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Long Term Monitoring Test Embankments Bloemendalerpolder – Geo-Impuls Program

F.J.M. HOEFSLOOT
Fugro GeoServices

Abstract. In the Bloemendalerpolder two test embankments were constructed, starting October 2010, to study the long term behaviour of embankments on very soft soils with respect to settlement and lateral pile loading resulting from horizontal soil deformations. A 4 to 6 m thick very soft peat layer underlies the existing grasslands at the Bloemendalerpolder with a groundwater at 0.2 m below ground level. Urban development requires 0.5 to 1.0 m clearance of the ground level above the groundwater table. Two test embankments consisting of sandfill were designed with a height of 3.0 m and a ground area 26 x 36 m^2 with slopes 1:2. The Geo-Impuls programme aimed to provide a well-described field test with long time monitoring results. In this paper a detailed description of the test embankments is given as well as detailed descriptions of soil investigation, laboratory tests and instrumentation for monitoring. Finally the monitoring data will be presented which form a basis for further analyses for interested researchers. Analyses of the tests regarding the validation of settlement models and the lateral behaviour of the piles due to horizontal soil displacement are presented in two accompanying papers.

Keywords. Long term monitoring Test Embankments Bloemendalerpolder – Geo-Impuls program

1. Introduction

Settlement of embankments for urban development or road construction on soft soils is a well-known issue. Commonly applied settlement models however give rise to a wide range of predicted settlements. Especially long term behaviour in very soft clays and peats is not easy to predict. A conservative approach to settlement predictions may increase direct construction costs whereas an optimistic approach may result in unexpected long term deformations. Validation of settlement models, in general, suffers from a lack of well-described field test data.

For an urban development in the Bloemdalerpolder in the Netherlands field tests were designed to study the settlement behaviour for a year. The GeoImpuls program took the opportunity to extend the field tests to a five year monitoring period as well as to include test piles for monitoring their behaviour due to horizontal soil deformations.

A 4 to 6 m thick very soft peat layer underlies the existing grasslands at the Bloemendalerpolder with a groundwater table at 0.2 m below ground level. Urban development requires 0.5 to 1.0 m clearance of the ground level above the groundwater table. Two test embankments consisting of sandfill were designed with a height of 3.0 m and a ground area 26 x 36 m^2 with slopes 1:2. The GeoImpuls program aimed to provide a well-described field test with long time monitoring results.

2. Test Embankments

The test embankments are located in the Bloemendalerpolder in The Netherlands, Figure **1**. The general layout is given in Figure 2.

Figure 1. Test location Papelaan Weesp NL.

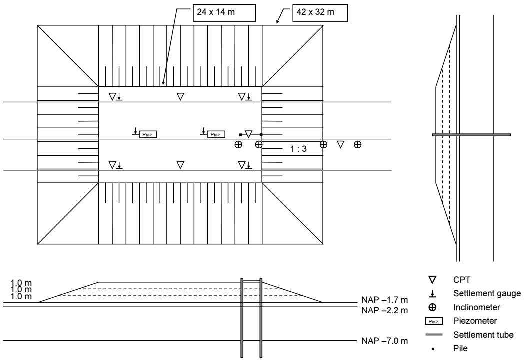

Figure 2. General layout.

Supply of fill material and construction has been realized by Maurik Groot-Ammers. With respect to slope stability under the very soft soil conditions a staged fill has been applied, starting with 1.0 m and consecutive stages of 0.5 m approximately every 3 weeks. After the first 1.0 m fill wick drains have been installed at Embankment 2 with largest thickness of peat layer to study the application of consolidation acceleration measures. The wick drains are installed in a triangular grid with spacing 1.0 m. Approximately one year after completion of the fill a preload of 0.5 m was removed at both embankments over half the total surface area. A detailed schedule of the staged construction is given in Table 1.

Table 1. Construction phases

Phase			1	2
Ground area [m^2]			36 x 26	36 x 26
Construction height [m]			3.0	3.0
Slope			1:2	1:2
Wick drains [triangular grid]			No	Yes
Phase	**Wk**	**Day**		
1st stage	1	0	1.0 m	1.0 m
Installing drains	2	5	n.a.	1 m c.t.c.
2nd stage	4	25	0.5 m	0.5 m
3th stage	7	47	0.5 m	0.5 m
4th stage	13	92	0.5 m	0.5 m
5th stage	16	112	0.5 m	0.5 m
Pile installation	19	133	2 pcs	2 pcs
Remove add. height over ½ embank.	60	416	0.5 m / 1.0 m	0.5 m / 1.0 m
End of field test	260			

To study the behavior of pile loading resulting from horizontal soil deformations, two H-beams (HEA 300) have been vibratory installed at the boundary of each embankment just after completion of the last fill stage. Piles have been located at the crest of the fill and 4.0 m from the crest as shown in Figure 3. The pile bending stiffness around the weakest axis is equivalent to a prefabricated concrete pile square 0.26 m. The pile properties are given in Table 2.

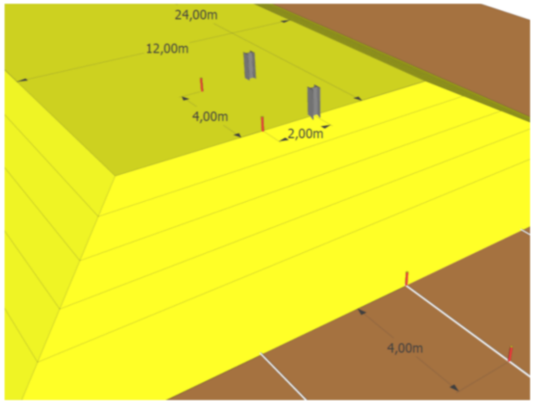

Figure 3. Pile and Inclinometer configuration.

Table 2. Pile properties.

Pile Type	HEA300	Prefab Concrete	Unit
Length	13.00		m
Pile tip level	-11.45		m+NAP
Dimensions	0.29 x 0.30	0.26 x 0.26	m
Young's Mod. [E]	210,000	35,000	MPa
Weakest bending stiffness [EI$_x$]	1.33 · 10^4	1.33 · 10^4	kNm^2

3. Soil Investigation

An extensive soil investigation has been performed to characterize the soil conditions.

- 12 CPTU, cone penetration test with pore pressure measurement at the tip (u1); 8 pc at each embankment and 2 pc at the reference location
- 4 ball penetration tests; 78 mm ball penetrometer (47.8 cm^2) with pore pressure measurement at bottom (u1) and top (u2)
- 12 vane tests at 4 locations at various depths; blade diameter/height 65/130 mm
- 8 CPM; cone pressuremeter tests at 2 locations, each 4 depths

- 3 Begemann borings; 1 at each embankment and 1 at the reference location; depth approximately 7 m (Deltares)

The soil investigation shows a constant thickness of the peat layer below each embankment but a relatively large difference between both embankments as can be seen from typical CPTU results in Figure 4 and Figure 5 and schematic stratification in Table 3 and Table 4. The groundwater table lies at approximately NAP -2.1 m.

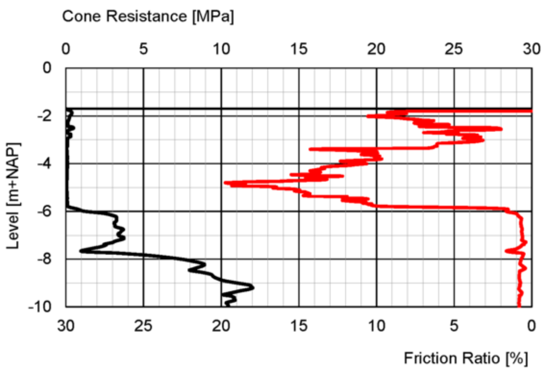

Figure 4. Typical CPTU Embankment 1

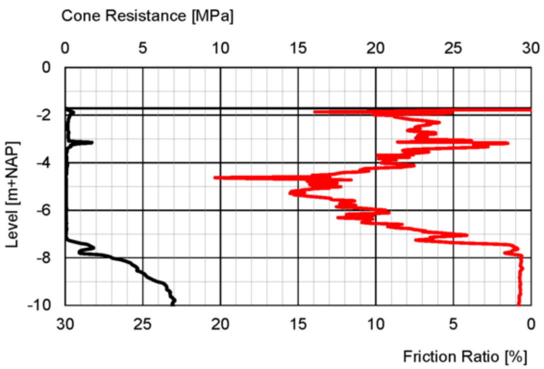

Figure 5. Typical CPTU Embankment 2

Table 3. Soil stratification at Embankment 1.

Top of Layer m+NAP	Soil Description
-1.7	CLAY slightly organic, unsaturated
-2.0	PEAT soft
-5.7	SAND loose to medium dense
-10.5	Maximum exploration depth

Table 4. Soil stratification at Embankment 2.

Top of Layer m+NAP	Soil Description
-1.8	CLAY slightly organic, unsaturated
-2.0	PEAT soft
-7.5	SAND loose to medium dense
-11.0	Maximum exploration depth

4. Laboratory Tests

An extensive program of laboratory tests have been performed by Fugro and Deltares on soil samples retrieved from the Begemann borings.

- Classification of undisturbed samples
- Photographs of undisturbed samples
- 30 pc Unit weight and water content; 11 pc at each embankment and 8 pc at the reference location
- 44 pc undrained shear strength tests, torvane
- 9 pc Organic content; Loss on ignition
- 5 pc Triaxial tests; consolidated undrained single stage tests (CUSS); 3 stages each test
- 5 pc Incremental Loading Consolidation tests
- 10 pc K_0-CRS; Constant rate of strain consolidation test with measurement of horizontal stress

The specific density of the peat layer has been derived from the loss on ignition according to Hobbs (1986). Similar relations are given by Den Haan (2003) and CUR (2012). Results are given in Table 5 and Figure 6. It is noted that sample 12 consists of organic clay as already had been observed from the relatively high saturated unit weight.

Table 5. Loss on ignition and specific density.

Boring	Liner	Loss on ignition %	Specific density kg/m^3
BT1	3	79.9	1550
BT1	4	73.0	1609
BT2	10	77.3	1571
BT2	11	64.8	1685
BT2	12	24.5	2200

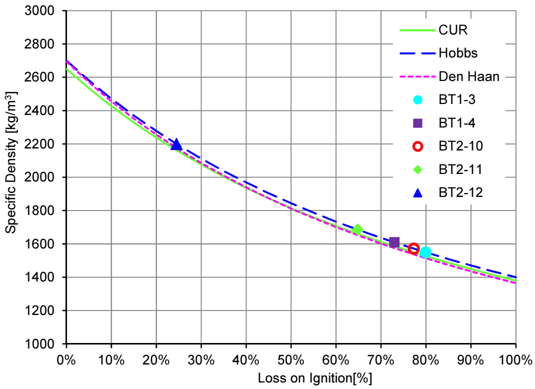

Figure 6. Specific density

From the laboratory tests settlement parameters were derived for three settlement models; Koppejan-Terzaghi-Buisman, NEN-Bjerrum isotache model and the a,b,c-isotache model. Additionally parameters for Terzaghi and Darcy consolidation models were derived as well: consolidation coefficient, permeability and strain dependent permeability strain factor. Details are given in an accompanying paper (Hoefsloot, 2015b).

5. Instrumentation

For monitoring of the behaviour of the embankments, various instruments were installed:

- 12 pc Settlement gauges; at each embankment 6 pc;
- 6 pc Settlement tubes; at each embankment 3 HDPE tubes diameter 100 mm were installed in longitudinal direction below the fill; measurements were performed with the Sisgeo Hydrostatic profile gauge.
- 5 pc Extensometers; 2 pc at each embankment and 1 pc at the reference location; Slope Indicator rod extensometers both manual and electric read out.
- 19 pc Piezometers; at each embankment 2 locations with piezometers at various depth within the peat layer and in the lower sand layer; 4 pc at the reference location at various depths.
- 8 pc inclinometers soil; at each embankment 4 vertical casings were installed on the longitudinal axis of the embankment, 4.0 m from the toe of the slope, at the toe, at the crest and 4.0 m from the crest; measurements with the Digitilt inclinometer probe of Slope Indicator at vertical intervals of 0.1 m.
- 4 pc inclinometers H-beams; steel casings, square 50 mm, welded over full length onto steel H-beams; measurements with the Digitilt inclinometer probe.

All gauges, tubes, extensometers, piezometers, inclinometers outside the perimeter of embankments were installed prior to any fill works. The steel piles and inclinometer casings in the embankments were have been installed 3 weeks after completion of the fill.

6. Monitoring Data

Monitoring of embankments was performed over the entire period before starting fill until to date and will continue till the end of 2015. In Table 6 the general monitoring schedule is provided.

Table 6. Monitoring schedule

Instrument	Wk 1-16	Wk 17-26	Wk 27-52	Wk 53-260
Settlement gauges	8	4	4	6
Settlement tubes	8	4	4	6
Inclinometer toe	8	4	4	6
Inclinometer crest	2	4	4	6
Piles x,y,z	2	4	4	6
Piles inclinometer	2	4	4	6
piezometers	Cont.	Cont.	Cont.	

In this paper characteristic monitoring data are presented to give an overview of the behavior of the embankments and piles. It is recommended to view these results in colored graphs given in the online version of this paper. Full monitoring data were reported in Dutch within the GeoImpuls program and are available at the websites www.geoimpuls.org and www.geonet.nl/684.

The author can supply digital monitoring data for interested researchers.

In Figure 7 the settlement of all 2 x 8 gauges of both embankments is given in time as well as the fill height (Emb. 1 and 2). Figure 8 presents the same data on logarithmic scale starting from the first fill. It is clear that the total settlement of Embankment 2 (ZB-T2) is much larger than for Embankment 1 (ZB-T1) as a result of the difference in thickness of the peat layer.

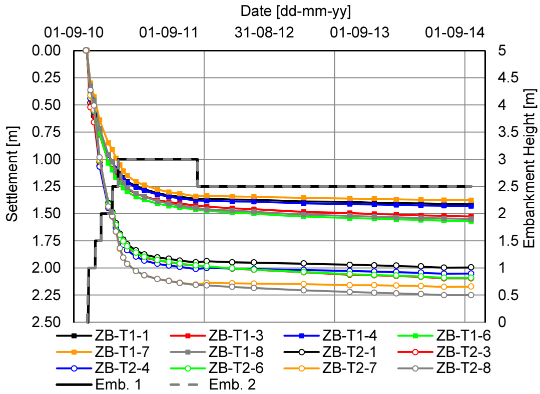

Figure 7. Settlement and fill height versus date

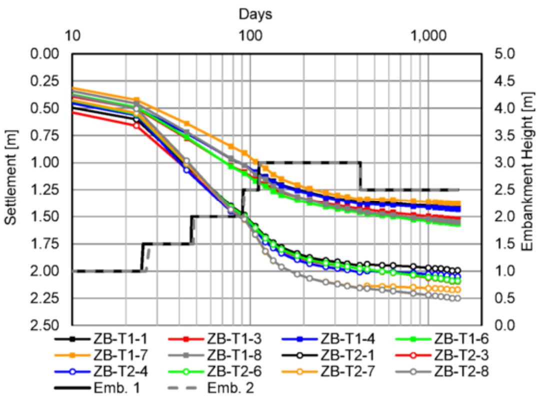

Figure 8. Settlement and fill height versus log time

The settlement distribution along the longitudinal axis based on the settlement tube data is shown in Figure 9 and Figure 10 for both embankments. The location of the fill is schematically given.

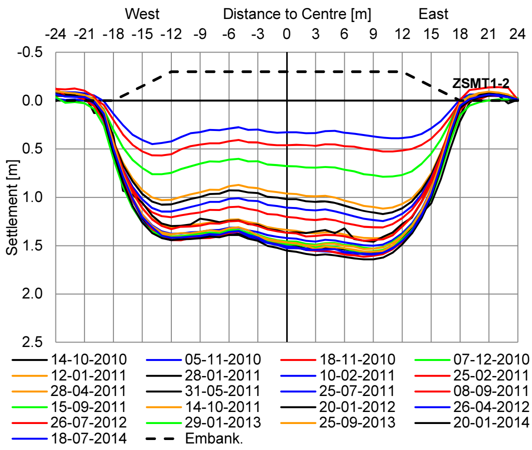

Figure 9. Settlement Embankment 1, (dates as dd-mm-yyyy)

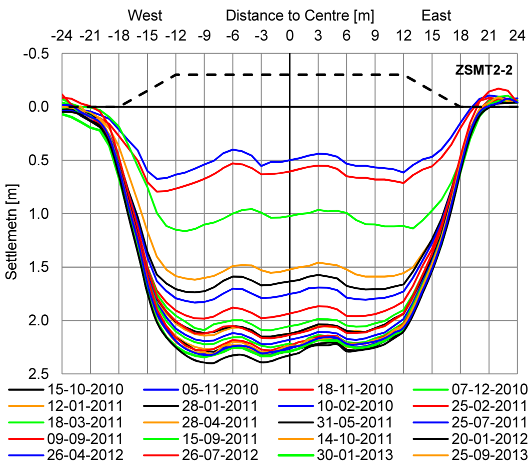

Figure 10. Settlement Embankment 2, (dates as dd-mm-yyyy)

Figure 11 and Figure 12 present the piezometer data for both embankments. Piezometers have been installed at various depth within the peat layer as well as in the deep sand layer. The incremental filling is clearly seen as well as consolidation after each stage. Embankment 2 is equipped with wick drains and consolidation takes approximately the same time as Embankment 1 despite the larger thickness of soft layers according to Table 3 and Table 4.

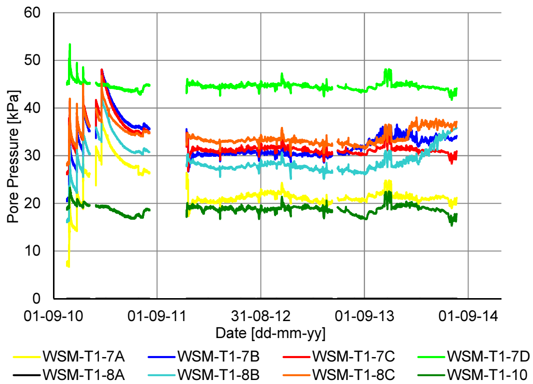

Figure 11. Piezometer results versus date, Embankment 1

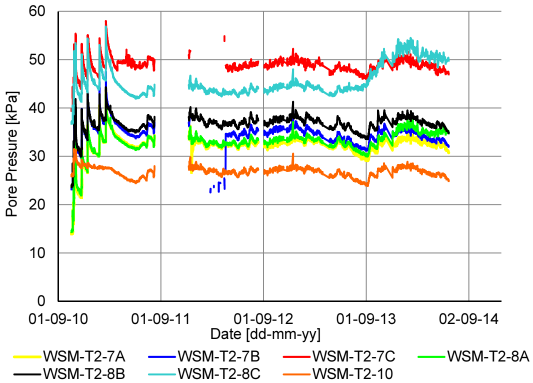

Figure 12. Piezometer results versus date, Embankment 2

A typical result of an inclinometer located at the crest and toe of the slope of Embankment 1 are given in Figure 13. Only the deformation away from the embankment is shown.

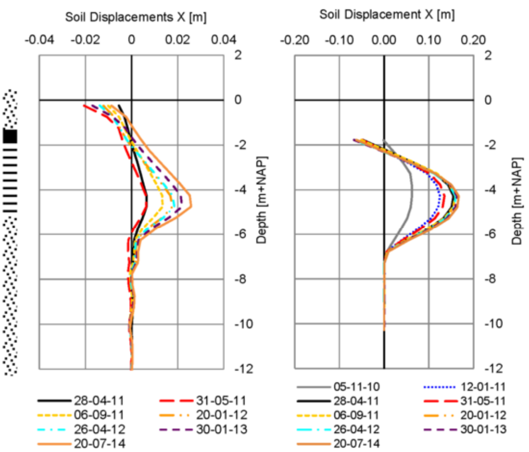

Figure 13. Inclinometer next to the pile (left) and at the toe (right) of Embankment 1.

Finally in Figure 14 the deformation of both steel H-beams in Embankment 1 are given. Again the positive deformation is directed away from the embankment.

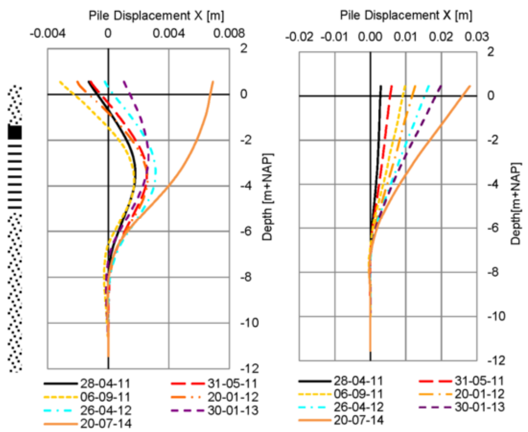

Figure 14. Inclinometer of the piles 4 m from the crest (left) and in the crest (right) in Embankment 1

7. Acknowledgement

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