Evaluation of triangular pile arrangement through a numerical study of the light embankment piling method

Evaluation d'agencements triangulaires de pieux par une étude numérique de la méthode légère de fondation par remblai sur pieux

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ABSTRACT: Embankment piling is a widely used foundation method in geotechnical engineering and the design is mostly based on empirical studies found on experimental or field evidents. Several studies have been conducted to capture the behaviour of embankment piles by means of numerical models. One of the issues is to simulate the arching effect between the piles. This has raised the question of the optimum pile arrangement. Along the northern coast of Sweden, where soft soil types and dense woodlands are common, timber piles have often been used in piled road and railway embankments. The pile group is designed as a semi-floating deep foundation in soft soil, where the piles are resting on top of the locally common firm glacial till bottom layer, naming the method light embankment piling. The Swedish design guidelines recently changed from a square to a triangular pile arrangement. However, the motivation of the changed lacked research which raised the question of optimal pile arrangement and centre-to-centre pile distance. This project aims to optimise the light embankment piling method through numerical analysis, verified by field and laboratory experiments. The optimisation will mainly focus on pile arrangement and centre-to-centre pile distance.

1 INTRODUCTION

Piled embankments with a basal reinforcement are widely used as a foundation method for road and railways on soft soils. The foundation method, known as geogrid-reinforced pile-supported embankments (GRPS), has a short construction time and creates efficient reduction of both vertical and horizontal displacements. The load transformation onto the piles (through arching in between the piles) and subsoil is complex and many studies have discussed the load transfer mechanism and how it could be optimised in design.

Currently there is an uncertainty in the Swedish industry concerning the optimum design of GRPS with timber piles, also called the light embankment piling method. The method is currently used for mainly sulphide soils with timber piles as its key feature and is classified purely in reducing settlement while stability increase is not taken into account.

The light embankment pile group considered here contain appr. 9000 piles per kilometre road for a two-lane road (13m wide), with the interest in the possibility of reducing the amount of piles. Main concern is whether the piles should be installed in a square or a triangular arrangement. The current Swedish design guideline for light embankment piling, TK Geo 13 (Trafikverket 2014), states that a triangular pile arrangement should be used as shorter diagonal distance between the piles yields more stable arches. There is however a lack of research supporting this statement, and the question also involves the optimum centre-to-centre distance (ctc-distance) of the piles. The maximum allowed ctc-distance of 1.2m is thought to be too narrow for the geogrid reinforcement (GR) to have any cost efficiency.

2 THE LIGHT EMBANKMENT PILING METHOD

Sulphide soil, more commonly known as acid sulphate soil, is an alluvial soil type formed during the last 10 000 years through sedimentation in anaerobe environments and a supply of sulphates. The soil type most ranges from clay to silt and can be found worldwide in coastal floodplains and inter-tidal swamps (Dent 1986). Sulphide soil can be found all along the Swedish northern coast as a result of the land rise following the withdrawal of the ice cap after the last ice age. The soil is characterised by its high content of pyrite and iron sulphides, which results in a black colour. When oxidised, iron ion solutions and sulphuric acid are leached, lowering the pH of nearby water bodies and makes the use of cement or steel based piles in the soil problematic.

In the early 1990's the long used method of timber piled embankments had an upswing as a competitive measure of reducing settlements along the northern coast of Sweden. A simple and cheap foundation method was needed to counter the high compressibility of the sulphide soil. Timber piled embankments proved to be the most sustainable foundation method for roads and railways in the area; the sulphide soil is environmentally hazardous to excavate and the large coastal woodlands provides a renewable resource of timber.

2.1 *Development of a standardised method*

The two main actors that have been involved in the development of the design criteria for the light embankment method are the Swedish Transport Administration (Trafikverket) and the Swedish Geotechnical Institute (SGI).

Trafikverket is responsible for the overall long-term infrastructure planning of road, rail, sea and air transport in Sweden. The administrations assignment also includes the construction, operation and maintenance of state roads and railways. Previous experience at Trafikverket has shown that the method of timber piled road and railway embankments has been carried out successfully throughout the years. With the thin end installed downwards, the natural conical shape of timber piles creates an additional upwards component of the normal force acting on the shaft in opposite to standard piles in concrete or steel.

Trafikverket implemented the light embankment piling method into TK Geo 13 (Trafikverket 2014) in 2014 with the intention of making it an accepted reinforcement method in Sweden. Earlier designs of the light embankment method were based on a combination of empirics and experience as well as criteria for related foundation methods. The implementation was performed through an assessment of the previous experience together with supplementary numerical simulations. The numerical simulations were at this stage restricted to 2D and rather simplified and used to raise knowledge and verify the experience and follow-up monitoring of projects carried out since the 1990's.

SGI, a governmentally directed expert authority with research on safe, efficient and sustainable foundation engineering, developed in the 1990's the analytical model used when designing GRPS for Swedish roads and railways. An updated version of the simplified method can be found in Rogbeck et al. (2005). The model is based on arching in between the piles, assuming the cross section area of the soil beneath the arch as a wedge with 30° top angle. The weight of the wedge is transferred onto the piles through the GR, assuming no load on the subsoil.

2.2 *The non-traditional design criteria*

Timber need to be kept in an anaerobe environment to avoid rotting. An anaerobe zone is created around the pile group by the saturated subsoil and a 10 cm layer of high capillarity soil placed on top of the pile heads, following TK Geo 13 (Trafikverket 2014). Further, the embankment is reinforced with two layers of GR spaced 20cm apart, with the lower layer 20cm above the fine grained soil. It is assumed that the two layers of GR interlock the soil particles. Horizontal stresses are thought to be built-in during compaction of the embankment, causing the lower part of the embankment to act like a beam resting on top of the timber piles. This beam effect maintains the arches in between the piles without the need of pile caps, whilst keeping the risk of punching failure low.

To avoid breaking the timber piles during installation, the piles are either driven with a low practical refusal blow count limit or pushed down if possible to a known firmer soil layer (most often glacial till, SGI 2015). The firm soil layer should allow for some settlements to mobilise skin friction and to yield relatively low toe resistance. In Swedish design guidelines this construction technique is called light embankment piling.

3 STATE OF THE ART

The model by Hewlett and Randolph (1988), the Zaeske (2001) model and the Concentric Arches (CA) model by Van Eekelen (2015) are analytical methods for determining the 3D arching in a piled embankment, focusing on a square pile arrangement. Zhang et al. (2016) developed a 3D arch model for equilateral triangular arrangements on the basis of the Hewlett and Randolph (1988) model. In the thesis by Van Eekelen (2015) the load components are divided into the load transferred directly onto the piles through the arches, and the load beneath the arches acting on the GR and subsoil. The load carried by the GR is transferred onto the piles at each end of the span, and the rest is carried by the subsoil. Through arching the load onto the subsoil is reduced in comparison to no arches forming.

Numerical analyses of GRPS have been performed increasingly in last years. Van Eekelen (2015) used finite element (FE) simulations to verify the shape of the arches assumed in the CA model. Lai et al. (2014) evaluated the effects of geosynthetic reinforcement in pile-supported embankments through discrete element simulations. Both studies proved that it is possible to clearly visualise the formation of the arches with numerical simulations. Lai et al. (2014) also found that the GR greatly improves the efficiency of load transfer and enhances the stability of soil arching.

Bhasi and Rajagopal (2015) observed in their numerical study that the arching effect is not instantaneous and that the arches are fully developed during the consolidation process after final construction. The arches formed were distinctly visible by analysing the vectors of the major principal stresses; as was also noticed in the work by Van Eekelen (2015).

Esmaeili and Khajehei (2016) evaluated the use of triangular pile arrangements as a viable option to square pile arrangements, studying deep mixed columns in loose subsoils. The results from their small-scale experiment indicate that the two arrangements give similar embankment support in terms of tolerated vertical load and settlement reduction.

4 AIM OF THE RESEARCH PROJECT

The current knowledge of the light embankment piling method, and GRPS in general, lacks extensive comparisons of square and triangular pile arrangements. The mentioned study by Esmaeili and Khajehei (2016) is to the authors' knowledge the only study which compares square and triangular pile arrangements. However, no study was found with focus on the use of timber piles with their particular natural conical shape in soft soils and the influence of the shape on the optimal pile spacing.

The aim of the project is to raise more knowledge about lightly piled embankments and create a Swedish national guide for an optimal design for different conditions that involves road or railway embankments on soft subsoil. The main focus is on Swedish conditions with soft clay or silt layers on glacial till. A theoretical analysis of the construction based on 2D and 3D FE modelling, verified by field and laboratory experiments, is to be performed, in order to optimise the light embankment piling method. The optimisation will focus on pile arrangement and ctc-distance by studying formation of arches, development of settlements and resource efficiency.

5 ACKNOWLEDGEMENTS

This study has been supported by the Swedish transport administration (Trafikverket), the Swedish joint research program for road and railway geotechnology Bransch-samverkan i grunden (BIG) and LTU. The authors would like to express their gratitude for the financial support.

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