Monitoring of a Railway Piled Embankment

Duijnen, P.G. van
Movares, Utrecht the Netherlands

Eekelen, S.J.M. van
Deltares, Delft, the Nederlands

Stoel, A.E.C. van der
CRUX Engineering, Technical University Twente, Netherlands Defence Academy

Keywords: monitoring, piled embankment, LTP

ABSTRACT: For the first time in Holland a railway is constructed on top of a Piled Embankment (P.E.) or Load Transfer Platform (LTP). The platform is a transition zone between a viaduct and a conventional railway track on an embankment. The rail fastening system is embedded track on the viaduct. The fastening system is ballast on the embankment. The settlements of the embankment during exploration are about 15 cm. The spacing between the piles near the viaduct is 1.25 x 1.4 m^2. Closer to the embankment the spacing between the piles increase to 1.45 x 1.9 m^2. A smooth transition is realized between the viaduct (no settlement) and the embankment. The thickness of the P.E. (vertical distance between top of rail and the pile head) is 2.8 m. The design of the reinforcement (strength) is done according to the EBGEO design rules. The performance of the P.E. is monitored intensively.
Within the paper the results of the monitoring are presented and a comparison with the results of the prediction calculations according the EBGEO design method. The measured arching effect complies with the arching effect calculated with EBGEO (2004). The contribution to the counter pressure is higher then predicted with EBGEO. This means fewer loads on the geosynthetic reinforcement then calculated. The passing of a very heavy railway wagon with loads comparable with the design load results in a temporary reduction of the arching. Common passenger and cargo trains do not have negative effects on the arching.

1 INTRODUCTION

The Netherlands have very soft compressible soils. Common practice in the Netherlands for building embankments is vertical drainage and a long construction time to allow settlements. The embankments function as a foundation for highway or railway tracks. Even after several years, settlements will lead to considerable maintenance. A possible solution to overcome settlement problems is a piled embankment with a geosynthetic reinforced granular layer in the middle. Piled embankments are a good solution to reduce construction time and maintenance costs. Compared to a concrete plate on top of a pile foundation a P.E. is cost effective. In Holland up to now about twenty P.E. constructions underneath local roads and highways are realized. Recently a 70m long P.E. was constructed underneath a railway track. This is the railway between Utrecht and Maastricht. This track has an average frequency of eight passenger trains and one cargo train every hour. The behavior of the P.E. is intensively monitored.

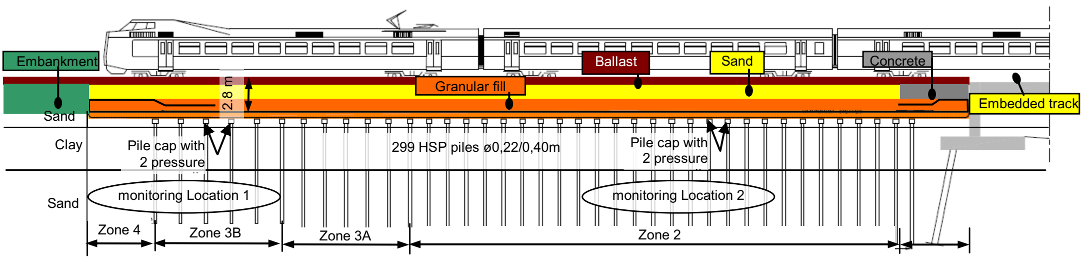


Figure 1: Longitudinal cross section of the LTP Houten

2 CONSTRUCTION

The construction of the P.E. is in detail described in Van der Stoel et al. The main function of the P.E. is a transition zone between a viaduct with an embedded railway track and the embankment with an track in ballast. Figure 1 presents a longitudinal cross section of the LTP. Table 1 and Table 2 give information about the pile distance and the reinforcement.

Table 1: General construction information

Length	The total length of the LTP = 70 m.
Width	Double track, the LTP has a width of 11m.
Soil conditions	1 m sand 3 m soft clay 20 m sand
Pile foundation	High Speed Piles (HSP) pile shafts ø0.22 m. pile heads ø0.40 m.
LTP	0.7 m ballast (0.4 m below the sleeper) 0.1 m sub ballast 1 m sand 1 m granular fill Distance top of rail – pile head is 2.8 m
Reinforcement	Fortrac M450-50 and T600-50

Table 2: Detailed information

		Zone 1-2	Zone 3A	Zone 3B	Zone 4
Monitoring		location 2		location 1	
Counter pressure (K_{sh} [kN/m^3])		0	100	300	
Length [m]		45	9,6	9,5	5
Pile distance [m]		1,25x1,4	1,45x1,6	1,45x1,9	no piles
Reinforcement	longitudinal	M450-50	M450-50	M450-50	M450-50
	lateral	M450-50	T600-50	T600-50	T600-50

3 DESIGN

The reinforcement is designed according the EBGEO (2004) equations. Other detailed design information is shown in Table 3.

Table 3: Design criteria

	Usability state	Ultimate state
Train load [kN/m^2]	10	43
Strain (total)	<2 %	-
Strain (train)	<0.5%	
Tensile strength [kN/m^1]	-	$F_{r;d} = F_{kar} / 2.36$
Tensile force [kN/m^1]		$1.2xF_{s;p}+1.5xF_{s;q}$

Finally the reliability index (β) of the construction is analyzed with a Monte Carlo simulation [Eekelen]. The minimum reliability index for failure of the reinforcement is 5, and for the total construction 4.2. The Dutch standard for railways requires a reliability index of 4.2.

4 MONITORING PROGRAM

One of the purposes of the monitoring program was to measure the load distribution in the embankment in time. To compare the calculated and measured load distribution load parts A, B and C are defined:

- load part A is transferred directly to the pile caps through arching,
- load part B is transferred through the reinforcement to the pile caps,
- load part C is resting on the soft subsoil.

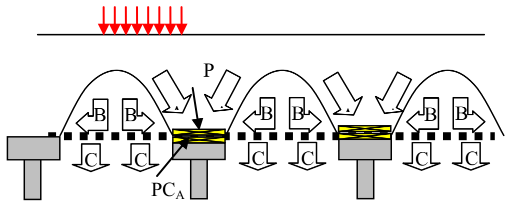


Figure 2:Load distribution piled reinforced embankment

The monitoring exits of 8 pressure cells and 8 strain gauges divided over 2 locations (see Table 2). Figure 3 shows the top view for location 1. On top of 2 identical pile heads 2 pressure cells are installed, below and directly on top of the reinforcement. The pressure cells below the reinforcement measure the total pile load, load part A+B (PC_{A+B}). The pressure cells above the reinforcement measure load part A (PC_{AB}). The difference between each two pressure cells, on the same pile head, is (A+B)-A = B. Four strain gauges are installed around one of the piles.

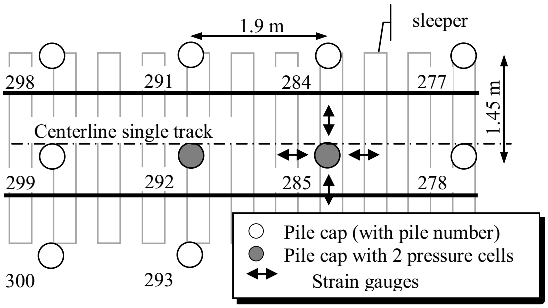


Figure 3: Top view monitoring location 1

The pressure cells and strain gauges are measured every 10 minutes. The measurements started immediately after the first construction stage, on 7 august 2008. On march 19th 2009 the frequency was increased to 1 measurement every minute. For short periods of time the frequency was increased to 25Hz.

5 STRESS DISTRIBUTION

Figure 4 shows the measured en predicted pile loads. The trains are passing one the peak of the graph.

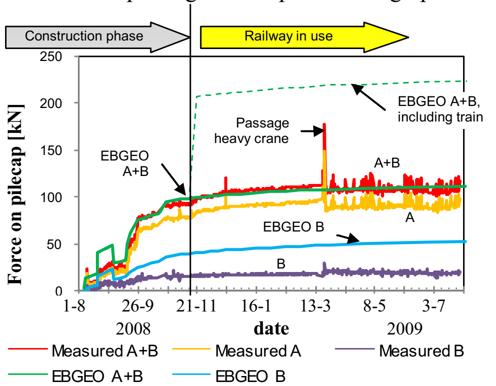


Figure 4: Pile forces (center to center 1,9 x 1,45 m)

The measured pile loads correspond well with the EBGEO calculation results. A constant improvement of the arching (increasing load part A) is visible. Load part B (is measured load part A+B - measured load part A) is about 30% of the calculated. This means that load part C, the counter pressure of the ground between the piles is higher then calculated. The Dutch committee for P.E. has concluded that EBGEO method is conservative related to load part C. The counter pressure in the centre area between 4 pile heads is neglected. (See Figure 5).

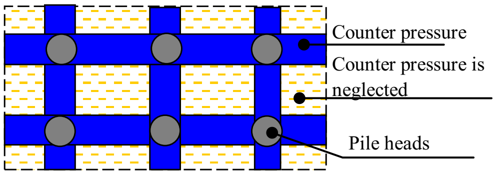


Figure 5: Top view counter pressure EBGEO

6 PASSING HEAVY RAILWAY CRANE

The P.E. was loaded with the maximum design load by the weight of the railway crane “Kirow”. This railway crane has 2 bogies with each 4 axis. The maximum axle load is about 235 kN; the average axle load is 135 kN. This railway crane has a much higher load then ‘normal’ passenger and cargo trains. (See Figure 9). Figure 6 shows the measured pile loads for both locations during the first passage of the Kirow. The passing of the Kirow is the largest load in the short history of the P.E in Houten. Location 1 gives a reduction of the arcing ($\Delta A = \Delta A + \Delta B \rightarrow \Delta B = 0$). This is in accordance with the arching cycle as mentioned in (Van Eekelen & Bezuijen) and possibly with the arching reduction caused by dynamic loads as described by Heitz. The high axis load exceeds the maximum strength of the arch, the load directly on the pile (load part A) decreases and load part B+C increases. If the construction is designed without any counter pressure (**location 2**) there is no dynamic reduction of the arching visible.

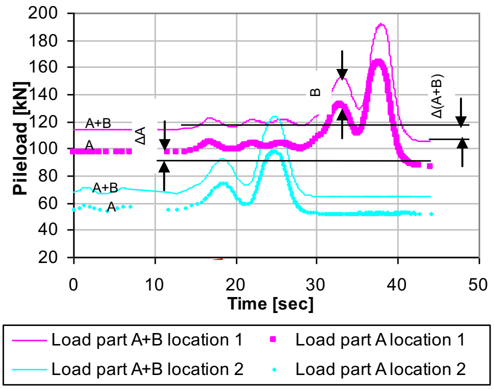
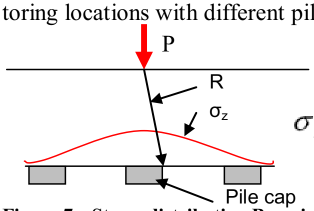


Figure 6: Passage heavy crane

The difference between the locations are mainly:
1. Location 1: The counter pressure (load part C) is necessary for carrying the load.
2. Location 2: P.E. without settlement. This part is capable of carrying the total loads without counter pressure.

7 PILE FORCES RELATED TO TRAIN

Apart from a confirmation of the arching cycle, the passing of the Kirow provides us with an theory view on the load distribution in longitudinal direction of the track. The railway wagon passes 2 monitoring locations with different pile distances.



$$\sigma_z = P \cdot \frac{3}{2\pi} \cdot \frac{z^3}{R^5}$$

Figure 7: Stress distribution Boussinesq

The Dutch code gives a method to convert axle loads to uniform loads. This method is based on the stress distribution according Boussinesq (see Figure 7). Figure 8 shows the measured pile forces caused by the passing of the railway crane. With the stress distribution a prediction of the pile forces is made. The depth (z) is the height between top of rail and the pile cap. The pile force is the summation of the total vertical stress. For location 1 the predicted pile force is higher then the measured pile force. The measured forces in location 2 fits well with the calculated pile forces.

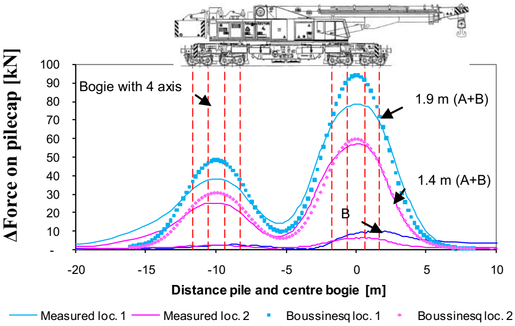


Figure 8: Load distribution (axles to pile loads) in the LTP for 2 pile distance of 1.4 m and 1.9 m.

8 HEAVY CARGO TRAIN

The Kirow passes the monitoring location with a speed of 13 km/hr. What happens when the speed increases? The passing of a heavy cargo train and a average passenger train are analyzed. Figure 9 shows the measured pile forces for a cargo train (95 km/hr) with the maximum recorded pile loads.

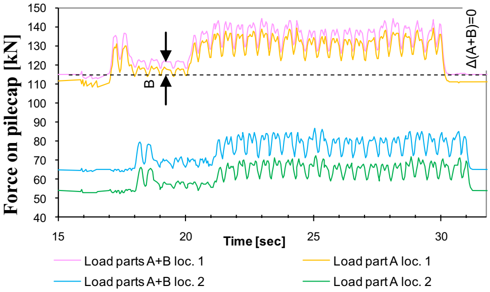


Figure 9: Passing heavy cargo train (speed 95 km/hr)

The locomotive and the wagons are visible. The wagons are heavier then the locomotive, but the loads are much lower then the loads from the Kirow. (compare maximum load Figure 6 with Figure 9)

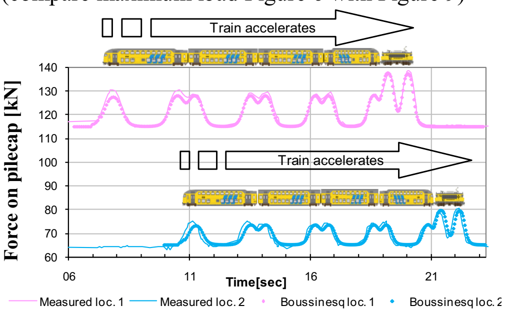


Figure 10: Passing passenger train

Heavy cargo trains don't have a permanent effect on the arching. The measured pile load before and after the passage is equal. Figure 10 shows the passing of a passenger train. For this train the measured forces on de pile a compared with the predicted pile forces. Nearby is a railway station, the train was still accelerating. That is why the time between axis passing is decreasing. The calculated forces on the piles fits very well with the measured forces. This is the case for every analyzed train.

9 CONCLUSIONS

The main conclusions are summarized below:

- The calculated load part A (EBGEO) agrees well with the measured values. Both for the construction stage with a thin P.E.
- The arching cycle is measured. The LTP improves with almost every passing train. Only the passage of extreme loads reduces the arching effect temporarily.
- EBGEO is pessimistic regarding the counter pressure of the soil between the piles. A small improvement of the EBGEO equations may solve this.
- The configuration of the piles seams to have no significant effect on the load distribution angle to the piles. Of course the maximum pile load itself is influenced by the pile configuration.

10 ACKNOWLEDEMENTS

The monitoring program would not have been possible without the support of several sponsors. These were (among others): Bataafse Alliantie, CRUX Engineering, Delft Cluster, Deltares, Huesker Synthetic, ProRail, CFE, KWS infra, Mobilis, Voorbij Funderingstechniek and Movares.

REFERENCES

EBGEO: Bewehrte Erdkörper auf punkt- und linienformigen Traggliedern, *Kapitel 9 from Empfehlung für den Entwurf und die Berecnung von Erdkörper mit Bewehrungen als Geokunststoffen*, Ausgabe 02/2009, Kapitel 6.9. Deutsche Gesellschaft für Geotechnik e.V. Arbeitskreis 5.2

Eekelen, S.J.M. van, A. Bezuijen, 2008, Design of piled embankments, considering the basic starting points of the British Design Guideline, *paper number 315 in the proceedings of EuroGeo4*, September 2008, Edinburgh UK.

Heitz, C., 2006, Bodengewölbe unter ruhender und nichtruhender Belastung bei Berücksichtigung von Bewehrungseinlagen aus Geogittern. *Schriftenreihe Geotechnik*, Uni Kassel, Heft 19, November 2006

Van der Stoel, A.E.Cet al., *First Railroad Widening in The Netherlands on Load Transfer Platform Construction*, to be published in the proceedings of 9ICG, Brazil, 2010

Zaeske, D., 2001, Zur Wirkungsweise von unbewehrten und bewehrten mineralischen Tragschichten über pfahlartigen Gründungselementen. *Schriftenreihe Geotechnik*, Uni Kassel, Heft 10, Februar 2001