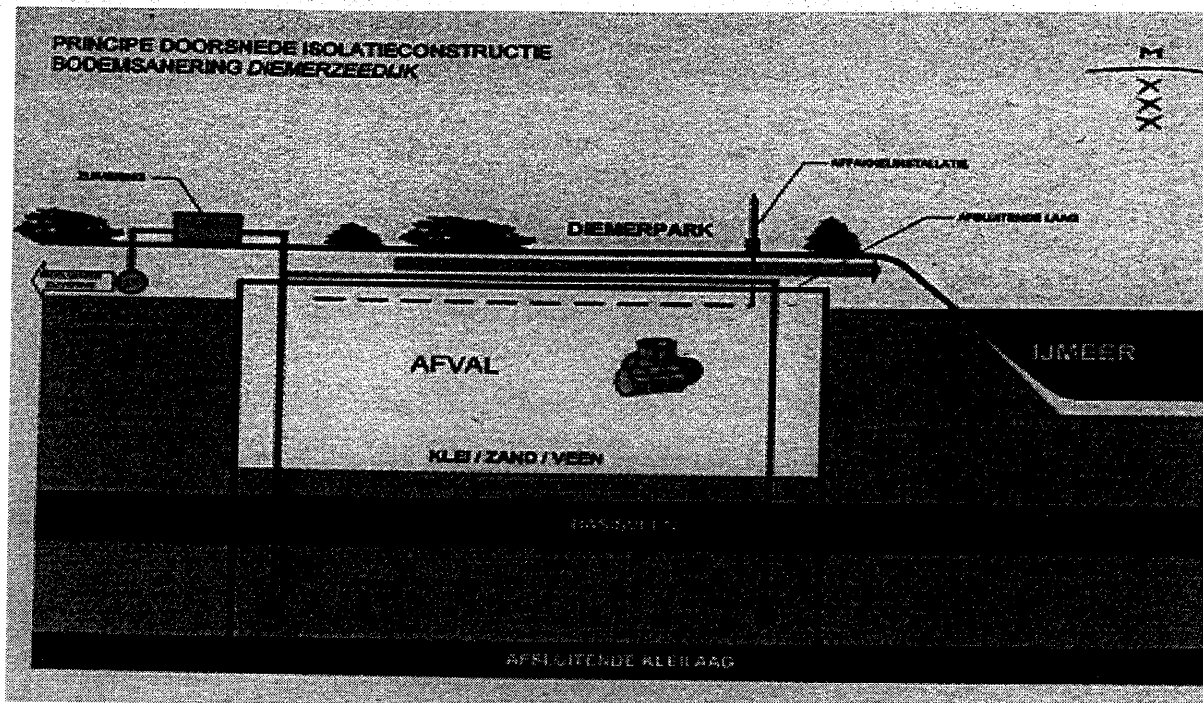


Figure 4: Schematic representation of IBC concept

The isolation of the contaminated soil is achieved by the construction of a cut-off wall extending to an impermeable layer at 22 m depth. A top cover will be provided to prevent any contact of the surface with the underlying layers.

This contribution will focus on this cut-off wall. Its construction in a slope at the site's boundaries, combined with subsequent landfills, requires further examination of the behaviour of the structure in terms of constructability and long term performance.

2 CUT-OFF WALL CONCEPT

2.1 Base case concept cut-off wall

The base case concept developed in the project specification phase consisted of a cement-bentonite cut-off wall. At the IJmeer-side (Northern side) this wall was reinforced by a sheet pile wall. The thickness of the cut-off wall is 0.6 m; its depth is approximately 22 m and varies slightly, depending on the required penetration (at least 1.5 m into the so called Eem-clay layer) and variations in ground level.

Upon completion of the cut-off wall the ground water table within the enclosed area is lowered, to initiate a ground water flow towards the contaminated mass and as such preventing further pollution of the area. The head created in this stage is approximately 3 m. The contract stipulates a minimum performance requirement of the hydraulic resistance of the cut-off wall of 1000 days.

A primary drainage system within the surrounding wall consisted of horizontal drains in the cohesive layers and a discharge at the edges of the contaminated area.

As it appeared that slope stability could not always be guaranteed during the land fill process it was decided to use vertical drains to accelerate the consolidation process. Vertical drains were envisaged in a pattern of 2 m intervals to a depth of approximately -7 m NAP.

2.2 Final concept

The final design differs in some aspects from the original concept outlined above. After in situ tests on the primary drainage system, and its observed disappointing performance, it was decided to change for a system with vertical drains. This modification reduces the required area and results in an inward shift of the cut-off wall by some 7 m.

Another change is to replace the sheet pile in the cut-off wall by a HDPE sheeting, which gives a total cost saving of the cut-off wall and double isolation of the contaminated soil.

Another modification of the original concept is its increase of vertical drainage to improve trench stability by a quick reduction of excess pore water pressures in the period prior to wall installation.

The construction programme is based on the following scheme of activities for the cut-off wall area. This scheme has been used in the PLAXIS analysis to verify the relevant parameters:

| Time scale [months] | Activity |
|------------------------|--|
| -2 | installation geotextile fill to +1.00 m NAP |
| 0 | installation drains fill to +1.5 m NAP |
| 0-2 | consolidation |
| 2 | fill to +2.0 m NAP |
| 2-6 | consolidation |
| 6 | installation cut-off wall |
| 6-8 | consolidation |
| 8 | isolation layer (top at +2.7 m NAP) |
| 8-10 | consolidation |
| 10 | cover layer (top at +3.5 m NAP) |

table 1: Construction scheme

3 PARTIES INVOLVED

The project is initiated by the City of Amsterdam, represented on site by the Project Bureau Diemerzeedijk (PBD). The original tender design and tender documents were prepared by Arcadis Heidemij Advies, who is now advising the City of Amsterdam during the construction stage.

The Hollandsche Combinatie Diemerzeedijk, a joint venture of the HBG-companies Hollandsche Beton- en Waterbouw, HAM-Van Oord Werkendam and Hollandsche Wegenbouw Zanen, operates as a general contractor for this remediation project and has also prepared the detailed design of the cut-off wall.

Nederhorst Grondtechniek (NGT) is the subcontractor for the installation of the cut-off wall.

4 GEOTECHNICAL INFORMATION SUBSOIL

The subsoil at the Diemerzeedijk site consists in general terms of a sequence of cohesive layers down to approximately -10.5 m NAP overlying a sand layer with an intermediate clay layer. The Eem-clay layer starting at approximately -23 m NAP depth is used as a bottom sealing of the contaminated soil. The site soil investigation programme comprised a series of Cone Penetration Tests and Boreholes. The laboratory tests carried out within the framework of this project were focused on the compressibility characteristics of the soil and the chemical analysis of groundwater.

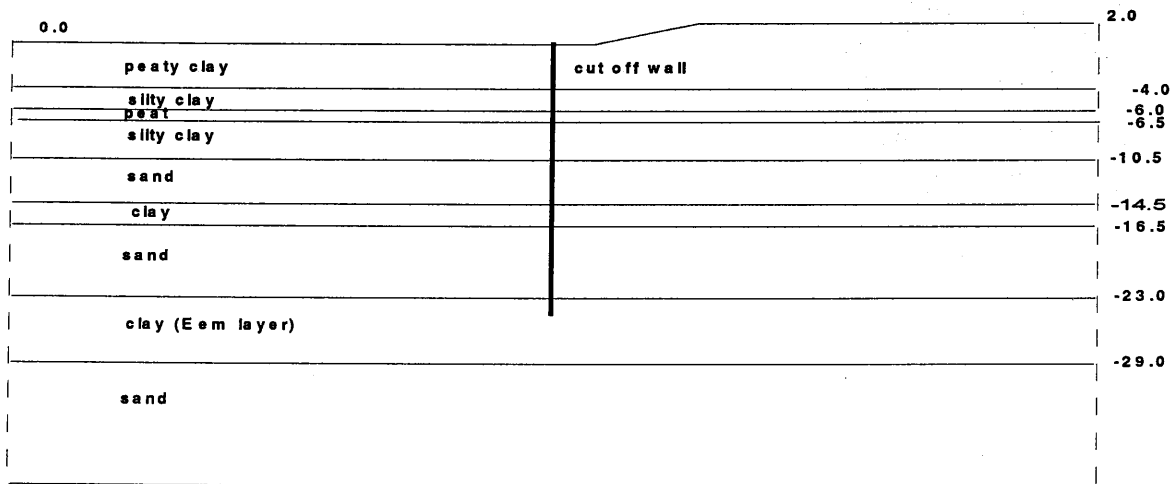


figure 5: simplified soil profile at cut-off wall

5 PROJECT PLANNING AND ACTUAL STATUS

The construction of the slopes and cut-off wall started in summer 1998 with preparatory activities in the Western part of the site. The vertical drains in this area were installed in autumn 1998. The first part of the cut-off wall has been constructed in december 1998 in the Diemerzeedijk section in an area that did not require a fill in soil level prior to cut-off wall installation. Completion of the cut-off wall installation is envisaged by the end of 1999.

6 OVERVIEW PROBLEM AREAS AND REQUIRED ANALYSES

The site will be raised in various stages to prevent slope instability. A thorough analysis is required to check the factors of safety throughout the construction period.

The cut-off wall is generally installed in the slope of the embankment. This aspect triggered the need for the analysis of the feasibility of the cut-off wall to retain its cut-off function under the anticipated negative skin friction combined with its horizontal deformation.

A third aspect needed to consider is the trench stability during installation of the cut-off wall. An important item in this respect are the excess pore water pressures that are generated during the preceding land fill operations, which have a negative influence on trench stability. The trench stability calculation has been carried out as a separate activity based on predefined limits for the excess pore water pressures in the soil in the trench area at the time the cut-off wall is installed.

7 SELECTION APPROPRIATE SOFTWARE

As indicated above, the simultaneous effect of excess pore water pressures, slope stability and deformations needed to be reviewed for a number of construction stages. Common slope stability programmes are not able to calculate deformations and require a manual input of the excess pore water pressures. Those types of software are not suitable for the considered case.

A simplified calculation of the excess pore water pressures on the basis of the Kjellmann-Barron theory is possible for the one-dimensional (horizontal) flow between the drains. However, the pore water pressures directly underneath the drains above the sand layer may be of interest for the trench stability during construction of the cut-off wall. This cannot be checked by such a simplified calculation model and requires software in which two-dimensional flow can be modelled.

A third important aspect in this respect is the estimated imposed deformation of the cut-off wall. This phenomenon required an adequate finite element model.

It was decided on the basis of these considerations that the use of PLAXIS for this problem would be appropriate. The PLAXIS version 6.31 was available during the detailed design stage and has been used to model this problem. This version was not able to model the effect of soil creep.

8 DISCUSSION INPUT PARAMETERS PLAXIS

The key soil parameters required by PLAXIS for this problem can be categorised as follows:

– Weight ;

The unit soil weight was derived from laboratory tests. These results were compared with general information derived from literature.

– Strength parameters (phi-value, cohesion)

In absence of laboratory test results, the strength parameters were concluded from correlations on the basis of CPT-results as included in the Dutch code NEN 6740.

– Stiffness parameters (G-modulus, Poisson-ratio)

It has already been indicated that the effect of soil creep could not be modelled with the version of PLAXIS available. The only key parameter available describing the relation between stresses and deformations is the G-modulus. This parameter should therefore include the combined effect of (more or less) instantaneous deformations and creep, which may be an important parameter for these soft soils. It was decided to develop a G-modulus value that would relate the additional loads and total deformations occurring after construction of the cut-off wall. These deformations also include creep contributions from load stages prior to construction of the cut-off wall.

The following approach has been adopted to arrive at the design G-values:

- Calculate the anticipated free field settlements resulting from the subsequent fill operations using the MZET program based on Koppejan's theory.
- Conclude the primary and secondary compression of each layer from this calculation for the period after installation of the cut-off wall ($=\Delta\epsilon$).
- Calculate a Youngs-modulus value from the ratio between the total load applied after installation of the cut-off wall and the concluded compression. The G-modulus was calculated from this Youngs-modulus using the theory of elasticity and a Poisson-ratio of 0.35.

– Consolidation parameters (permeability)

The results of oedometer tests have been used to conclude c_v -values describing the time dependency of the consolidation process. The objective in deriving permeability parameters of the soil is to obtain a correct description of the consolidation process. The well-known relation

$$k_v = c_v \gamma_w m_v \quad (m_v = (1-2\nu) / (2G(1-\nu)))$$

has been used, in which:

k_v = permeability soil [m/s]

c_v = coefficient of consolidation [m²/s]

γ_w = unit weight water [kN/m³]

m_v = coefficient of volume change [m²/kN] = (1-2ν) / (2G(1-ν))

ν = Poisson ratio

G = shear modulus [kN/m²]

Since the G-modulus assumed in the PLAXIS calculations also includes creep effects, the value is not a true shear modulus. As such the input value for the permeability does not necessarily represent the correct physical value. However, the c_v -value concluded from the relation between k_v and m_v will be correct. Hence, the time aspect of the consolidation process is modelled correctly.

It has already been pointed out that vertical drains have been applied to accelerate the consolidation process. The drains are modelled in accordance with the recommendations included in CUR 191.

9 OVERVIEW RESULTS PLAXIS ANALYSES

The analysis of eleven cross sections was required to cover the most sensitive areas. The results presented below are limited to a single cross section to illustrate some typical conclusions.

Figure 6 gives an overview of the resulting excess pore water pressures during the construction of the cut-off wall. It clearly demonstrates the effect of the vertical drains. These results indicate that at depths with a predominantly horizontal groundwater flow towards the drains the resulting excess pore water pressures are well below the required value of 10 kPa. The peak values arise in the layer directly underneath the drains and are still below the limit value. A simplified analysis has been carried out to check at shallow depth whether the PLAXIS results comply with the results based on the Kjellmann/Baron equations. The outcome was satisfactory.

The next three figures show the behaviour of the cut-off wall. Figure 7 illustrates the maximum deformation as a function of the construction progress. It can be concluded that the land fills to 2.7 m and 3.5 m NAP result into total deformations of 0.12 and 0.35 m respectively. It has already been pointed out that groundwater table within the area is lowered upon completion of the cut-off wall and earth works. This will result into a nett inward loading on the cut-off wall. The figure shows the effective elimination of creep driven outward deformations, and more or less fixation of the cut-off wall in the shape reached at the moment this lower groundwater table occurs. The drains at the inner side of the cut-off wall will accelerate the process of groundwater level change in the cohesive layers, and as such reduce the time required to reach the final situation. Another typical result for the sections in this area is the shape of the deformed cut-off wall. It more or less behaves as a beam cantilevering from the sand layers. The bending moments and curvatures are also included.

The two curves shown in figure 8 correspond with a cut-off wall with the nominal stiffness and a value of 20% of this stiffness. The effect of the cut-off wall deformations is marginal, and it was therefore concluded that the cut-off wall follows the imposed soil deformations, rather than acting as a soil retaining structure.

Figure 9 shows the actual slip surface concluded from the PLAXIS calculations. This slip surface is concentrated at the outer side of the cut-off wall. The associated factors of safety are marginally lower than 1.1. This is predominantly caused by the residual excess pore water pressures at the passive side. Subsequent consolidation will reduce this value and consequently improve the slope stability.

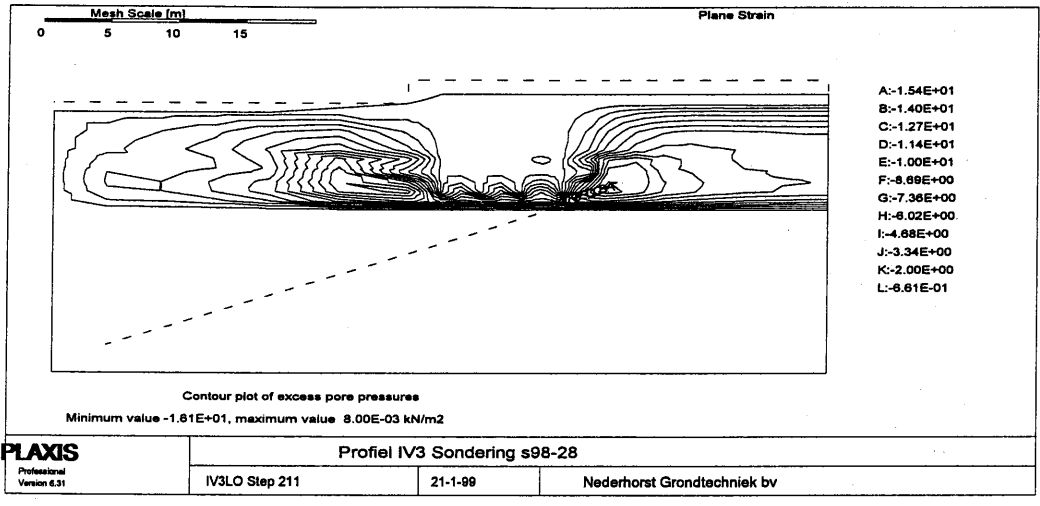


figure 6: Excess pore water pressures during construction cut-off wall

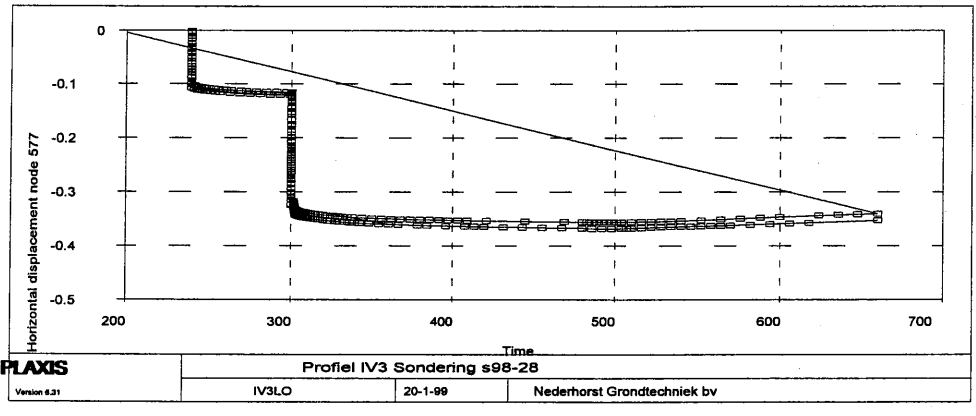


figure 7: Time function of maximum deformation cut-off wall

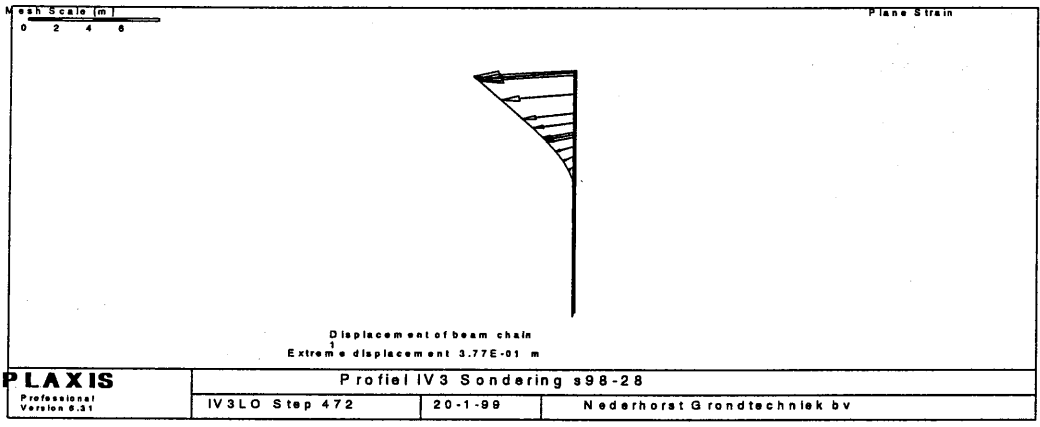


figure 8: Deformations cut-off wall

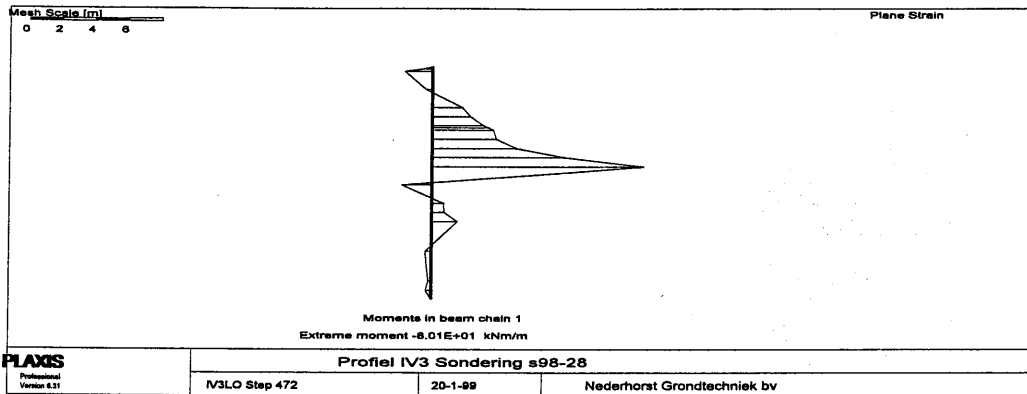


figure 9: Bending moments in cut-off wall

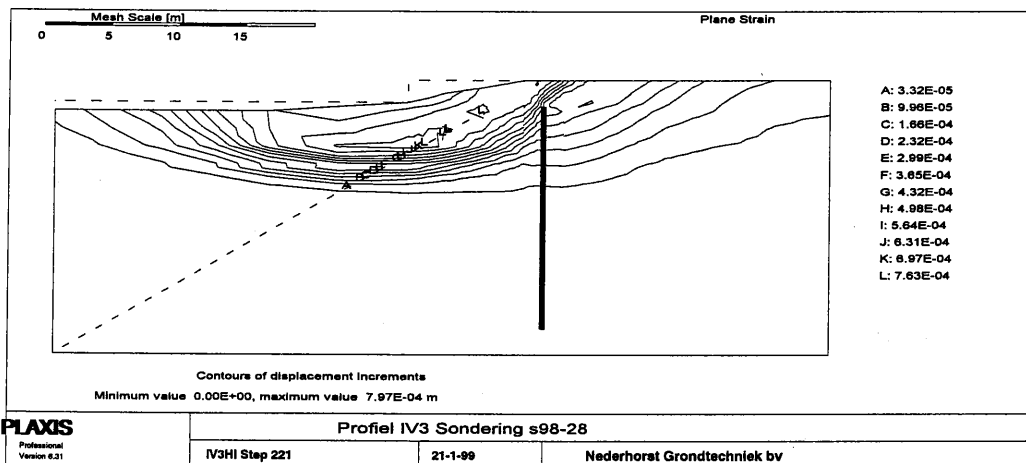


figure 10: Resulting slip surfaces

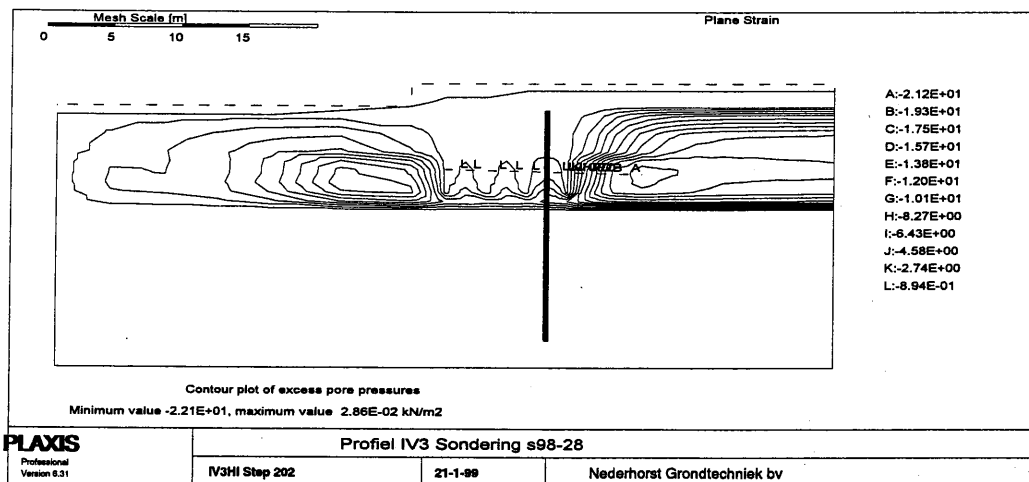


figure 11: Excess pore water pressure contours at completion land fill operations

10 EVALUATION / INTERPRETRATION RESULTS

It has already been stated that an evaluation of the displacements of the cut-off wall was one of the objectives of the PLAXIS analysis. The displacements should not result into a complete failure of the cut-off wall and consequently to loss of its cut-off function. As the cut-off wall is subjected to a combination of compressive forces due to negative skin friction along the wall and imposed curvatures resulting from slope deformations, an assessment of the performance of the cut-off wall should consider both aspects. This combined action is discussed below.

The capacity of the cut-off wall is based on an assumption of the material characteristics presented in the figure indicated below. This stress-strain diagram represents a simplification of the lower bound values of the laboratory test results on the cut-off wall material (see figure 12).

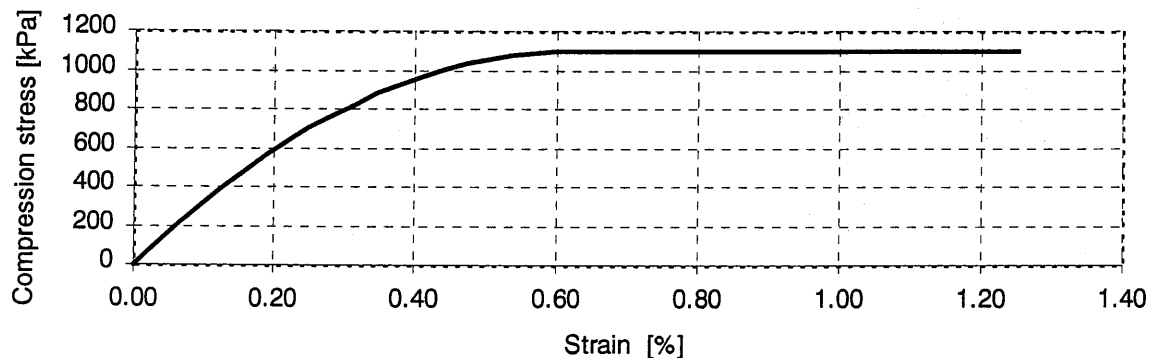


figure: 12: Design stress strain relation cut-off wall material

A graph has been developed on the basis of this stress-strain curve showing the relationship between the maximum acceptable curvature as a function of the applied axial force in the cut-off wall. (see figure 13). The solid line shows the limiting condition for an uncracked cut-off wall. A uniform stress in this 0.6 m thick cut-off wall results into a normal force of $0.6 \cdot 1100 = 660$ kN/m. The maximum curvature of an uncracked cut-off wall is $(1.25\% / 0.6 \text{ m}) = 0.021$ 1/m. The associated axial force in the cut-off wall is approximately 550 kN/m. In case the imposed curvature exceeds this value a crack will be developed and the width of the compression zone reduced. The dashed line shows the limit value. It can also be concluded from this figure that in case the negative skin friction reduces with identical values for the imposed curvature, cracks will also be developed.

An aspect that has also been evaluated is the advantageous effect of cut-off wall creep/relaxation, which will reduce the imposed stresses in the cut-off wall. However, in view of the limited information available of the creep performance of this material, the result of the evaluation of beneficial creep has not been included in the final conclusions, but merely treated as a kind of hidden capacity.

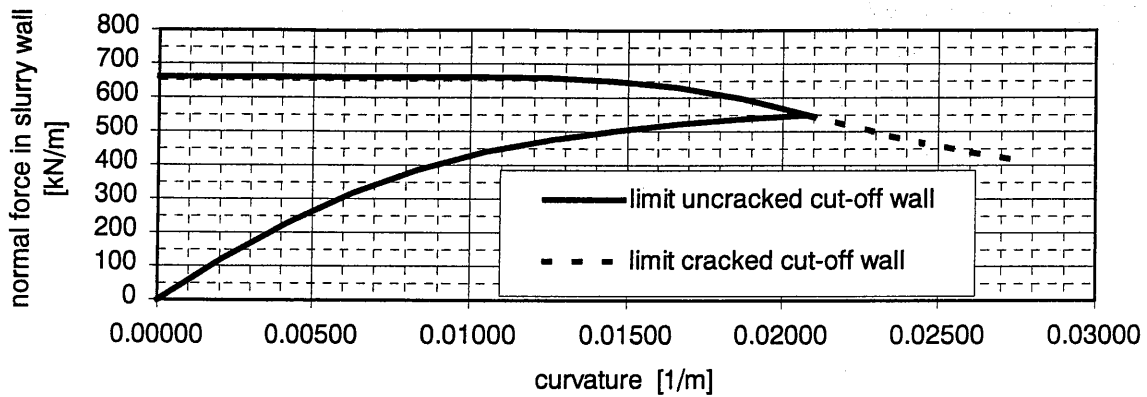


figure 13: axial / bending capacity curve cut-off wall

11 ENVISAGED TESTS / MEASUREMENTS TO VERIFY RESULTS

A number of tests are envisaged in relation with the cut-off wall / slope performance. The material tests were already discussed.

The test programme further includes inter alia the items briefly discussed below:

- the hydraulic resistance is measured upon completion of the construction works and after lowering the ground water table.
- a detailed CPT programme is part of the contract to assess the level of the impermeable clay layer and to check the soil characteristics along the cut-off wall.
- excess pore water pressures are measured to safeguard the stability of the trench. Construction works will not start if unacceptable levels of excess pore pressures are measured.
- inclinometers are installed in the cut-off wall to follow the deformations as work proceeds.

12 CONCLUSIONS

PLAXIS has been used for this project to evaluate the imposed deformations of the cut-off wall, the excess pore water pressures and slope stability throughout the construction period. The latter two phenomena are relatively straight forward calculations. However, the assessment of the anticipated imposed cut-off wall deformation required some preprocessing to arrive at representative input values for the soil stiffness that includes soil creep effects. The evaluation of the cut-off wall in terms of stress levels and likelihood of crack development was done as a separate calculation on the basis of the PLAXIS results.

The result of this analysis indicated that the capacity of the cut-off wall is sufficient to maintain a watertight compression zone. This result and the presence of a HDPE sheet in the cut-off wall provide a guarantee for an adequate isolation of the contaminated area.

13 REFERENCES

1. CUR-publication 189; Cement-bentoniet schermen (in Dutch) 1997
2. CUR-publication 191; Achtergronden bij numerieke modellering van geotechnische constructies (in Dutch); 1997
3. Kayser J.; Spannungs-Verformungs-Verhalten von Einphasen Dichtwandmassen; Heft 49, Mitteilung des Instituts für Grundbau und Bodenmechanik, Technische Universität Braunschweig (in German); 1995