



**S.J.M. van Eekelen**  
Deltares,  
The Netherlands



**R.A. Zwaan**  
Deltares,  
The Netherlands



**A. Nancey**  
Solmax / TenCate  
Geosynthetics,  
France



**M. Hazenkamp**  
Solmax / TenCate  
Geosynthetics,  
The Netherlands



**Y. H. Jung**  
Kyung Hee University,  
Republic of Korea

# FOUR YEARS FIELD MEASUREMENTS IN A PARTLY SUBMERGED WOVEN GEOTEXTILE-REINFORCED PILE-SUPPORTED EMBANKMENT

## Introduction

The design guideline CUR226:2016 for geosynthetic-reinforced pile-supported (GRPS) embankments adopted the Concentric Arches (CA) model of van Eekelen (2013, 2015), which was validated with more than 100 measurements taken in the field and in experiments. These embankments were all reinforced with at least one layer of geogrid. Furthermore, all the embankments were unsaturated, and installed above the groundwater table.

Limited research was done on the influence of water in a piled embankment. Brianc on and Simon (2012), Sloan (2011), and van Eekelen et al. (2020) showed that heavy rainfall affects measurements. Song et al. (2018) concluded from 2D trapdoor tests with sand that groundwater can degrade the soil arching mechanism. Wang et al. (2019), however, found strengthening of soil arching with increasing water level in full-scale 3D model experiments.

The validated use of CUR226:2016 is possible for

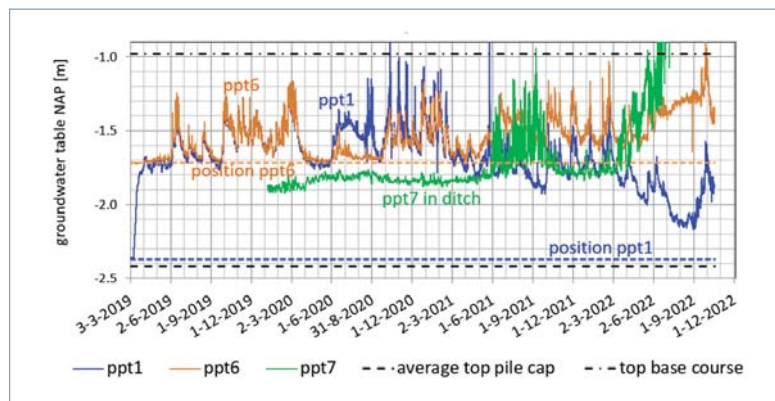
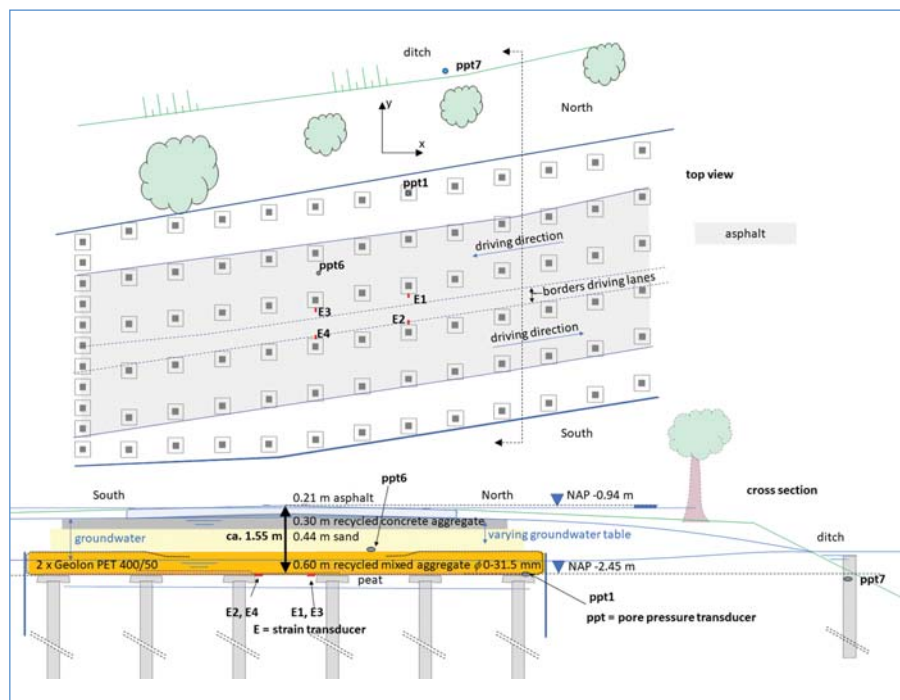
geometries, conditions and materials that match the situation where the measurements for the validation were taken. If these requirements are not met, the guideline requests additional measurements to demonstrate that the CA model gives good results for these conditions, too.

For this purpose, field measurements were done in a partly submerged piled embankment, reinforced with geotextiles only, without geogrids. This paper compares the measured strains with the varying groundwater table and air temperature, and calculations with the CA model of CUR226:2016. This paper is a modified version of van Eekelen et al. (2023).

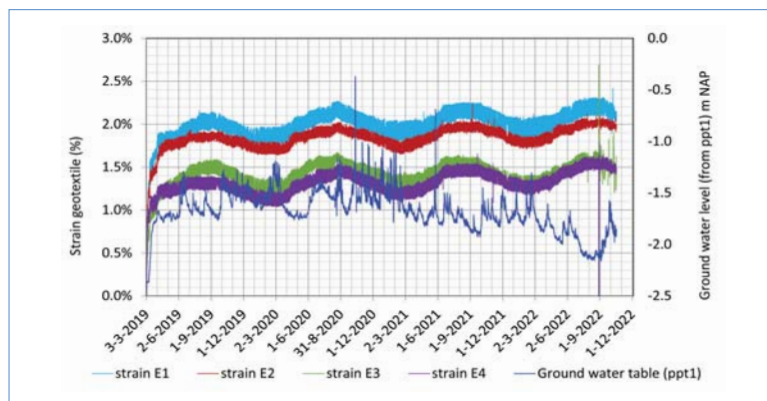
## A partly submerged geotextile-reinforced piled embankment

Van Eekelen et al. (2022) describe a piled embankment in the Netherlands for a regional motor way that was opened on 6 April 2019. Pile caps (0.75 m x 0.75 m), with smooth, rounded edges, were installed on end-bearing prefabricated concrete piles with an average centre-to-centre spacing of 2.28 m x 2.27 m. Two layers of woven geotextile (TenCate Geolon® PET 400/50) were installed, one with the machine (strong) direction across the road axis, the second parallel to the road axis. Figure 1 shows part of the monitoring set-up. In addition, the air temperature was measured hourly. For more details of the experimental set-up, we refer the reader to van Eekelen et al (2023).

**Figure 1 – Lay-out of the geotextile-reinforced piled embankment and the monitoring equipment.**



**Figure 2 – Measured pore pressures, translated into groundwater table (ppt1 and ppt6) and ditch water table (ppt7).**



**Figure 3 – Comparison measured geotextile strains and to measured groundwater table (ppt1).**

## ABSTRACT

This paper describes measurements in a partly submerged piled embankment, reinforced with geotextiles only. The seasonal effect in the measured geotextile strains strongly matches the seasonal temperature variation. No correlation with the varying groundwater table was found. The measurements remain sufficiently

on the safe side of the results of the Concentric Arches model. Therefore, the CUR226:2016 design guideline may be used for this type of geotextile-reinforced pile-supported embankments, of which the embankment is installed partly below the groundwater table.

## Measurements

### PORE PRESSURES AND GROUNDWATER TABLE

Figure 2 shows the measured pore pressures, translated into groundwater level in m NAP, where NAP is the Dutch reference level. The figure indicates the positions of ppt1 and ppt6; ppt1 lies in saturated soil. However, ppt6 is located higher, and the groundwater table sometimes drops below ppt6.

Figure 2 shows what can happen if a pore pressure transducer is installed in unsaturated soil. Until June 2020, ppt1 and ppt6 match. Just before 1 June 2020, the groundwater table drops below ppt6. This causes an air bubble that starts disturbing the measurements of ppt6, keeping the values of ppt6 well below those of ppt1. In September 2020, the groundwater level passes ppt6 again, the air bubble disappears, and ppt1 and ppt6 match again. In April 2021, the groundwater table passes ppt6 again, resulting in another air bubble that makes the measurements of ppt6 unreliable again.

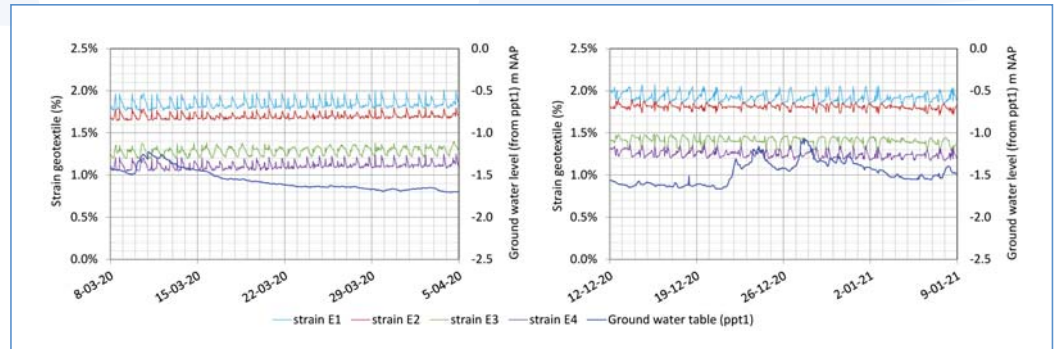
It seems plausible that ppt1 continuously gives reliable results; it shows a low water table during the very dry summer of 2022, followed by a rainy period in September 2022. The pore pressure transducer in the ditch gave reliable results between February 2020 and June 2021 and between November 2021 and March 2022.

### GEOTEXTILE STRAINS COMPARED TO GROUNDWATER TABLE AND AVERAGE DAY AIR TEMPERATURE

Strain gauges E1 and E2 give higher values than strain gauges E3 and E4 (Figure 3). We cannot explain this difference. The strains show a sea-sonal effect; the strains are higher during summers than during winters. Furthermore, each summer gives slightly higher strains than the previous summer. This can be explained by the creeping behaviour of the geotextile. The measured strains do not correlate clearly with the groundwater table.

Figure 4 zooms in on four dry weeks and four wet weeks. The figure shows a clear daily cycle, the cause of which is unclear. A similar daily effect was found earlier by van Eekelen et al. (2007). The daily cycles of traffic load or soil temperature may have an influence. However, the different strain gauges do not show a peak at the same time of the day.

Figure 4b shows an immediate response on rain: the daily cycle is less clear. Possibly, the relatively

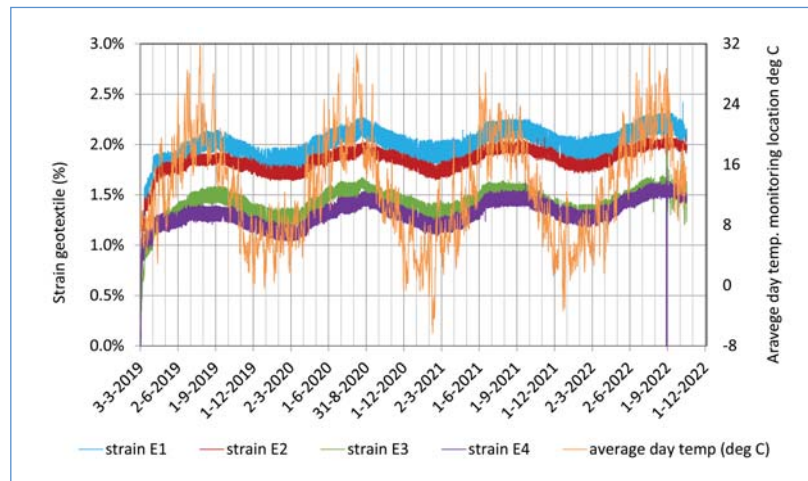


**Figure 4 – Two four-week details of Figure 3; measured geotextile strains and measured groundwater table (a) dry period (no rain) and (b) wet period (several rainy periods).**

**Table 1 – Parameters used for the calculations with the Concentric Arches model\***

Date	2019					2020	2030
	28 Feb	1 Mar	5 Mar	12 Mar	24 Apr	29 Feb	25 Aug
Height fill (m)	0.00	0.30	0.60	1.00	1.51	1.51	1.51
Tensile stiffness geotextile (kN/m)	3200	3200	3200	2961	2722	2544	2426

\*Other input values: centre-to-centre distance piles  $s_x = 2.27$  m,  $s_y = 2.28$  m, square pile caps width  $a = 0.75$  m, unit weight fill  $\gamma = 19$  kN/m<sup>3</sup>, fill friction angle fill  $\phi = 34^\circ$  and  $38^\circ$ , subgrade reaction  $k = 0$  kN/m<sup>3</sup>, traffic load  $p = 0$  kPa and 11.5 kPa (25% of the design load), soil arching reduction coefficient  $K$  is either 1.0 (no soil arching reduction) or 1.58 (soil arching reduction).



**Figure 5 – Comparison measured geotextile strains and the day-average of the air temperature which was measured hourly at the field monitoring location.**

constant and low temperature caused by the rain flattens the daily cycle.

Figure 5 shows that the seasonal cycle of average day temperature clearly correlates with the geotextile strains. The geotextile strains are higher in summer. The thermal expansion of the road surface is too small to play a significant role in this seasonal cycle.

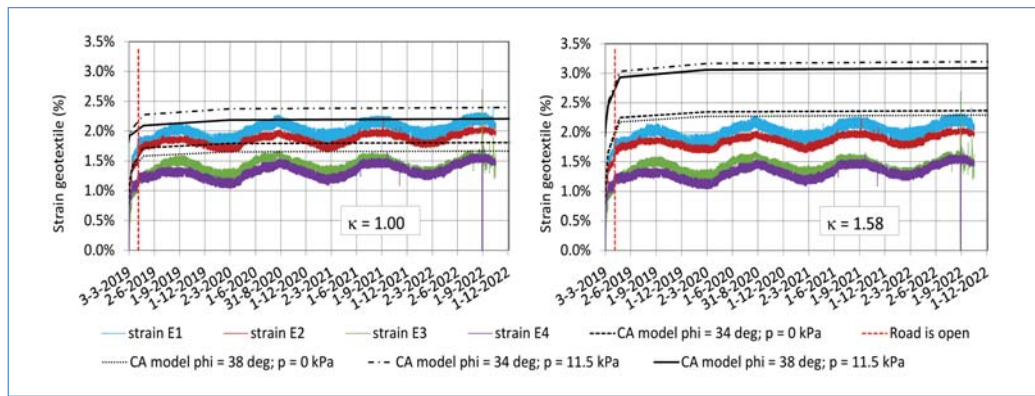
### Calculations with the Concentric Arches model

The geotextile strains were calculated using the CA model (van Eekelen, 2013, 2015, CUR226:2016). No partial factors were used. Table 1 gives

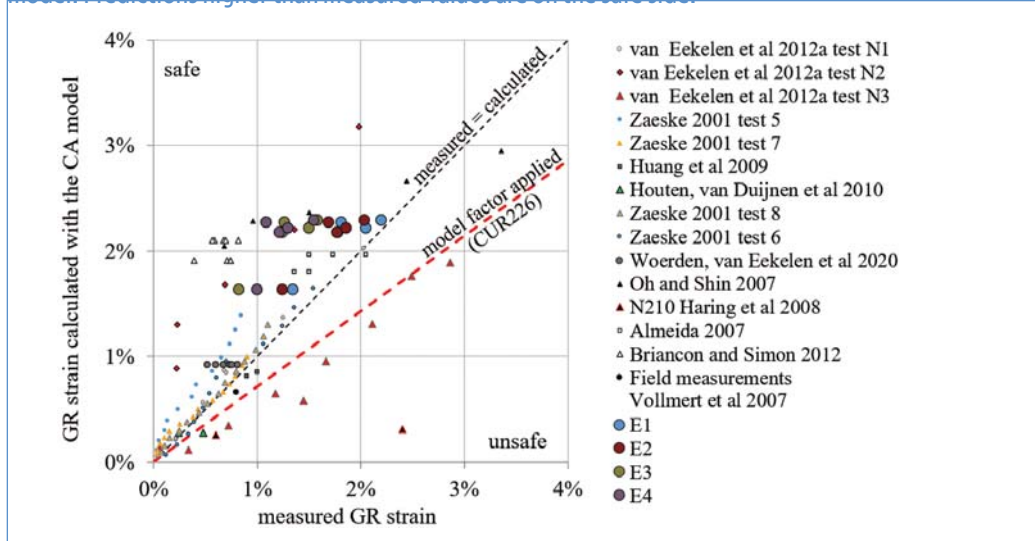
the input parameters. Some remarks:

- Usually, the traffic load is chosen  $p = 0$  kPa when comparing the model results to field measurements. In addition to that, a calculation was performed with 25% of the design load, to account for the permanent influence of the traffic load on the strains in the geotextile.
- CUR226:2016 requests to reduce the soil arching for a relatively thin piled embankment like this one, with a high traffic load. It is assumed that the soil arching is reduced permanently due to the on-going traffic load. The soil arching reduction factor ( $K$ ) equals 1.58 for this configuration and traffic load, following Table





**Figure 6** – Comparison measured geotextile strains and geotextile strains calculated with the CA model. Predictions higher than measured values are on the safe side.



**Figure 7** – Extension of the validation of the CA model with the new data, with in the calculations:  $\varphi = 38^\circ$ , traffic load  $p = 0$  kPa and  $\kappa = 1.58$ . Measured values of E1, E2, E3, E4 are day averages on 12-3 / 24-4 / 1-9-2019 and 29-2 / 1-9-2022. The calculations were done using the input values given in Table 1.

2.3 of CUR226:2016.

- It is expected that the calculation with some traffic load and soil arching reduction matches the real situation best.

### Comparisons measurements and calculations

Figure 6 compares the measured and calculated geotextile strains. The smallest calculated strains agree reasonably well with the average values of E1 - E4. All other calculations give higher values than the measured values, so application of CUR226:2016 leads to a safe design.

Figure 7 extends of the validation of van Eekelen et al. (2015). The figure shows that the measurements of E1 and E2 agree well with the calculations, and the measurements of E3 and E4 give lower values than calculated. This result is on the safe side, too. From this, we may conclude that the CA model, and therefore CUR226:2016, is applicable for this piled embankment of which the embankment was installed partly below the groundwater table. This conclusion is valid for woven geotextiles as applied in this monitoring project.

### Conclusions

A partly submerged geotextile-reinforced piled embankment was monitored. The measured geotextile strains show no correlation with the groundwater level. However, the measured strains have a strong seasonal cycle that match the seasonal cycle in the average day air temperature quite well. This seasonal relationship between the air temperature and the geotextile strains should be further analysed.

The CA model matches the measurements well. The CUR226:2016 design guideline adopted this CA model. Therefore, CUR226:2016 is applicable for this type of geotextile-reinforced piled embankment, which is installed partly below the groundwater table. This conclusion is valid for the woven geotextiles as applied in this monitoring project.

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