Does a piled embankment ‘feel’ the passage of a heavy truck? Field measurements.

S.J.M. van Eekelen
Deltares and Delft University of Technology, Delft, Netherlands

A. Bezuijen
Ghent University, Belgium and Deltares, Delft, Netherlands

P.G. van Duijnen
Mobilis, Apeldoorn, Netherlands

ABSTRACT: The highway’s exit of the A12 near Woerden (The Netherlands) was reconstructed with a basal reinforced piled embankment. Traffic loads on the asphalt, load distribution and deformations are being measured. Furthermore, optic fibres were used to measure the strains in both the geosynthetic reinforcement (GR) and the piles.

Measurements were carried out every 10 minutes to study the development of the distribution of the permanent load. Additionally, high frequency measurements (500 Hz) were carried out during truck passages. The measurements were compared with predictions of EBGEO/CUR and its modified version, with an inverse triangular load distribution (Van Eekelen et al., 2012a, b and c). The inverse triangular load distribution and the resulting GR strains agree better with the field measurements than the equally distributed or triangular distributed load of respectively BS8006 or EBGEO/CUR. This implies both for the long term-static situation, but also for the dynamic measurements during truck passages.

1 INTRODUCTION

In 2010, the Netherlands, Germany and Britain published new or revised design guidelines for the design of basal reinforced piled embankments (CUR226 2010, EBGEO 2010 and BS8006 2010). A research program carried out for further optimizing the Dutch design guideline comprises three long term field studies, an extensive laboratory test series (Van Eekelen et al. 2011b, 2012 a, b, Van Eekelen & Bezuijen 2012c), finite element analysis (Den Boogert et al. 2012), and further development of the analytical design rules for the geosynthetic reinforcement (GR), (Van Eekelen et al. 2012b).

This paper reports one of the field studies, the highway’s exit of the A12 near Woerden in the Netherlands. The measurements include the load distribution, deformations, GR strains and traffic loads. Measurements at this location are registered every 10 minutes. However, on September 6th, 2011, high frequency measurements at 500 Hz were carried out. This makes it possible to compare the behaviour under permanent and temporary load.

2 SUMMARY DESIGN GUIDELINES

GR strains resulting from the vertical load are usually calculated in two steps, as shown Figure 1. The first (“arching”) step divides the vertical load into two parts: part *A* that is transferred to the piles directly, and part *B*+*C* (Figure 1). The second calculation step considers the GR strip between two piles. It is assumed that the GR strip is loaded by *B*+*C* and, if allowed, supported by the subsoil. From this, the GR strain ε is calculated. CUR and EBGEO calculate with a triangular load distribution on the GR strip, while BS8006 chose for an equally distributed load (Van Eekelen et al. 2011a). Van Eekelen et al. , (2012b) suggested using an inverse triangular load distribution as shown in Figure 1. They also suggested extending the subsoil support for the entire area below the GR, thus not only the area below the GR strip, as described in Lodder (2012).

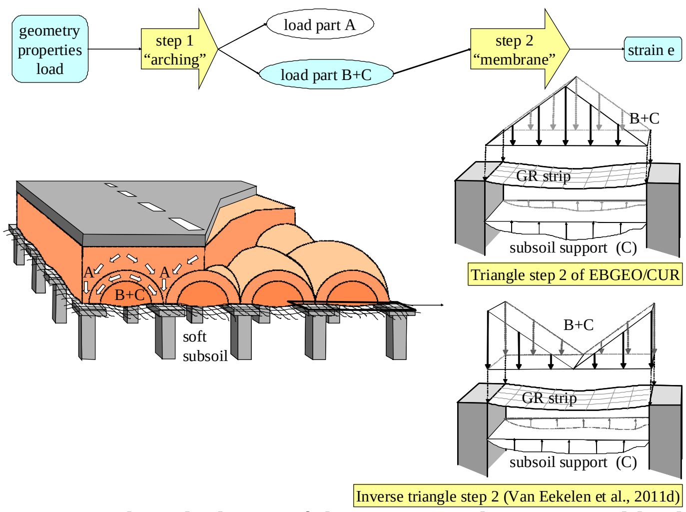

Figure 1. The calculation of the GR strain due to vertical load is carried out in two steps.

Step 2 implicitly results in a further division of the vertical load, as shown in Figure 2; load *B* is transferred through the GR to the piles and load *C* is carried by the subsoil. It should be noted that load *A*, *B* and *C* are in most cases expressed in kN/pile and that *A*, *B* and *C* are vertical loads.

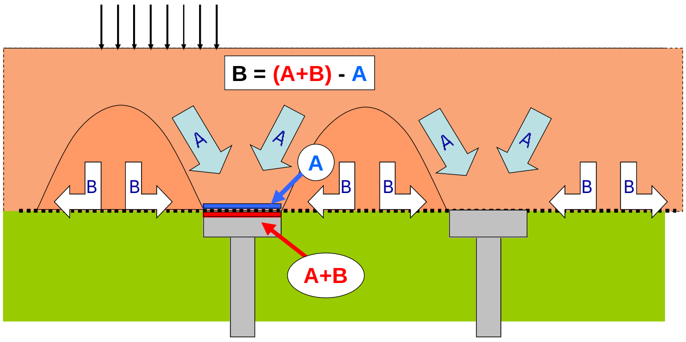

Figure 2. Load distribution in a piled embankment.

3 THE WOERDEN PILED EMBANKMENT

3.1 *Reconstruction of a highway's exit*

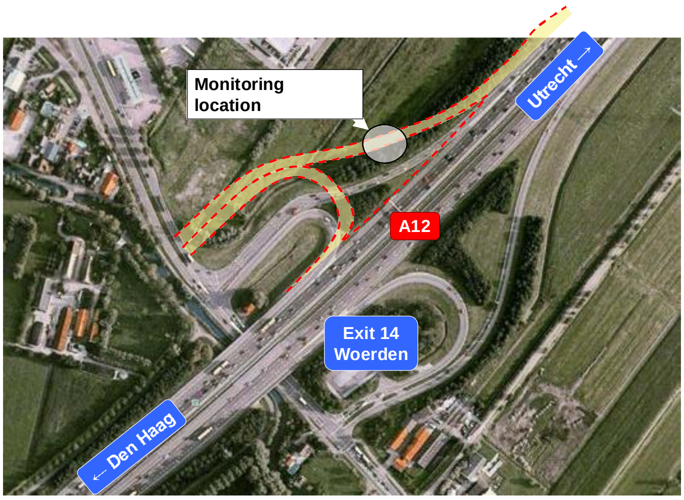

Figure 3. Reconstruction of the highway's exit near Woerden.

The highway's exit near Woerden was reconstructed as shown in Figure 3. Part of the new road was built on a basal reinforced piled embankment, because the subsoil was a ca. 17 m thick layer of very soft soil, and the available construction time was limited. The road construction started in April 2010, and the road was taken into use in June 2010.

Figure 4 gives a cross section of the piled embankment at the monitoring location. The system consisted of more than 900 prefabricated piles with average 2.20x2.26 m^2 centre-to-centre (CTC)-spacing and square prefabricated concrete pile caps with smoothly rounded edges. On top of the pile caps lies 0.05-0.16 m sand. The GR lies directly on the sand. The compacted fill consists of broken recycled construction material (0-40 mm), such as concrete and bricks.

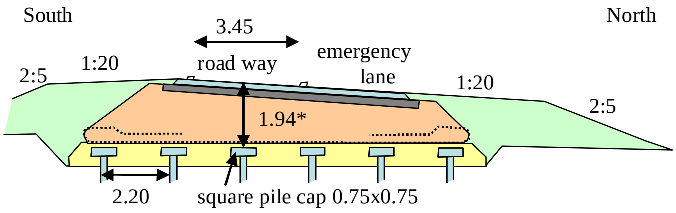

Figure 4. Cross-section piled embankment
* Distance between road surface and the pile cap of pile 692, see Figure 6. Pile 693 lies on the right hand side of pile 692.

A layer of Stabilenka 600/50 (PET) lies directly upon the sand, across the road, and a layer of Fortrac R 600/50 T (PET) lies on top of that along the road axis. The GR time-dependent behaviour was determined from isochronous curves, provided by the supplier, and is given in Table 1. On top of the fill lies 0.25 m Agrac (asphalt granular material mixture) and 0.18 m asphalt.

Table 1 Tensile stiffness of GR

Time under load	Ultimate tensile strength (UTS)	Tensile stiffness* J (kN/m)
	kN/m	kN/m
1 month	650	(12.28/1.5)*650 = 5319
1 year	650	(11.95/1.5)*650 = 5180

* J = (% of UTS / strain) x UTS, herein values at 1.5 % strain

3.2 *Monitoring program*

Measurements will be carried out for ten years and include (between others) load distribution, deformations and GR strains, see Figure 6. The load distribution and GR strains are being registered every 10 minutes.

On 6 September 2011, high frequency measurements were carried out at 500 Hz sampling rate. This paper specifically reports the passage of two trucks: truck 1 (32 tons, 6 axles) and truck 2 (14.4 tons, 4 axles), see Figure 5. Purpose was to determine whether step 1 and 2 behave the same for temporary loading as for permanent loading such as soil weight.

The ground water level lay at 0.02 m below the average top of the pile caps of test piles 686, 687, 692, 693, 698 and 699 on this day.

Figure 5. Truck passages at 6 September 2011,
truck 1 (left): 32 tons and 6 axles and truck 2 (right): 14.4 tons, 4 axles.

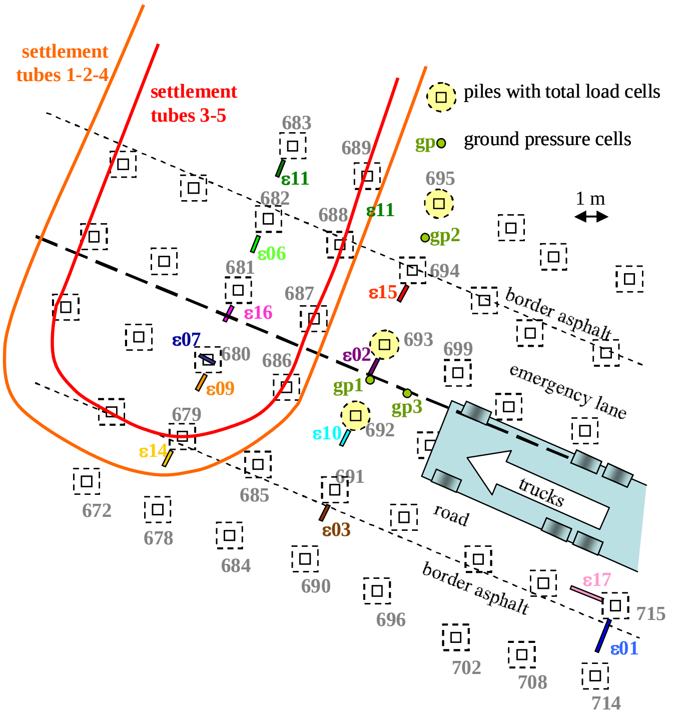

Figure 6. Top view monitoring program Woerden.

3.3 *Analytical predictions*

The distances between - and the weight of the wheel axles were measured. The Boussinesq-approach given in CUR226 (Van Eekelen et al, 2010a), gives the normative equally distributed input-loads: 7.52 kPa for truck 1 and 3.62 kPa for truck 2.

Analytical predictions were carried out, both with EBGEO/CUR and the modified version with the inverse triangular load mentioned before. For the 'no traffic' situation, the GR stiffness after one year of loading was applied (Table 1), for the 'truck situation', the GR stiffness for a loading time of 1 month was chosen. Table 2 gives predictions for the assumed starting-value for the fill friction angle φ=37.5° and the experimentally determined φ=49.0° Den Boogert et al., (2012).

Table 2 Analytical prediction with EBGEO/CUR, φ = 37.5°/49°

		A*	B*	B(+C**) average between piles	average GR strain EBGEO /CUR	average GR strain inversed triangle
		kN/pile	kN/pile	kPa	%	%
Pile 692/680	No traffic	98/135	80/43	18/10	1.94/1.30	0.66/0.37
	Truck 1	119/164	97/52	21/12	2.17/1.45	0.78/0.44
	difference	21/29	17/9	4/2	0.23/0.15	0.12/0.07
	Truck 2	108/149	88/47	19/11	2.03/1.36	0.72/0.40
	difference	10/14	8/4	2/1	0.09/0.06	0.05/0.03
Pile 693/681	No traffic	93/130	80/44	18/10	1.95/1.32	0.66/0.37
	Truck 1	114/158	98/54	21/12	2.18/1.48	0.78/0.44
	difference	21/29	18/10	4/2	0.24/0.16	0.13/0.07
	Truck 2	103/143	89/49	19/11	2.04/1.38	0.71/0.40
	difference	10/14	9/5	2/1	0.10/0.07	0.06/0.03

*Prediction is the same for EBGEO/CUR and its modified version, ** It is assumed that the subsoil has consolidated and has no contact with the GR: subgrade reaction k = 0 kN/m^3 and thus C=0 kN/pile

4 PERMANENT SITUATION

The load distribution is measured with two total pressure cells (TPCs), one on top of the GR (measuring *A*), and one below the GR (measuring *A*+*B*, Figure 2). The diameter of the TPCs and pile cap is the same. This system was applied successfully in several projects before (Van Duijnen, et al. 2010, Van Eekelen et al., 2010b) and in experiments (Van Eekelen et al., 2012a).

However, the TPC diameter in Woerden is so large, ∅ 0.84 m, that some complications occurred. A smaller wooden plate ∅ 0.75 had to be applied between bottom TPC and pile cap due to problems with the relatively stiff sides of the TPCs. Furthermore, the top TPC lies on a settling sand layer that did not necessarily remain flat. Both TPCs measure a pressure (kPa), which is the pressure that works on the area of the TPCs foundation. It is decided to determine the total load (kN) on both TPCs by multiplying the measured pressure with the area of the wooden plate, because the pressure is only exerted on the wooden plate. This introduces an uncertainty in the presented measurements.

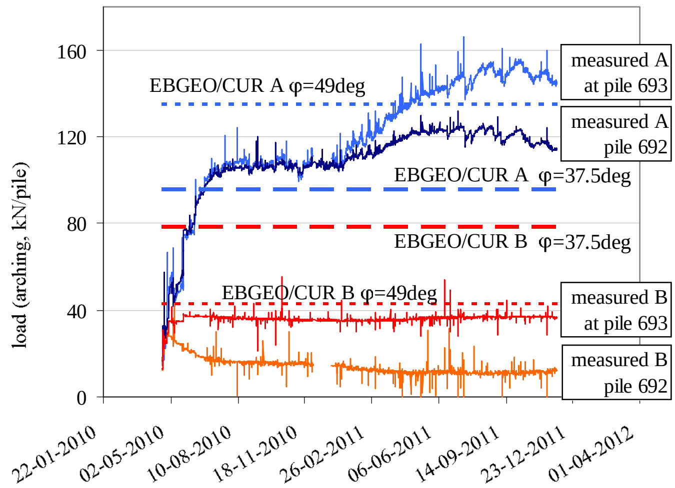

Figure 7. Load distribution, measured on pile caps and predicted (without traffic load).

The measured values for *A* increase in time (Figure 7). Probably, the shear strength of the fill increases, due to compaction during the dry spring of 2011. Increasing the φ in EBGEO/CUR gives more agreement with the measurements. Proven changes in φ can be used in the design. However, this is not the case for changes in cohesion, as this extra cohesion can be destroyed during extreme situations.

The extra GR settlement, due to soft soil consolidation is less than 0.021 m between November 2010 and October 2011. This does probably not fully explain the increase of *A*, although Van Eekelen et al., (2012a) found that consolidation of subsoil gives an increase of arching (*A*). EBGEO/CUR does not describe this.

The measured load part *B*, directly related to the GR strain ε and the GR tensile force T, is (much) lower than its prediction, which is therefore on the safe side. These results agree with measurements in other field tests, like in Houten (Van Duijnen, et al., 2010). The road surface was scanned 5 times in 16 months with 3D laser scanning technique. No settlements were measured within the accuracy of 1 to 2 mm.

Figure 6 shows the position of settlement tube 3, which lies directly upon the GR. The GR strain ε, determined from the shape of the GR between piles 687 and 688 is 0.92%. This includes the initial slag (more GR than ground surface area) that is usually present. The second derivative of these measurements corresponds directly with the load distribution on the GR strips. Taking the second derivative introduces some scatter, even after taking the average of each two successive points, but the shape of the lines clearly approaches more the inversed triangle than a triangular or constant load distribution.

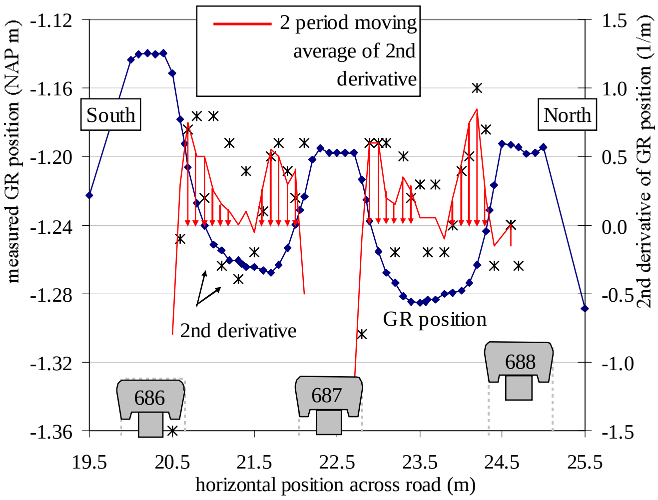

Figure 8. Position GR measured on 17 October 2011, after using the road for 16 months.

5 TRUCK PASSAGES

The shape of the two trucks can easily be recognized in the measured load distribution presented in Figure 9 and Figure 10. The increasing load part *A* agrees reasonable well with or is less than the calculated *A*. Thus contrary to the permanent load, CUR/EBGEO tends to over-predict the response of the arching *A* to temporary load.

This means that the 'rest-load', B+C (not measured) for truck 1 should be around 1.4-3.4 kPa (table 2). This B+C is probably concentrated in the area around the piles, as limited ground pressure changes were measured between 2 or 4 piles (Figure 10). This agrees with the theory of inversed triangular load distribution, in this case thus for a short, temporary load. Note that in the centre of 4 piles (gp3) much more response is measured than in the centre between 2 piles (gp2).

The measured changes in *B* are very limited (max. 4% of the prediction). Obviously, the subsoil carries the major part of the temporary B+C.

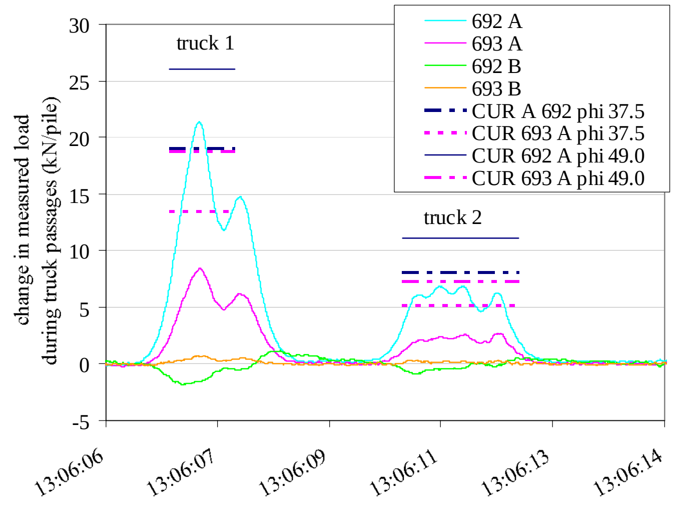

Figure 9. Distribution of the extra load of the passing trucks in kN/pile, see Figure 2.

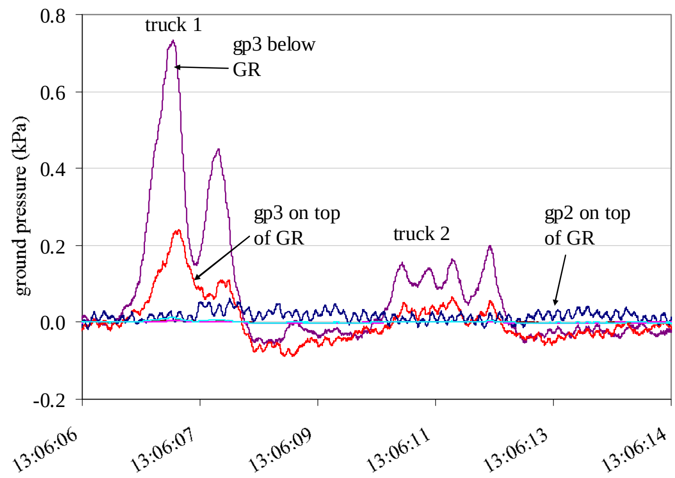

Figure 10. Pressure between piles on top of GR (B+C) and below GR (C), in kPa.

Figure 11 presents the response of the GR to the truck passages, measured with 0.5 m or 1.0 m long optic fibres. Figure 12 compares the measurements and the predictions (Table 2) for the strain gauges next to pile 692/680 and 693/681. The figure shows that the inverse triangular model approaches the measurements better than EBGEO/CUR. The calculation with φ=49° in combination with the inversed triangle leads to an underestimation of the strain. This is the result of the over prediction of A (calculation step 1, Figure 9). When the calculated A (step 1) is replaced by the measured A, calculation step 2 with the increased triangle leads to an over-estimation of the GR strain.

6 CONCLUSIONS

Long-term measurements are being carried out in the piled embankment of the Woerden high way-exit. Permanent and short-term loading, and the results of calculation steps 1 and 2 are distinguished in the analysis.

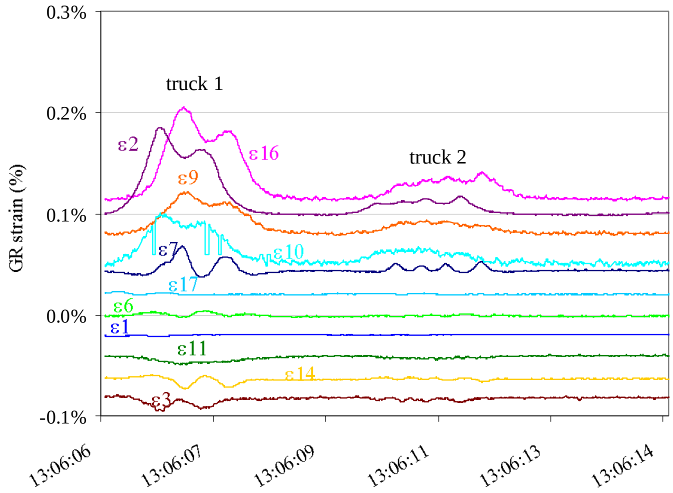

Figure 11. Response of GR strains to the truck passages. For clarity reasons, each curve has been given an off-set (does not start at ‘zero’)

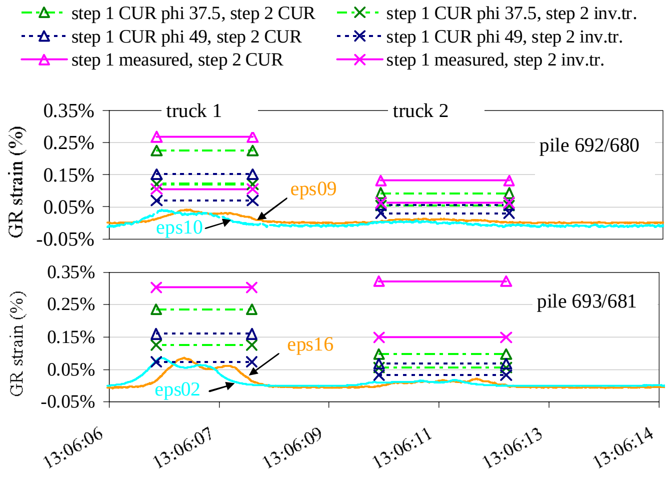

Figure 12. Comparison measured and calculated change in GR strains due to truck passages, close piles 692 and 693 and their equivalents.

The measured distribution of the permanent load (calculation step 1) shows that the arching *A* improved. This is probably mainly due to an increasing shear strength as a result of fill compaction during the dry spring of 2011. Assuming that this increasing shear strength is due to an increasing friction angle φ, prediction and measurements of the load distribution of the permanent load agree reasonably well. This is different for temporary loading, where the predicted change of arching *A* is generally higher than the measured change of *A*. The influence of subsoil consolidation is probably limited in this case of temporary loading.

The measured GR settlements show that the load distribution on the GR resembles the inverse triangle of Van Eekelen et al. (2011b, 2012b) more than the load distributions assumed by EBGEO, CUR and BS8006. This inverse triangle load distribution was already measured in model tests, but is now also measured in the field.

The GR strain measurements during truck passages show that for step 2 the inverse triangular approach gives better agreement with the measurements, both for the long-term loading as for the short-term loading conditions.

ACKNOWLEDGEMENTS

The authors are grateful for the assistance and financial support of the Dutch research program GeoImpuls, Province Utrecht, The Dutch Ministry of Public works, Huesker, KWS Infra, Movares and Deltares.

REFERENCES

BS8006-1: 2010. *Code of practice for strengthened/reinforced soils and other fills.* British Standards Institution, ISBN 978-0-580-53842-1

Den Boogert, T.J.M., Van Duijnen, P.G., Peter, M.G.J.M. and Van Eekelen, S.J.M. 2012. Paalmatrasproeven II, Eindige elementenberekeningen, *GeoKunst*, GeoTechniek January 2012, pp. 52-57, in Dutch

CUR 226. 2010. *Ontwerprichtlijn paalmatrassystemen (Design guideline piled embankments).* ISBN 978-90-376-0518-1 (in Dutch)

EBGEO. 2010. *Empfehlungen für den Entwurf und die Berechnung von Erdkörpern mit Bewehrungen aus Geokunststoffen* – EBGEO, 2. Auflage, German Geotechnical Society, ISBN 978-3-433-02950-3 (in German, also available in English).

Lodder, H.J., Van Eekelen, S.J.M. and Bezuijen, A. 2012. The influence of subsoil reaction in a basal reinforced piled embankment. In the Proceedings of *EuroGeo 2012*, Valencia in Spain.

Van Duijnen, P.G., Van Eekelen, S.J.M. and Van der Stoel, A.E.C. 2010. Monitoring of a Railway Piled Embankment, In: *Proceedings of 9 ICG, Brazil:* 1961-1964.

Van Eekelen, S.J.M., Jansen, H.L., Van Duijnen, P.G., De Kant, M., Van Dalen, J.H., Brugman, M.H.A., Van der Stoel, A.E.C., Peters, M.G.J.M. 2010a. The Dutch Design Guideline for Piled Embankments. In: *Proceedings of 9 ICG, Brazil*: 1911-1916.

Van Eekelen, S., Bezuijen, A. and Alexiew, D. 2010b. The Kyoto Road, monitoring a piled embankment, comparing 31/2 years of measurements with design calculations, in: *Proceedings of 9ICG, Brazil, 2010,* pp. 1941-1944

Van Eekelen, S.J.M.; Bezuijen, A. and Van Tol, A.F. 2011a. Analysis and modification of the British Standard BS8006 for the design of piled embankments. *Geotextiles and Geomembranes* 29:.345-359.

Van Eekelen, S.J.M., Lodder, H.J., Bezuijen, A. 2011b. Load distribution on the geosynthetic reinforcement within a piled embankment, in: Proceedings of *ICSMGE 2011*, Athens: 1137-1142.

Van Eekelen, S.J.M., Bezuijen, A., Lodder, H.J., van Tol, A.F. 2012a. Model experiments on piled embankments. Part I, *Geotextiles and Geomembranes* 32: 69-81

Van Eekelen, S.J.M., Bezuijen, A., Lodder, H.J., van Tol, A.F. 2012b. Model experiments on piled embankments. Part II, *Geotextiles and Geomembranes* 32: 82-94

Van Eekelen, S.J.M. & Bezuijen, A. 2012c. Basal reinforced piled embankments in the Netherlands, Field studies and laboratory tests, to be published in the proceedings of *ISSMGE - TC 211 International Symposium on Ground Improvement IS-GI* Brussels