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Validation of analytical models for the design of basal reinforced piled embankments

S.J.M. van Eekelen [a, b, *], A. Bezuijen [c, a], A.F. van Tol [a, b]

[a] Deltares, Unit Geo-Engineering, P.O. Box 177, 2600 MH, Delft, Netherlands
[b] Delft University of Technology, Netherlands
[c] Ghent University, Belgium

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ABSTRACT

Van Eekelen et al. (2012a,b, 2013) have introduced an analytical model for the design of the geosynthetic reinforcement (GR) in a piled embankment. This paper further validates this model with measurements from seven full-scale tests and four series of scaled model experiments. Most of these measurements have been reported earlier in the literature.

The new model describes arching with the “Concentric Arching model” (CA model). This model is an extension of the single arch model of Hewlett and Randolph (1988) and the multi-scale model of Zaeske (2001), which is also described in Kempfert et al. (2004). For load-deflection behaviour, Van Eekelen et al. (2012a,b, 2013) proposed the use of a net load distribution that is inverse triangular instead of uniform or triangular. These authors also proposed the inclusion of all the subsoil support beneath the GR in the calculations.

On the basis of comparisons between the measurements and calculations, it is concluded that the CA model matches the measurements better than the models of Zaeske or Hewlett and Randolph.

Where there is no subsoil support, or almost no subsoil support, the inverse triangular load distribution on the GR strips between adjacent piles gives the best match with the measurements. Cases with subsoil support generally lead to less GR strain. In the cases with significant subsoil support, the load distribution is approximately uniform. In the cases with limited subsoil support, it should be determined which load distribution gives the minimum GR strain to find the best match with the measurements.

1. Introduction

Basal reinforced piled embankments are increasingly popular due to the good performance of these structures, mainly in areas with soft soil. They can be constructed quickly, they do not exert horizontal soil pressure on adjacent sensitive structures and residual settlement is very limited or absent. As a result, they require very limited maintenance. Several design guidelines have been published or updated lately in Europe, including the German EBGEO (2010), the Dutch CUR226 (2010, described in Van Eekelen et al., 2010b), the British BS8006 (2010, described and analysed in Van Eekelen et al., 2011) and the French ASIRI (2012). The CUR226 committee is currently working on an update to bring the CUR226 in line with recent research results. This paper presents a validation study that has been carried out to support the choices made for the update of CUR 226 (2015).

Analytical design models for the design of the basal reinforcement in piled embankments include two calculation steps. The first step calculates the arching behaviour in the fill. This step divides the total vertical load into two parts: load part A, and the ‘residual load’ ($B + C$ in Fig. 1). Load part A, which is also referred to as ‘arching A’, is the part of the load that is transferred to the piles directly.

The second calculation step describes the load-deflection behaviour of the geosynthetic reinforcement (GR, see Fig. 1). In this calculation step, the ‘residual load’ is applied to the GR strip between each pair of adjacent piles and the GR strain is calculated. The GR strip may or may not be supported by the subsoil, depending on the local circumstances.

An implicit result of step 2 is that the ‘residual load’ is divided into a load part B, which passes through the GR to the piles, and a load part C, resting on the subsoil, as indicated in Fig. 1.

* Corresponding author. Deltares, Unit Geo-Engineering, P.O. Box 177, 2600 MH, Delft, Netherlands. Tel.: +31 88 335 72 87.
E-mail address: suzanne.vaneekelen@deltares.nl (S.J.M. van Eekelen).

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Glossary of terms

A, kN/pile Load part transferred directly to the pile (‘arching *A*’ in this paper) expressed as kN/pile = kN/unit cell
a, m Width of square pile cap
a_{eq}, m Equivalent width of circular pile cap
all Support of subsoil underneath *all* GR between the pile caps
B, kN/pile Load part that passes through the geosynthetic reinforcement (GR) to the pile expressed as kN/pile = kN/unit cell
CA Concentric Arches Model (Van Eekelen et al., 2013)
C, kN/pile Load part that is carried by the soft soil between the piles (this soft soil foundation is referred to as the ‘subsoil’ in this paper) expressed as kN/pile = kN/unit cell
c, kPa cohesion
d, m Diameter circular pile (cap)
DEM Discrete Element Method
E, kPa Young's modulus
GR Geosynthetic reinforcement
H, m Height of the fill above the pile or pile cap
inv Inverse triangular load distribution (see Fig. 3c)
J_x, J_y, kN/m Tensile stiffness of the GR parallel to the road axis (*x*) or perpendicular to the road axis (*y*).
k, kN/m^3 Subgrade reaction
MD Machine direction of a GR (the long direction)
p, kN/m^2 Uniformly distributed surcharge on top of the fill (top load)
PET Polyester
PP Polypropylene
PVA Polyvinyl Alcohol
str *Str*ip: support of subsoil underneath the GR *str*ips between adjacent pile caps only
s_x, s_y, m Pile spacing parallel to the road axis (*x*) or perpendicular to the road axis (*y*).
t, m Thickness of a soft soil layer underneath the embankment
tri *Tri*angular load distribution (see Fig. 3a)
uni *Uni*form load distribution (see Fig. 3b)
XMD Direction perpendicular to the machine direction of a GR
Z Multi-scale arching model of Zaeske (2001)
γ, kN/m^3 Fill unit weight
φ Internal friction angle
ψ Dilation angle
600/50, kN/m and kN/m Indicates the strength of geosynthetic reinforcement layer. The first value (600 kN/m in this case) gives the characteristic short-term tensile strength in machine direction (MD) and the second value (50 kN/m in this case) gives the characteristic short-term tensile strength in the direction perpendicular to the machine direction (XMD).

Several analytical models have been proposed in the literature to calculate the first calculation step, the arching. They are listed and explained in Van Eekelen et al. (2013). They include frictional models, rigid arch models, models using mechanical elements and limit equilibrium models. The frictional models, which are based on Terzaghi (1943), include McKelvey (1994), Russell and Pierpoint (1997), McGuire et al. (2012), Naughton (2007) and Britton and Naughton (2008) and the model of Marston and Anderson (1913), which was modified by Jones et al. (1990) and adopted in the British Standard BS8006 (2010). The rigid arch models include Scandinavian models such as Carlsson (1987), Rogbeck et al. (1998, modified by Van Eekelen et al., 2003), Svanø et al. (2000), the enhanced arch model described in, for example, Collin (2004), the design method of the Public Work Research Center in Japan (2000, discussed in Eskişar et al., 2012). The models that consider the behaviour of the separate mechanical elements and match their boundaries are described in, for example, Filz et al. (2012), Deb (2010), Deb and Mohapatra (2013) and Zhang et al. (2012). The present paper focuses on the last family of arching models: limit equilibrium models. The following section describes these models.

Several approaches for the second calculation step have also been presented in the literature. The German approach (adopted in EBGEO, 2010; CUR 226, 2010), including some variations, is described in the following section. An approach using finite differences and minimisation of the total energy has been presented

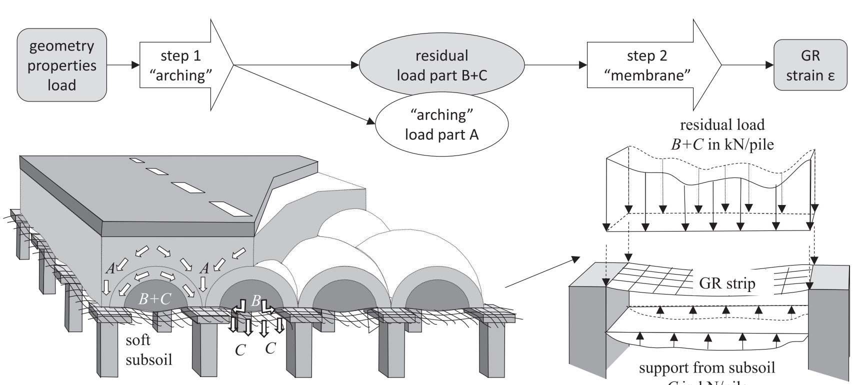

Fig. 1. Calculating the geosynthetic reinforcement (GR) strain comprises two calculation steps.

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