Settlement free embankments with AuGeo-piling system

Ing. N.G. Cortlever, Cofra b.v. Amsterdam

INTRODUCTION

Fast realisation of maintenance free infrastructure on very compressible soil needs new techniques that can be applied economical and at large scale. The research project NO-RECESS, set up by DWW (Dutch Road Authorities) and HSL (High Speed Train) gave the possibility to test new soil improvement techniques in a test field in 's Gravendeel.

At Test Embankment 5 (HW5), the last one of a series of test embankments, Cofra has together with Vermeer Infrastructure made a design of a piled embankment, whereby a geogrid was used to transfer the load of the embankment to the piles.

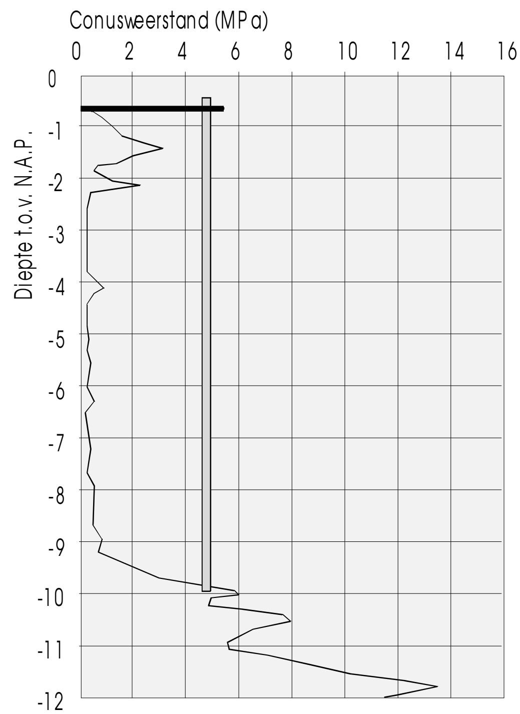
AUGEO

AuGeo is a piling system that is characterised by relative light pile that are provided with an enlarged point and a pile cap. The piles are pushed in the soil on very close distances by a so-called drain stitcher, which is adapted to push piles in the soil at high speed and force. In contrast with a regular pile foundation, where it is important that there will no settlements in the piles at all, small settlements of the AuGeo piles are not harmful to the spread of forces in the embankment and the geogrids. At Test field HW5 an AuGeo piling system, consisting of PVC-tubes filled with foam concrete, is proposed. Foam concrete piles were already successfully tested at several occasions. The PVC casing was used for manufacturing purposes and also to give the pile a certain bending resistance.

CALCULATION OF THE PILINGSYSTEM

The bearing capacity of an AuGeo pile is determined by the installation rig. Cofra uses a stitcher with a maximum pushing force of 250 kN. Because of the high installation speed the friction force can be neglected. The foot plate of the AuGeo pile has an area of 0.04 m². At layers with a cone resistance of 6 MPa, the rig will reach its maximum installation force. Based on the CPT made at the location of the test embankment, such a layer can be expected at a depth of 9 meter under the surface. Difference in the depth of the sand layer will not affect the bearing capacity of the pile due to the installation method. To avoid punching of the sand layer a safety factor of 3 is applied. The maximum bearing capacity of the pile is 85 kN.

Test embankment HW5 consists of a 20 meter long section with a height of 1m, a transition area with a length of 40 m where the level rises from 1 to 5 meter, and a 20 meter long area of 5 m high. The width of the test embankment is 10 m at the top. Based on load factors of 1.3 to 1.5 and fill material with a weight of 20 kN/m², a foundation with a weight of 19 kN/m² and a traffic load of 35 kN/m² the following pile loads are calculated.



Height embankment (m)	Weight embankment (kN/m²)	Pile distance (m²)	Pile Load (kN)
1	83	1	83
1-3	106	0,9	86
3-5	125	0,8	80

The AuGeo-piles consist of a PVC-tube with a diameter of 160 mm and a wall thickness of 2 mm filled with foam concrete.

Material properties of foam concrete are:

- Mass mixture 1200 kg/m³
- Dry mass 938 kg/m³

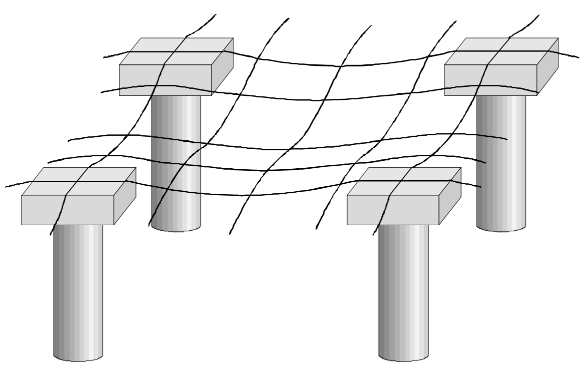
- 350 kg CEM III/B 42,5 LH HS, 400 kg powder carbon flyash100 kg paper ash, 340 kg water and 31,6% (V/V) foam.
- E-modulus E_s is 8000 MPa after 91 days
- Compression strength foam concrete is 12 MPa after 91 days
- Bending strength foam concrete is 2 MPa after 91 days
- Compression strength for calculations is 50 % of the cubicle strength, or f'_s = 5 MPa
- Bending strength for calculations is 70% of the average bending strength, or f_{bs} is 1,12 MPa

Material properties PVC:
- Elasticity modulus E_p = 3000 MPa
- Bending strength f_p is 50 Mpa

Load on the piles
- Normative pile load ($F_{r,d}$) is 86 kN

Compression and bending strength
The axial stiffness is determined by EA:
- for casing: $A = \pi/4 * (160^2 – 156^2) = 993\ mm^2$; EA = 2,98 MN
- for foam concrete: EA = 1152.9 MN

This means that the core of foam concrete takes 98,5% of the total axial load. With compression strength of 5 MPa the pile has a maximum bearing capacity of 97kN. Taking the maximum allowable point load of 86 kN in consideration the pile fulfils its task.



The lateral stiffness is determined by the bending resistance of the pile and the bedding stiffness of the soil. The wet mass of the soil is assumed to be 14 kN/m³, the cohesion is equal to zero and a friction angle of 15 degrees. At small displacements (mm) the soil has a spring resistance of 20 kPa and at large displacements (dm) it is 100 kPa. Kinking is not normative at foundation piles because the soil is generation an increasing supporting force when the pile is bending. It is relevant to determine which moments the pile can handle and which head displacements can occur without failing.

The bending stiffness (EI) of the core is 96% of the total bending stiffness; this means that the core will crack at a moment of 776 Nm. At a moment of 1937 Nm the casing will fail as well.
If the pile head is lateral loaded, the core will fail at a displacement of 20 mm, while the casing fails at a displacement of about 250 mm. These calculations show that the AuGeo pile with PVC casing acts sufficiently tough, so lateral displacements are allowed without failure.

CALCULATION OF THE GEOGRID

The geogrid is dimensioned based on the directives of assessments mentioned in the British Standard BS8006 "Code of practice for strengthened/reinforced soils and other fills" and calculation methods developed by Hewlett & Randolph and Hans-Georg Kempfert. The design is based of the following parameters:

life	120 year
pile distance (triangular)	1 – 0,9 – 0,8 m
cross-section pile cap	300 mm
height embankment	1, 3, 5 m
mass fill	20 kN/m^3
dead load	18 kN/m^2
life load	35 kN/m²

Two layers of Geogrid are placed crosswise. The first layer was placed in the length direction the second in cross-direction of the embankment. The calculations show that at higher embankments the required rupture strength of the geogrids is decreasing. The tighter pile distance causes this while the loading force is constant. On top of that there is an increasing arching effect in the fill material. The reduction factors for reinforced piled embankments as the German authorities establish them, are as follows:

- test data 1.0
- installation damage 1.2
- creep 1.7
- chemical attack 1.0
- safety 2.0
- dynamic load 1.0

The results of the calculations are given in following table

Height fill (m)	Pile distance (m)	Pile cap (m)	Tension (kN/m)
1	1	0,3	320,4
3	0,9	0,3	239,6
5	0,8	0,3	199,9

INSTALLATION AUGEO PILES

The AuGeo piles are installed from a working platform. A Cofra MY-200 stitcher pushes a square steel tube with the dimensions of 200*200*10 mm, in the soil. The tube is at the bottom capped with a 5 mm thick steel plate that closes of the tube and acts as an enlarged pile point. The plate stays behind in the soil. Insertion of the tube is done with a constant speed so disturbance of the soil will stay at a minimum. When the tube experiences a resistance of 250-300 kN the installation comes to a halt and a PVC tube 160*2 mm is placed in the steel tube.
The foam concrete is pumped from a mobile mixing unit via rubber hoses to the temporary storage bin at the rig. 200 litre foam concrete is pumped in the PVC tube. This amount is equal to the content of 10 m PVC tube. Because of compression of the air in the concrete at greater depth the mass of the concrete will increase. The steel tube is retracted and the PVC tube is cut off at the desired level and if necessary refilled to the top. A concrete pile cap 300*300*16 mm is placed on the top.
During installation two different working methods are applied. Besides the above-mentioned method, which asks for a very strict co-ordination between the production of the foam concrete and the installation speed, also a system is applied whereby the PVC tubes are temporary filled with water. The water is pumped out after a few days and replaced by foam concrete. Disadvantage of this system is the chance of collapsing of the PVC tube during pumping when the internal pressure disappears.
When the co-ordination is optimal a production of 20 piles per hour is feasible. Streamlining of the installation system can increase the production to even higher values.

QUALITY CONTROL

During the installation of the AuGeo-piles care is taken to control the following parts.

- Position of the rig
- Logging of the data
- Check continuation of the pile
- Quality control properties of the concrete

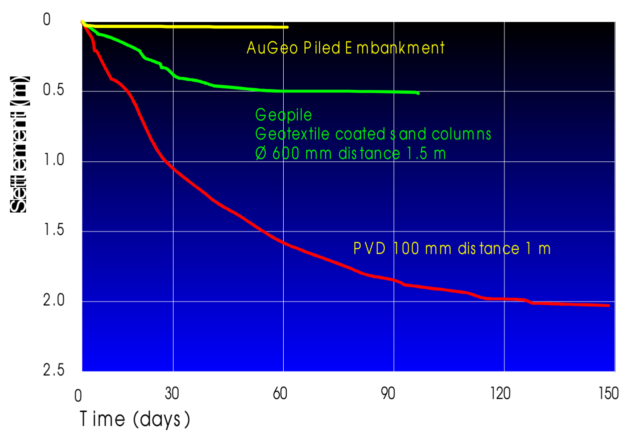
Before starting of the installation the verticality of the rig is assured and if necessary adjusted. During insertion the following data is automatically logged:

- Position of the pile (with DGPS) by 300 mm
- Soil resistance (interval 250 mm)
- Maximum installation depth and resistance
- The total amount of installed piles
- The date and time

When the pile is installed, the continuity of the pile is checked with a sounding device. This is especially important at a close pile spacing, when a newly installed pile can influence the quality of the already installed piles.
To assure the quality of the foam concrete, samples are taken which are tested on compression strength in the laboratory after 28 and 90 days. On top of that the cut off top sections of some piles are tested whereby compression strengths varying from 230 kN to 250 kN are measured.
At the border of the embankment six piles are placed to test the maximum loading capacity of the piles in situ.

CONCLUSION

Construction of the test embankment HW5 is finalised in June 1999 and will be pulled down again in October 2000 to inspect the geogrid and pile caps.



Settlements HW1, HW4 and HW5

The settlements are well within the maximum allowable values. In June 2000 dynamic tests were executed with the DyStaFit method. These tests showed that the construction was suitable for trains with maximum speeds up to 350 km/h.
The costs of an AuGeo piling system are considerable higher than the traditional way of construction of embankments with vertical drains.
There are however a number of advantages that can influence the price considerable.

- less fill material
- shorter construction time
- no consolidation period
- less area required
- less maintenance
- less load on piles of bridge approaches