THE BERENG BENGKEL TRIAL EMBANKMENT

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ABSTRACT

In the framework of the Memorandum of Understanding (MOU) between the Ministry of Public Works of Indonesia and the Ministry of Transport, Public Works and Water management of The Netherlands, a number of projects are ongoing. One of them is titled Soft Soil Engineering. The project's targets are to produce a guideline, especially focussed on building roads on very soft, peat soils, to have courses on Finite Element Method Plaxis, to have a training of teachers program (TOT), to have a pilot project through test embankments in Central Kalimantan and to have regional teaching seminars.
The construction of roads over peat soils, as present in large areas in Kalimantan and Sumatera, provides a major challenge for the Indonesian Ministry of Public Works (PU). The main problems are associated with the high compressibility and the low shear strength of these soils, causing significant and long lasting deformations and stability related problems of road embankments.
The topic is under study in several research platforms, which are co-ordinated by the PU Institute of Road Engineering (IRE), Bandung. For peat soils the main activities are:
1. MoU Indonesia-Netherlands: Improvement of design practices. A guideline for the design of roads over peat and organic soils is being prepared under a co-operation programme with the Dutch Ministry of Transport, Public Works and Water Management (Rijkswaterstaat). Also a need for more field research was generally identified. Further training activities are envisaged.
2. IGMC Project: A Worldbank funded project, which is aiming at improving laboratory facilities and practices. It covers procurement of laboratory equipment, site characterisation and training.
At present there are funds available from various sources:
1. The World Bank made a budget of 1.8 BRp available for preparation, construction work and monitoring;
2. The MoU provides financial support of hardware for monitoring (NLG 60,000) that has to be imported from abroad and technical support in preparation of the research plan and evaluation of the results.

1. INTRODUCTION

1.1 OBJECTIVE

Within the framework of the MoU 1999-2001 between the Ministry of Public Works (PU) of Indonesia and the Ministry of Transport, Public Works and Water Management (Rijkswaterstaat) of the Netherlands operates the co-operation on soft soil engineering. The co-operation on soft soil engineering deals with road construction on soft, peaty soils. One part of the co-operation deals especially with the realisation of a trial embankment for a road construction site near Bereng Bengkel in the Kalimantan Tengah province of Indonesia, where 7 km of artery road has to be constructed on 3-11 metres of very compressible mainly fibrous peat.

The general objective of the trial embankment part of the co-operation is to obtain more knowledge on the behaviour of peat and to investigate the effectiveness of various construction techniques, such as:

- conventional work methods: staged construction, pre-loading;

- traditional soil improvement methods: corduroy, crack;

- modern technologies: geotextile, slender piles, Expanded Polystyrene (EPS).

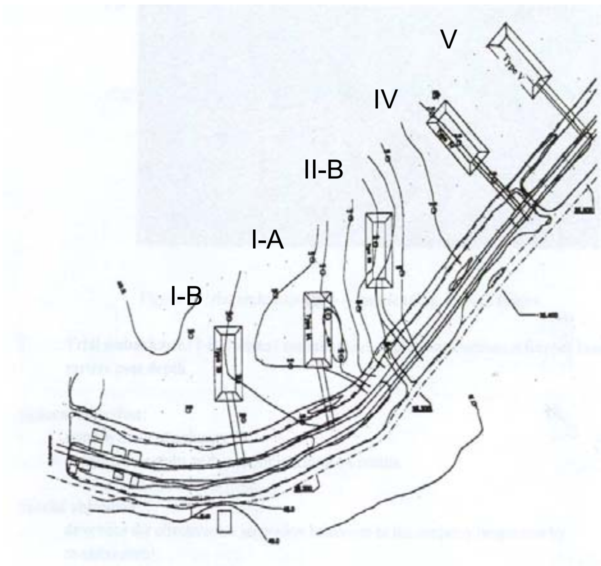

Figure 1.1: *Site plan Bereng Bengkel test site*

1.2 Execution of trial embankments

Characteristics of embankments

The various trial embankments are located on a peat soil profile with depths of 3 m, 5 m and 11 m, depending on the objectives of the test. The embankment option numbering refers to the IRE research proposal.

The test site consists of 5 types of embankments:

- Type IA, normal embankment, height 4 m, with corduroy platform;

- Type IB, surcharged embankment, height 6.5 m, with corduroy platform;

- Type IIB, timber piles embankment;

- Type IV, embankment with JHS minipiles;

- Type V, embankment with EPS foam.

The type V embankment is not part of the MoU project and will not further be described. For a site plan of the test, see Figure 1.1.

For each embankment the following objectives have been described:

Trial embankment I-A: pre-loading, critical height, at 3 meters peat depth

General objectives:

- determine the time settlement behaviour and compare with the prediction (calculation);

- determine compressibility characteristics of in situ soils (Cc, Cv, Pc etc);

- determine the relationship between decreasing of excess pore pressure with the settlement rate;

- determine the horizontal deformations;

- determine the increase of shear strength (undrained Cu) during the consolidation process;

- determine compressibility characteristics behaviour of in situ soils (Cc, Cv, PC etc.) during the consolidation process.

Specific objectives

- effectiveness of pre-loading to reduce residual settlement;

- determine the critical height;

- determine the influence of geotextile for the reinforcement behaviour (higher critical height?, steeper slope?).

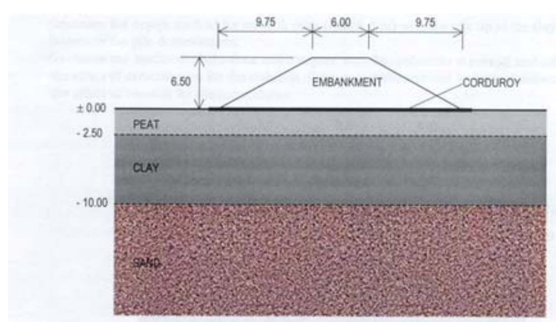

Figure 1.2: *Trial embankment I-A, pre-loading, critical height*

Trial embankment I-B: Normal embankment, rapid construction, reference case, at 3 meters peat depth

General objectives:

- same as trial embankment IA;
- compare the results with trial embankment IA results.

Special objectives:

- determine the effectiveness separation behaviour of the corduroy (inspection by re-excavation)

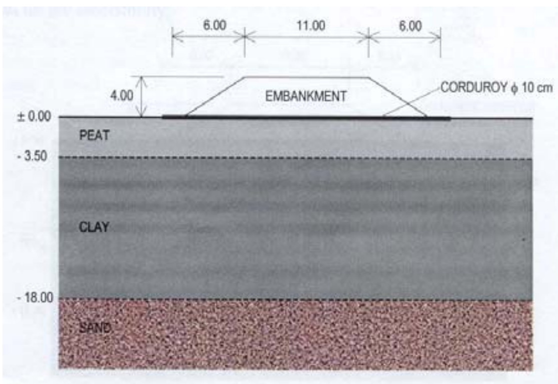

Figure 1.3: *Trial embankment I-B, normal embankment, height 4 m*

Trial embankment II-B: Cerucuk piles + corduroy (etc 0.3 m) at 3 meters peat depth

Objectives:

- determine the design method for cerucuk piles (length 4 m) with the pile tip in the clay layer;
- determine the pile deformations;
- determine the settlement behaviour and compare with the settlement at normal embankment;
- the effect of cerucuk piles for the stability, difference settlement and horizontal deformation;
- the effect of cerucuk for the accessibility.

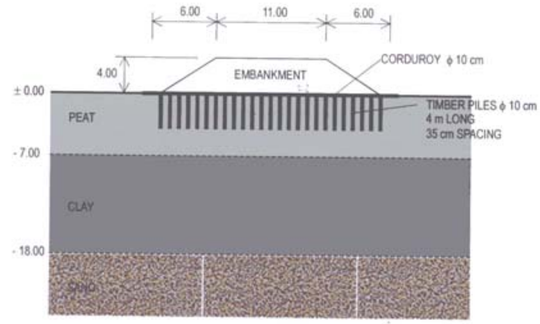

Figure 1.4: *Trial embankment II-B: Cerucuk piles + corduroy (etc 0.3 m) at 3 meters peat depth*

Trial embankment IV, JHS mini-piles

General objectives:

- effectiveness of a mini-pile system;
- determine the pile deformations;
- determine the settlement behaviour and compare with the settlement at normal embankment;
- the effect of mini-piles for the stability, difference settlement and horizontal deformation; the effect of mini-piles for the accessibility.

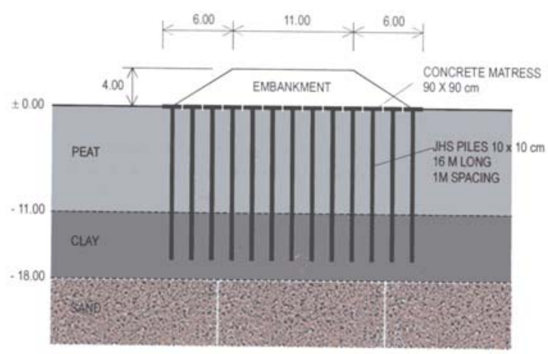

Figure 1.5: *Trial embankment IV, JHS mini-piles*

2. GENERAL INSTRUMENTATION SPECIFICATION

2.1 Introduction

During construction of embankments on highly compressible soil, equipment can be installed to measure:

- Vertical settlement of the original ground level;
- Vertical settlement of layers subject to deformation as a function of depth;
- Pore water pressure distribution or consolidation of particularly compressible layers;
- Horizontal displacement at ground level;
- Horizontal displacement of layers subject to deformation as a function of depth.

2.2 DEFORMATION MEASUREMENT EQUIPMENT

Peg

Vertical and horizontal ground level displacements are determined by visual measurement of pegs previously installed. When working over specific lengths, the out of line deviation can be determined by accurate alignment. Over greater distances, distance measurements are taken with precise measurement tapes in transverse direction or multiple angle measurements. Reference points should be chosen to be up to distances of at least 5-10 times the thickness of the layer subject to deformation.

Settlement plate

To determine vertical deformation or settlement, settlement plates are generally used. These consist of a rigid plate approximately 1 m square laid on the ground; a pipe is attached to the plate, the upper edge of which is then surveyed at regular intervals. If filling occurs, the pipe is extended until the top projects above the new ground level.

When small (to avoid filter constructions) holes are made at the bottom of the pipe near the rigid plate, the settlement plate can also perform as an open stand pipe. This is useful to measure the freatic water level in the sand fill.

Inclinometer tube

Horizontal subsoil deformations can be measured using inclinometer tubes. Flexible tubing, typically 50 mm internal diameter is placed in a hole drilled to approximately 2 m into firm strata below the compressible layer. As the casing is removed, fine gravel is placed to surround that part of the pipe in the deep firm layer. This ensures an optimum connection between the pipe and ground. In the upper compressible layers, the surrounding material consists of clay granules, which swell on water absorption in order to make the necessary contact between pipe and ground and also to prevent vertical leakage along the tube. The flexibility of the pipe is so low that it has no effect on soil deformations.

An inclinometer is then lowered in the pipe. This registers the inclination of the pipe continuously at relatively short distances. By integration, the complete position of the pipe is determined. To prevent inclinometer rotation, guide grooves are made in the measurement pipe. The accuracy with which horizontal deformations can be determined is a few centimetres at 15-m depth when an accurate inclinometer is used.

Extensometer

The vertical settlement measurement hose or extensometer consists of a hose placed or pushed into a drilled hole. The casing is then withdrawn and the annulus sealed with bentonite. The ribbed form of the hose makes it easily deformable in a longitudinal direction. It is fitted with magnetic rings, typically at 0.5 m intervals. For measurement purposes, a depth-measuring sensor is inserted in the hose, which generates a signal when it passes a ring. Periodic repetition of this measurement gives the compression behaviour of the various layers through which the hose passes.

A variation of this system consists of attaching cords to the rings. This cord extends above ground level and thus reflects the settlement.

2.3 Pore water pressure measurement equipment

Open stand pipe

A so-called open stand pipe is a tube with a filter at its base. This filter is placed in the fill, in a peat layer or in a deep sand layer. The tube is driven home or placed in a bore hole. The piezometric waterlevel in the tube corresponds to the water pressure at the depth of the filter. The open tube records the prevalent water pressure accurately but in low permeability layers has a very slow response time. In such strata so-called electrical or BAT piezometers should preferably be employed.

Piezometer

A piezometer (electrical or BAT) consists of a fluid pressure detector, installed in a housing, in which a filter is incorporated. The measurement signal are relayed to a measuring box on the surface via an electric cable. Because water displacement is negligible, response is virtually immediate.

Several types only differ in accuracy and in removeability of the detector from the filter.

3. INSTRUMENTATION AND MONITORING

3.1 Types

It is necessary to monitor the behaviour of an embankment and the soil during and after the filing. This monitoring instrumentation should be installed at least two weeks prior to the start of the trial embankment construction so that baseline readings can be established in the soil layers of interest. The instruments and associated cabling and pipe work need to be protected during construction. The type of measurement considered are vertical displacements or settlements, horizontal displacements, pore water pressures and earth pressures. Table 3.1. shows the suggested types of instrumentation for the Bereng Bengkel trial embankment monitoring program.

Table 3.1. *Instrumentation for trial embankments*

function	types
vertical settlements	Settlements plates on original and new ground surface, Extensometer at centre of embankment
horizontal settlements	Inclinometers at the toe of the embankment and 5 to 10 metres outside the toe of the embankment. Extensometer at the centre of the embankment
pore pressures	Piezometers, open standpipes

3.2 Layout of the monitoring

The monitoring system of the Bereng Bengkel test site consists for each embankment of the following instruments:

15 settlements plates, in 3 cross sections (5 settlements plates at centre line, 2 rows of 5 settlements plates at 2 cross sections 10 m to the centre line), for measuring settlements;

extensometer at the centre of the embankment;

3 clusters of Bat sensors at the centre line of the embankment. Each cluster consists of 3 Bat sensors for measuring excess pore water pressures at a depth of 2 m, 4 m and 6 m;

2 inclinemeters, one at the too of the embankment, one at a distance of 10 m out of the too of the embankment, for measuring horizontal settlements.

Additional 2 open standpipes in the field as well as 2 benchmarks are placed in the field at a distance large enough from the test embankments in order not to being in the influence zone of the filling.

4 EVALUATION PLAXIS AND ANALYTIC CALCULATION

4.1 General

The evaluation of the stability and settlements behaviour is based on general finite element method (FEM) calculations. A FEM analysis is chosen due to the complexity of trial embankments on peat, especially creep behaviour, drainage behaviour, distribution stress and also interaction between soil and the structure (cerucuk and JHS pile).

Plaxis, a two-dimensional finite element code for soil and rock analyses (version 7.2, 2000), is used for this purpose. The reasons are:

- Modelling soil condition, staged construction and load combinations;
- Modelling the complex non-linearity of the soil;
- Modelling of soil-structure interaction;
- Check of deformations and strength of soil;
- Check of deformations and forces in structural elements;
- Check of overall stability by phi/c-reduction method.

- A substantial number of calculations have been carried out to check the influence of geometry, parameters, soil condition, and staged construction.

4.2 Analysis

Modelling

For modelling aspects reference is made to the Plaxis Manual version 7.2. The soil is modelled using Soft soil creep material model. This model was chosen because at the location of the Bereng Bengkel test site the stratification of the sub-soil consists of soft layers of peat and clay. Peat and clay show a stress dependant non linear behaviour in which the stiffness of the material is stress dependant. Furthermore creep and consolidation plays an important role in the time dependant settlement behaviour when applying a load (embankment) on the sub soil. Therefor the soft soil creep model has been chosen for making predictions of the behaviour of the Bereng Bengkel test embankments.

A new Plaxis module has been used, in which updated mesh analysis was combined with creep and consolidation. In an updated mesh analysis the finite element mesh is updated after every displacement increment, so that every nodal point (x,y) will be updated to a new co-ordinate (x+Δx, y+Δy). The updated mesh analysis was chosen, as large deformations were expected. In such a case the traditional stress-strain relation will not be accurate

Condition, staged construction and load combinations

The Bereng Bengkel test site consists of 5 type of embankments. Three types of test embankments have been back analysed:

- Type I-A, normal embankment;
- Type I-B, surcharge loading;
- Type II-B, corduroy+curucuk;

The geometries of type 1-A (normal embankment) for the Plaxis analysis are shown in Figure 5.1 to Figure 5.3.

Boundary conditions

Standard Plaxis boundary conditions were used, that is horizontal fixities at the left and right boundary of the finite element mesh and horizontal and vertical fixities at the bottom of the mesh. For the consolidation boundary, closed consolidation boundary has been chosen at the left and right side of the geometry. Changes in freatic level was taken into account as shown in *fig. 4.1., fig. 4.4 and fig. 4.7.*

Material properties

The soil profile and parameters for calculations are given in Annex 13. From the lab and in-situ test data Plaxis input parameters have been derived, see ***table 4.1 en 4.2***.

The Plaxis soil parameters has been derived from the parameters shown in Annex 13. Some engineering judgement was made to arrive to the Plaxis parameters as shown in table 6.1 and 6.2. The pre-overburden pressure (POP) in the Plaxis calculations were taken 10 for all layers, except POP=5 for the organic clay layer in type I-A. When evaluating the material properties from field en lab data, a decision has to be made whether the permeability from lab data or from field test data should be used in the calculations. The permeability from field tests were in general a factor 6 to 10 higher than the permeability from lab tests (oedometer).

According to literature the values for the permeability found by field and lab tests both are within the range one should expect. In all Plaxis calculations it is decided the permeability from field test will be used, because it's known that permeability found by using lab tests will give too low values for the permeability in peat samples. Comparison of the results from Plaxis calculations and the measured settlements and excess pore water distribution as function of time, show that this engineering judgement was correct. The material stiffness properties for the cerucuk wooden piles have been reduced in order to take into account the fact that in Plaxis 2D calculations the wooden piles have been schematised as a 'wall', and not as separate piles with a h.t.h. disctance of 0.35 m.

Depth from [m]	Depth until [m]	Layer name	λ^*: $C_c/(2.3*(1+e_1))$ [-]	κ^*: $3C_s/(2.3*(1+e_2))$ [-]	μ^*: $C_a/(2.3*(1+e_0))$ [-]	ν_{ur} [-]
0	2,5	Crust peat	0,16	0,037	0,0037	0,15
2,5	5	Upper soft	0,06	0,015	0,0017	0,15
5	10	Lower soft	0,07	0,02	0,0018	0,15
10	-	Sand				
0	3,5	Crust peat	0,16	0,037	0,0037	0,15
3,5	5	Upper soft	0,06	0,015	0,0017	0,15
5	11	Lower soft	0,07	0,02	0,0018	0,15
11	18	Organic Clay	0,11	0,011	0,0017	
18	-	Sand				
0	6,5	Crust peat	0,16	0,037	0,0037	0,15
6,5	7	Upper soft	0,06	0,015	0,0017	0,15
7	18	Lower soft	0,07	0,02	0,0018	0,15
18	-	Sand				
0	11	Crust peat	0,16	0,037	0,0037	0,15
11	12	Upper soft	0,06	0,015	0,0017	0,15
12	17	Lower soft	0,07	0,02	0,0018	0,15
17	-	Sand				

Table 4.1: Material properties for Plaxis analysis

Layer name	permeability k_x [m/d]	permeability k_y [m/d]	γ [kN/m^3]	ϕ [o]	c [kN/m^2]	Density ρ_s [kg/m^3]	Porosity n [-]	Void ratio e [-]
Crust peat	7,00E-02	7,00E-02	10,21	17,5	5	1,7	0,941176	16
Upper soft	9,36E-04	4,68E-04	17,03	22	10	2,62	0,545455	1,2
Lower soft	3,35E-04	3,35E-04	16,00	20	10	2,64	0,615385	1,6
Sand								
Crust peat	7,00E-02	7,00E-02	10,16	17,5	5	1,5	0,928058	12,9
Upper soft	9,36E-04	4,68E-04	17,03	22	10	2,62	0,545455	1,2
Lower soft	3,35E-04	3,35E-04	16,00	20	10	2,64	0,615385	1,6
Organic Clay	5,00E-04	5,00E-04	14,39	19	2	2,4	0,666667	2
Sand								
Crust peat	7,00E-02	7,00E-02	10,16	17,5	5	1,5	0,928058	12,9
Upper soft	9,36E-04	4,68E-04	17,03	22	10	2,62	0,545455	1,2
Lower soft	3,35E-04	3,35E-04	16,00	20	10	2,64	0,615385	1,6
Sand								
Crust peat	7,00E-02	7,00E-02	10,16	17,5	5	1,5	0,928058	12,9
Upper soft	9,36E-04	4,68E-04	17,03	22	10	2,62	0,545455	1,2
Lower soft	3,35E-04	3,35E-04	16,00	20	10	2,64	0,615385	1,6
Sand								

Table 4.2: Cont. Material properties for Plaxis analysis

Calculation steps

The calculation steps made with Plaxis for all embankments are given in ***table 6.3 to 6.7***. Basically, the calculations consist of the following steps:

1. Determine initial stress conditions due to the self weight of the sub soil using K_o-procedure;
2. Plastic nilstep;
3. Apply in a staged construction step a layer of fill material in an undrained condition. Standard filling has been done in 0.3 day (so 8 working hours per day);
4. Consolidation in 0.7 day or more, depending on the building rate;
5. Repeat step 3-4 until final building stage;

Consolidation up to time $t=t_{final}$;

According to literature the values for the permeability found by field and lab tests both are within the range one should expect. In all Plaxis calculations it is decided the permeability from field test will be used, because it's known that permeability found by using lab tests will give too low values for the permeability in peat samples. Comparison of the results from Plaxis calculations and the measured settlements and excess pore water distribution as function of time, show that this engineering judgement was correct. The material stiffness properties for the cerucuk wooden piles have been reduced in order to take into account the fact that in Plaxis 2D calculations the wooden piles have been schematised as a 'wall', and not as separate piles with a h.t.h. disctance of 0.35 m.

Calculation steps

The calculation steps made with Plaxis for all embankments are given in ***table 6.3 to 6.7***. Basically, the calculations consist of the following steps:

6. Determine initial stress conditions due to the self weight of the sub soil using K_o-procedure;
7. Plastic nilstep;
8. Apply in a staged construction step a layer of fill material in an undrained condition. Standard filling has been done in 0.3 day (so 8 working hours per day);
9. Consolidation in 0.7 day or more, depending on the building rate;
10. Repeat step 3-4 until final building stage;
11. Consolidation up to time $t=t_{final}$;

Calculation results

The calculation results are given in fig 4.1 until 4.9.

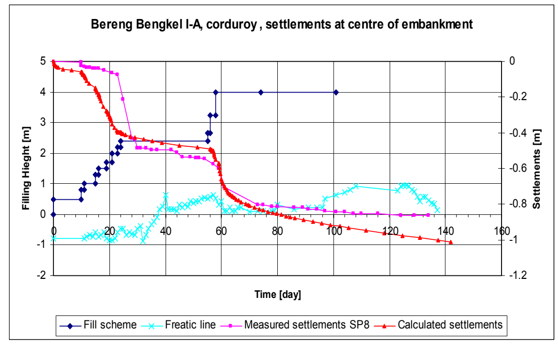

Figure 4.1: *Trial embankment I-A: Fill rate, ground waterlevel, measured and calculated settlements*

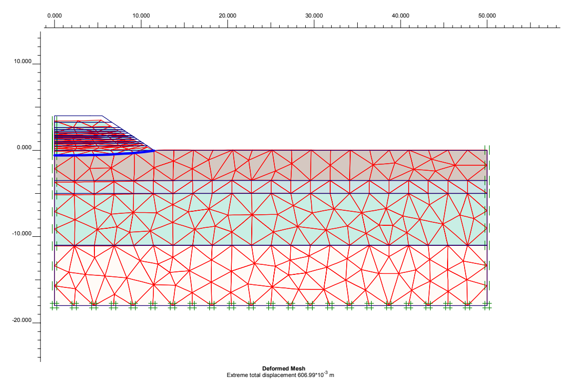

Figure 4.2: *Trial embankment I-A: Deformed Mesh*

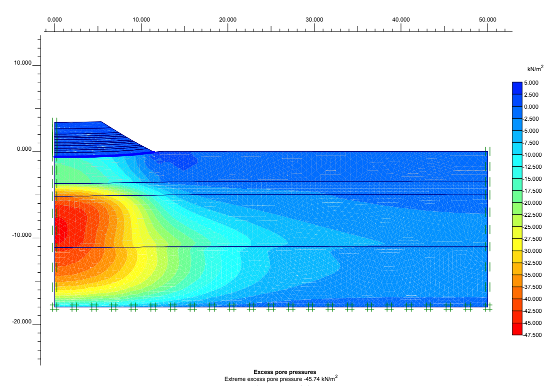

Figure 4.3: *Embankment I-A: Excess pore pressures*

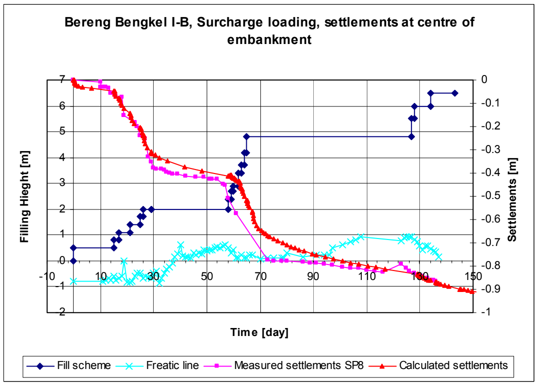

Figure 4.4: *Embankment I-B: Fill rate, ground water-level, measured and calculated settlements*

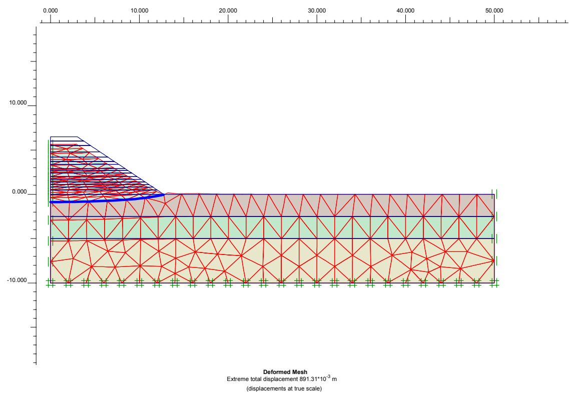

Figure 4.5: *Eembankment I-B: Deformed Mesh*

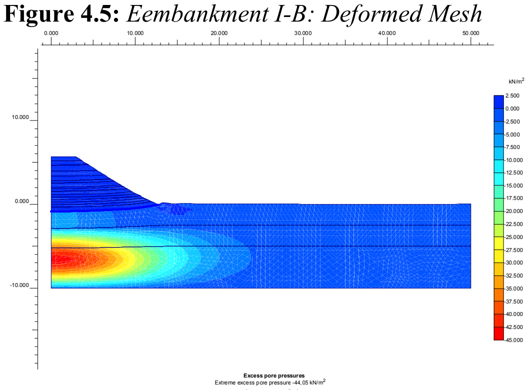

Figure 4.6: *Eembankment I-B: Excess pore pressures*

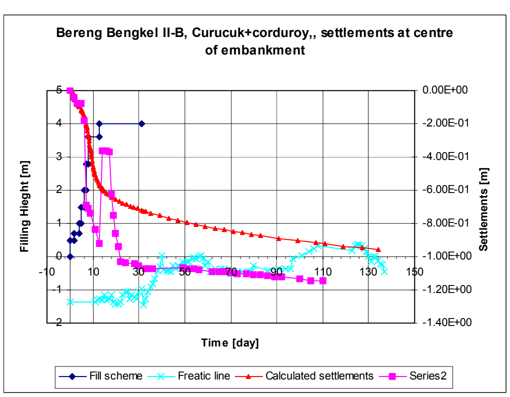

Figure 4.7: *Embankment II-B, Fill rate, ground water level and calculated settlements*

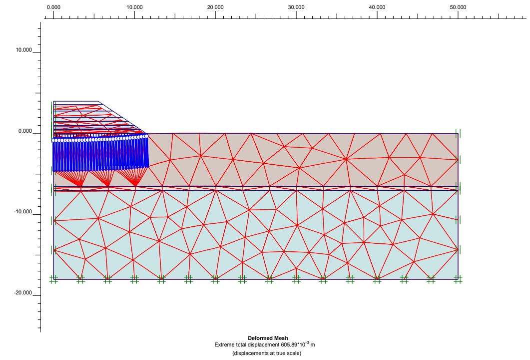

Figure 4.8: *Trial embankment II-B: Deformed Mesh*

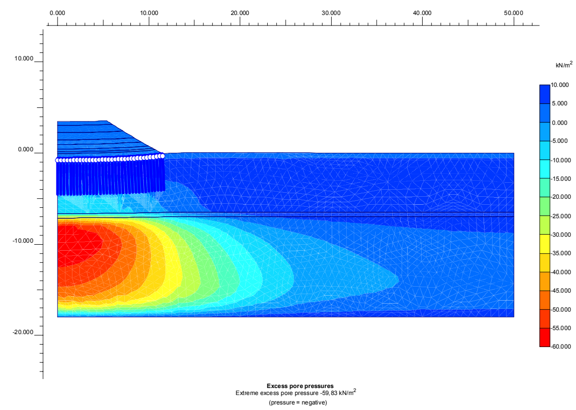

Figure 4.9: *Trial embankment II-B: Excess pore pressures*

5 FINANCING OF THE TEST SITES

5.1 Basic cost estimation

In Table 5.1 a first cost estimation is given for most of the mentioned equipment. Peg's and settlement plates are not included because they can easily be constructed with local materials and using local personnel.

Table 5.1: *Cost estimation equipment*

Equipment	Cost estimation for 1st apparatus (NLG, excluding VAT)	Cost estimation for 2nd, 3rd, etc. apparatus (NLG, excluding VAT)
Computer	5.000,--	--
Inclinometer	29,956,--	456,--
Extensometer	3.251,--	1.651,--
Open stand pipe	1.938,--	288,--
Piezometer	6.615,--	315,--
BAT-piezometer	3.195,--	450,--

5.2 Cost estimation

Based on the above estimated amount of monitoring equipment and the unit costs mentioned in the previous chapter a cost estimation for the five trial embankments can be made as follows:

Table 5.2: *Equipment and cost estimate for the original embankments*

Equipment	Number of embankments	Number per embankment	Reference number	Total number	Cost estimation (NLG, excluding VAT)
Com puter	5	0	1	1	5.000,--
Inclinometer	5	2	0	10	34.060,--
Extensometer	5	1	0	5	9.855,--
Open stand pipe	5	4	1	21	7.698,--
Piezometer	5	8/12	1	49	21.735,--
Totals	5	--	--	--	78.348,--

6. CONCLUSIONS

The back analysis of the Bereng Bengkel test embankments using the Plaxis Soft Soil Creep model shows that the calculated settlements are in agreement with the monitored settlements. Furthermore it is demonstrated that the time dependent behaviour, consisting mostly of the consolidation process, as it is shown that there is not much creep involved, is according the monitored behaviour. The values for the permeability of the peat, mainly based on the field permeability tests, which have been used for the FEM calculations seem to be correct; the calculated hydrodynamic period and the settlements seem to be in agreement with the monitoring data.

The predictions for test embankment II-B, corduroy raft with curucuk piles, give too low settlements compared with the monitored settlements. A better prediction can be reached by adjusting the stiffness properties of the wooden piles, taking into account the 2d schematisation.

It was not possible to compare the calculated excess pore water pressure as function of time with the monitored excess pore water pressures, as the computer used for reading out the BAT sensors in the field was heavily damaged. For future projects it is advisable to have a backup monitoring system (spare extensometers, bat sensors, laptop etc), as the extra costs for such a back up system is minimal compared to the costs for setting up the test embankments.

Furthermore, it's important that in designing a monitoring system, one should take into account the availability of local qualified staff. In the case of the Bereng Bengkel test embankments, due to ethnic clansing, qualified local staff was withdrawn, so no bat sensor readings are available now. It is expected that using standard piezometers would have given some monitoring results.

AQKNOWLEGDEMENT

The authors wish to express their gratitude to Dr Soumann and Rakhman Tauffic (IRE) for their support and collecting the monitoring data.

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