Research on Basal Reinforced Piled Embankments, Arching and Load-Deflection Behaviour

S.J.M. van Eekelen, A. Bezuijen and A.F. van Tol

Introduction

The first basal reinforced piled embankment was constructed in the Göta älv valley in South West Sweden in 1972. Britain followed in 1982 and the Netherlands' first was finished in 2002. Since then, hundreds of basal reinforced piled embankments were constructed in many countries, among them at least 50 in the Netherlands.

In the early years of this millennium it was still rather unclear how to design the geosynthetic basal reinforcement (GR). Several design models were available, but their designs differed much; a factor 10 difference in necessary tensile strength was not uncommon!

Several years ago, the Dutch compared the available design models with axial symmetric Plaxis calculations and measurements in two field cases and chose to adopt the calculation method of Zaeske (2001) of the German design guideline EBGEO (2010). After some adaptations and extensions they published the current Dutch guideline CUR 226 (2010).

In the meantime, *Deltares, a Dutch institute for applied research* cooperated with several partners in developing a new design model that describes reality better. A series of specialized scaled model experiments, field measurements and numerical analysis gave the necessary data. Suzanne van Eekelen will receive her PhD for this work in 2015. Together with her daily supervisor and promoter professor Adam Bezuijen and promoter professor Frits van Tol, she received an IGS award *at the IGC10 in Berlin* for this work, described in five journal papers that were published in Geotextiles and Geomembranes (Van Eekelen et al., 2011a, 2012a, b, 2013 and 2014). This paper summarizes the results of this research that focused on the determination of the necessary tensile strength to carry the embankment and traffic weight.

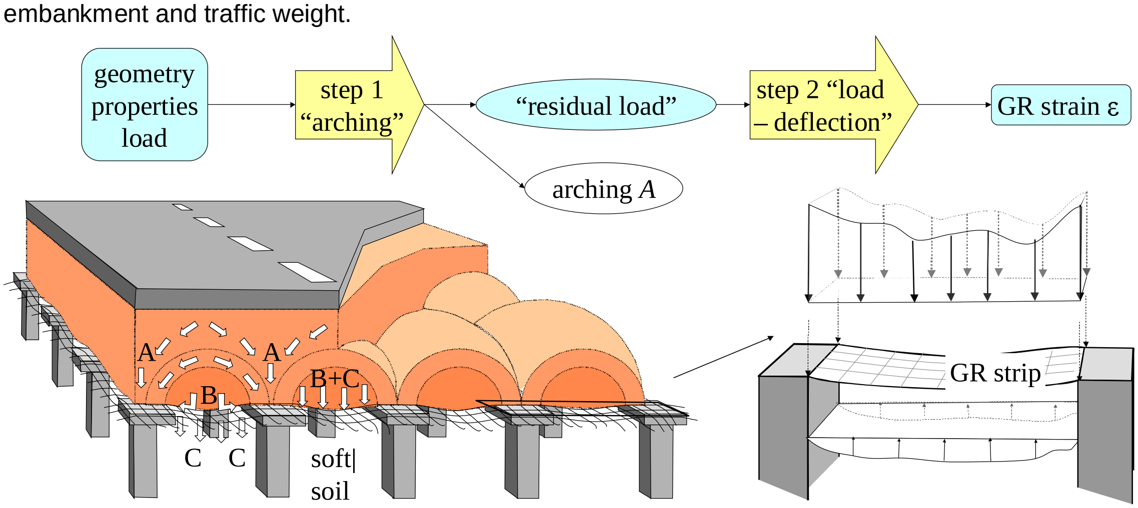


Figure 1. Calculating the geosynthetic reinforcement (GR) strain comprises two calculation steps.

GR design in two steps

A basal reinforced piled embankment consists of a field of piles, with usually pile caps, with on top of that an embankment reinforced with a geosynthetic reinforcement (GR), as shown in Figure 1. Arching occurs within the embankment. This is the mechanism that load is attracted to stiffer elements, in this case the piles. It is due to this arching that the GR and the subsoil *are* not loaded heavily.

In some countries it is quite common to build piled embankments without GR. This is done in for example France, where the subsoil is relatively stiff. Without GR, the load between the piles is more or less uniformly distributed (Figure 2a). Measurements show that the application of a GR concentrates the load on the strips between each pair of adjacent piles, as shown in Figure 2b. Furthermore, the application of GR makes the arching is more efficient; more load is transferred to the piles directly. In the case that no or nearly no subsoil support is available, the load distribution on the GR strips is more or less 'inverse-triangular' *(Van Eekelen et al. (2011b, 2012b, 2014)*. This is discussed more in detail later in this paper.

For the determination of the necessary GR strength, it is needed to determine the GR strain. This is determined in two steps, see Figure 1. The first calculation step divides the load into two parts. One part is transferred directly to the piles ("arching" A in Figure 1), the other part is the "residual load". Load part A is relatively large due to arching. For calculation step 2 only the GR strip between a pair of adjacent piles is considered. This strip is loaded with the residual load of step 1 and possibly also supported by the subsoil between the piles. The following section describes the calculation models for these two steps separately.

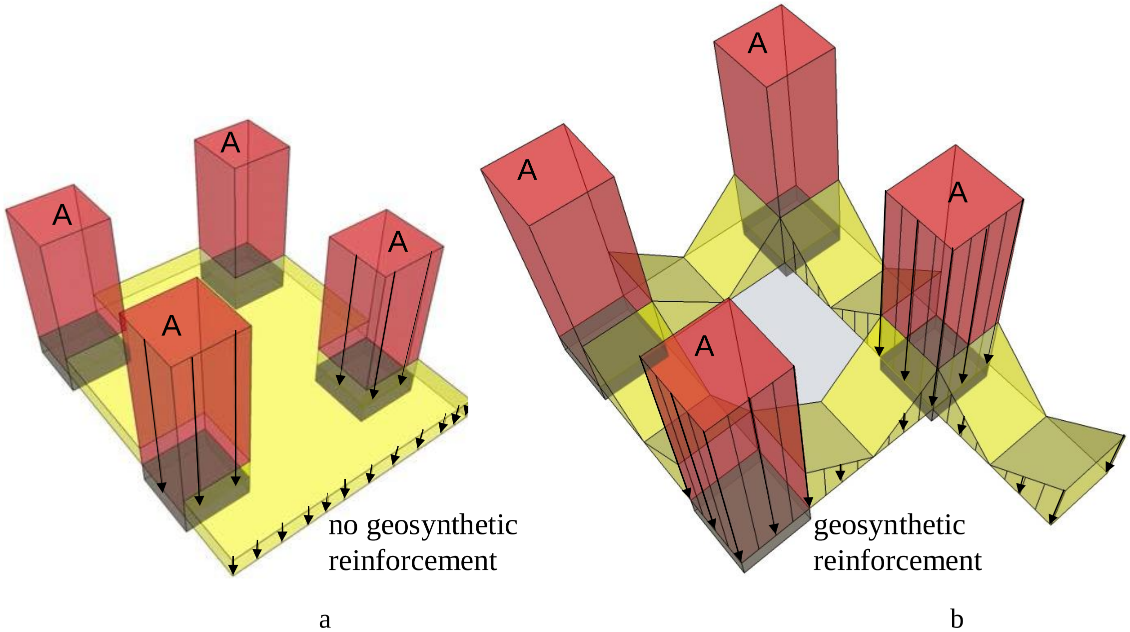


Figure 2. Schematized load distribution over subsoil and piles (a) just above the piles or pile caps in a piled embankment without GR and (b) just above the GR.

Calculation step 1; the arching model

The current CUR226 (2010) and EBGEO (2010) use the model of Zaeske (2001, Figure 3). The load is transported towards the piles along the scales. The vertical pressure in the point indicated in the figure is calculated. It is assumed that this pressure is representative for each location between the piles, resulting in a load distribution as given in Figure 2a. This does not match the load distribution of Figure 2b, which was approximately observed in several measurements and numerical calculations.

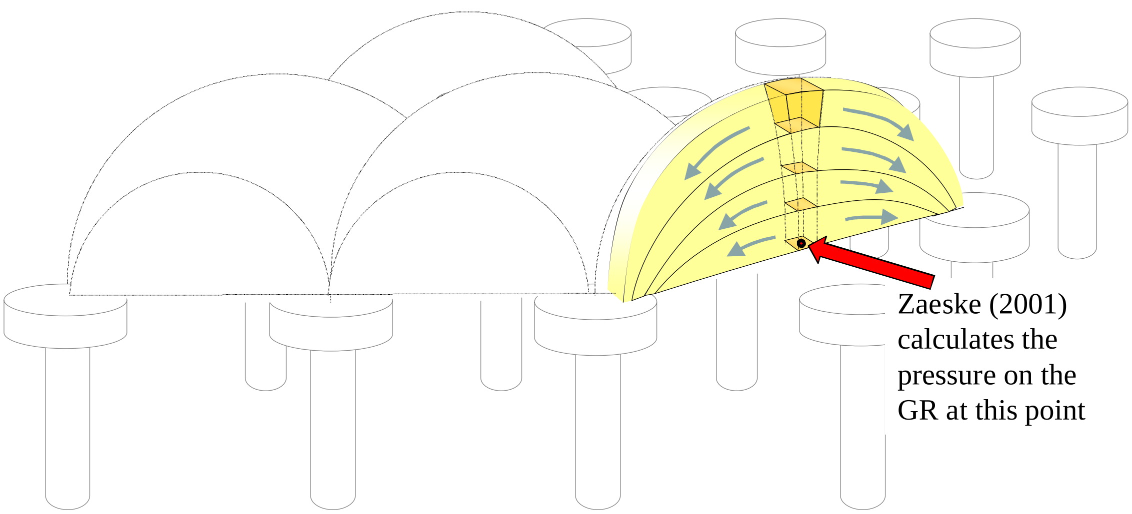


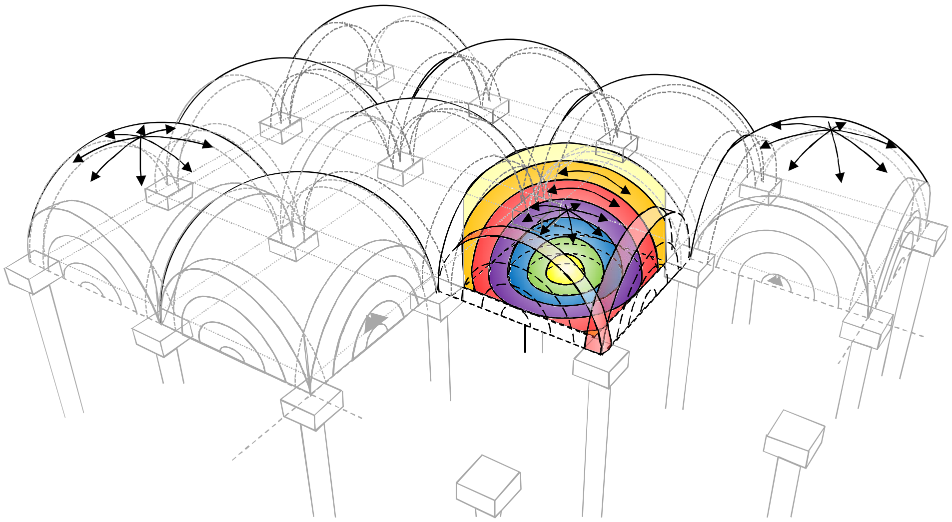
Figure 3. Arching model of Zaeske (2001) that was adopted in EBGEO (2010) and CUR 226 (2010).

Van Eekelen et al. (2013) present a new arching model that more or less gives the load distribution of Figure 2b. This model is called the Concentric Arches (CA) model, see Figure 4. Firstly, the load is transported along the 3D hemispheres (Figure 4a) towards the subsurface or in the direction of the 2D arches of Figure 4b. These 2D arches transport the further towards the subsurface or the piles. Van der Peet and Van Eekelen (2014) show that the results of the new CA model match 3D Plaxis calculations better than the Zaeske model. Tara van der Peet was honoured with the IGS Young Member Session Award for this paper, during the ICG10 conference in Berlin.

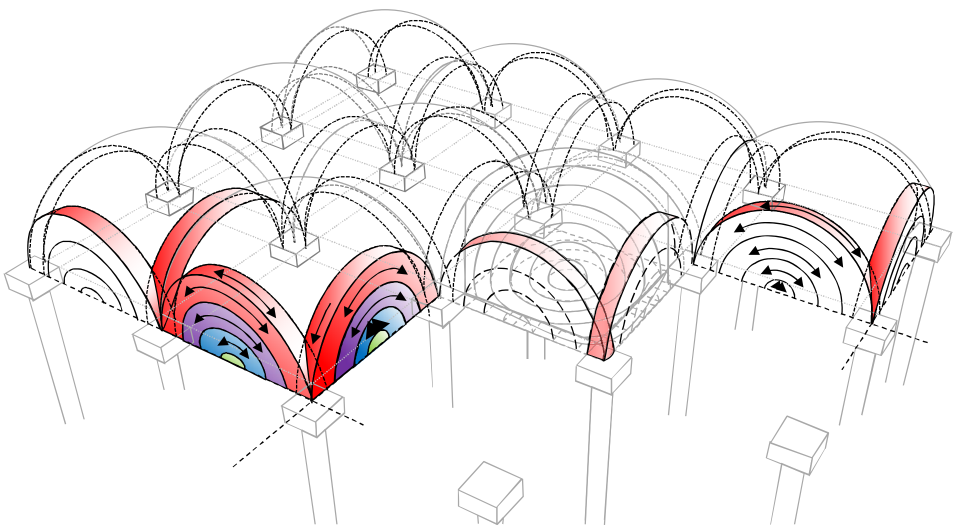
Calculation step 2; load-deflection behaviour

The GR strain is calculated by concentrating the residual load of step 1 on the GR strips between each pair of adjacent piles. It is an issue how this load is distributed on the GR strips. Figure 5 shows three options. The first, the triangular distribution is Zaeske's step 2 (2001) and currently in use in EBGEO (2010) and CUR226 (2010). This is combined with support of the subsoil underneath the GR strip.

Measurements and numerical calculations show that if there is no or nearly no subsoil support, the load distribution approaches the inverse-triangular load distribution of Figure 5c. In the case that the subsoil gives considerable support, the uniform load distribution of Figure 5b is a better approximation. Additionally, it is theoretically better to calculate with all subsoil underneath the GR, not only the subsoil underneath the GR strips. Lodder et al., 2012, elaborated these equations.

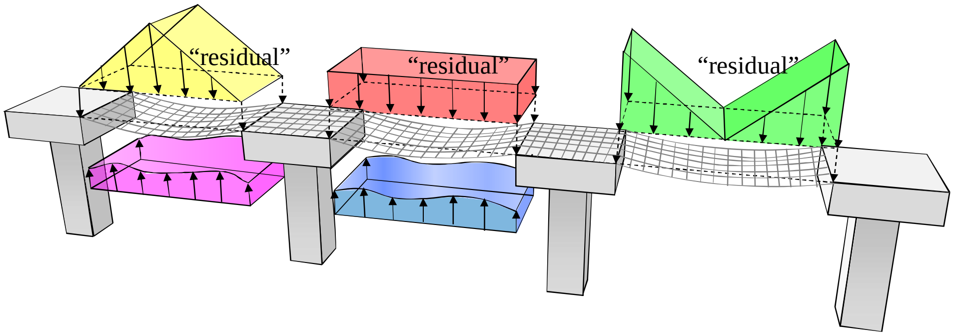


(a)



(b)

Figure 4. The Concentric Arching (CA) model of Van Eekelen et al. (2013); the load is transferred along (a) the 3D hemispheres, partly towards the GR underneath and partly towards the (b) 2D arches, who subsequently transport the load towards the GR underneath or the piles. The new CUR226 (2015) uses this CA model.



(a) (b) (c)

Figure 5, Calculation step 2 (a) current design method with triangular load distribution for the situation with or without subsoil support(b) new design method with uniform load distribution for the situation with subsoil support (c) new design method with inverse triangular load distribution for the situation without or nearly no subsoil support. The new CUR226 (2015) uses (b) and (c), as described in Van Eekelen et al., 2014.

Validation with eleven cases

Van Eekelen et al. (2014) describe seven field cases and four scaled model experiment series, mostly taken from literature. These cases were carried out in Rio de Janeiro, (Almeida et al., 2008), Woerden, the Netherlands (Van Eekelen et al., 2012c), Houten, the Netherlands (Van Duijnen et al., 2010), France (Briancon & Simon, 2012), Finland, (Huang et al., 2009), Krimpenerwaard, Netherlands (Haring et al., 2008), Hamburg, Germany (Weihrauch et al., 2010), Bremerhaven, Germany, (Vollmert et al., 2008), Korea (Oh & Shin., 2007), Kassel Universiteit, Germany (Zaeske, 2001) and Deltares, Netherlands (Van Eekelen et al., 2012a).

Comparison calculations and measurements

Figure 6 compares the measured and calculated GR strains. The results of two calculation models are shown. Figure 6a shows the results for the current models used in EBGEO (2010) and CUR226 (2010). This is the combination of the step 1 – model of Zaeske (2001, Figure 3) and the triangular load distribution of Figure 5a. Figure 6b shows the results of the new model, that has been adopted in the adapted CUR226 (2015). This is a combination of the Concentric Arches (CA) model and the uniform and inverse-triangular load distributions (Figures 5b and 5c).

The dotted lines in Figure 6 indicate the positions in the figures where the measured and calculated values match. The continuous lines give the trend lines through the data. The figure shows that the 'old' model gives GR strains that overestimate the measured strains with 146% on average. The new model overestimates the measurements with only 6% and therefore matches the measurements much better than the old model.

A design guideline should adopt a calculation model that describes reality as good as possible. Therefore, the new model has been adopted in the new CUR226 (2015). Additionally, a set of partial safety factors will be adopted that guarantees that the reliability required in the Eurocode will be satisfied.

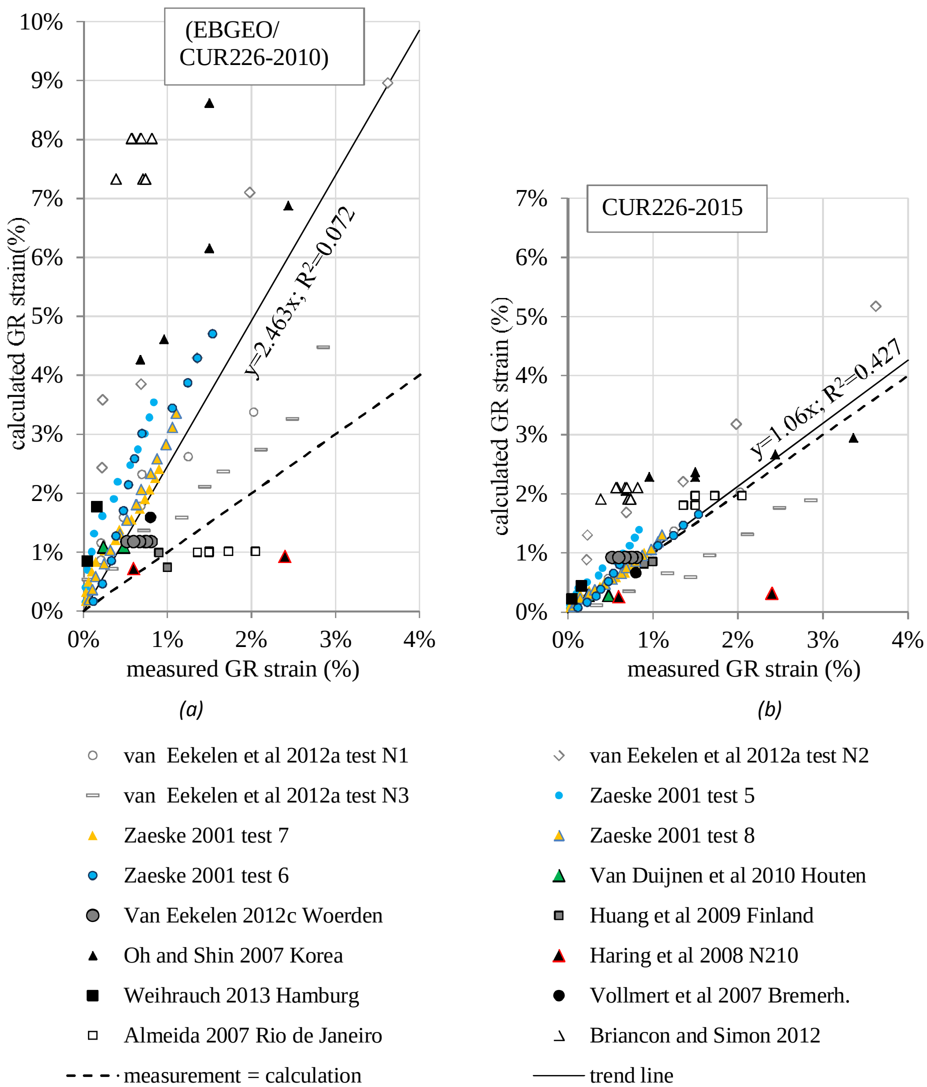


Figure 6. Comparison measured and calculated GR strains. Calculations with: (a) EBGEO (2010) and the old CUR226 (2010) with the arching model of Zaeske (2001, Figure 3), the triangular load distribution (Figure 5a) and subsoil support underneath the GR strips and (b) the new CUR226 (2015) with the Concentric Arches model of Van Eekelen et al. (2013), the uniform or inverse – triangular load distribution (Figure 5b and 5c) and taking into account all subsoil underneath the entire GR between the piles. The calculations were carried using expected values for the parameters.

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