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Widening of Road N247 founded on a geogrid reinforced mattress on piles

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ABSTRACT: To stimulate the use of public transport, the authorities of a province in the North of The Netherlands have decided to broaden the N247 Road with a separate bus lane. The construction of the bus lane will be made over a length of 4.2 km and will have to be realised within the existing Province ownership boundaries. From several considered design possibilities the one on a soft foundation, consisting of a geogrid reinforced soil mattress on piles was found to be the most suitable. The design included an extensive research in design methods for these types of constructions. After the comparison of the analyses with different theoretical models the Jenner/Guido principle was used for the preliminary design. The final design was done using PLAXIS. The design was tested for a period of two months on a 200 m long field trial section. During the test period all traffic has been lead through the trial section. The design has been evaluated and proved to be satisfactory for the rest of the road-widening

1 INTRODUCTION

To stimulate the use of public transport, the authorities of the province 'Noord-Holland' in the Netherlands have decided to widen the N247 Road with a separate bus lane. The bus lane will be constructed over a length of 4.2 km. The bus lane had to be constructed within the existing Province ownership boundaries. The Province ownership boundaries are marked by a waterway at only several metres distance from the existing road (see fig. 1).

figure1 Local situation

The boundary conditions set by the client were the following:

realisation of a bus lane within the current ownership boundaries;

only a short available time for construction of the bus lane;

future maintenance costs for the bus lane should be as low as possible;

the construction should meet all (safety) requirements with respect to settlements and stability.

As the subsoil at the bus lane location consists of 7 metres of soft soil (peat and clays), a construction based on conventional methods was not deemed possible because of limitations in time and space. A feasibility study has been carried out into a number of construction methods, which met the aforementioned requirements. The following alternatives were chosen for further development:

a steel sheet pile wall, possibly anchored by grout anchors;

a foundation of the road using lime cement columns (ground improvement);

a flexible foundation with a geogrid reinforced soil mattress on piles.

After a thorough feasibility study, which included technical design and risk assessment of the three types of construction, the reinforced soil mattress turned out to be most feasible both economically and technically.

2. PRINCIPLE OF THE CONSTRUCTION

The principle of the geogrid reinforced soil mattress on piles is the load redistribution of the fill over a number of piles. Due to the arching effect within the fill material, a large proportion of the load caused by the fill is not placed on the weak soil layers, but transferred to deeper, stiffer soil layers by the piles. The arching effect within the fill material is enhanced by the geogrids, which improve the fill properties. The geogrids are placed in several layers over the piles. To prevent the piles from punching through the soil mattress and to reduce the spans of the geogrids between the piles, pile caps are applied. The surcharge, consisting of the weight of the road foundation and traffic loading, is carried by the piles through the reinforced soil mattress.

3. DESIGN OF THE CONSTRUCTION

The design-process of the construction can be divided into a number of steps, which are:

assessment of the arching effects within the planned soil mattress;

analytical design (analytical engineering calculations of a/o. pile capacity, settlements and stability);

verification of deformations and overall behaviour of the construction using finite element modelling.

3.1 *Assessment of arching effects*

The first and most important step in the design process is the assessment of the amount of arching that will take place within the planned construction. The arching effect mainly depends on the amount of geogrids and spacing of the geogrids, configuration of the piles and size of the pile caps. A second very important factor of influence on the arching effect is the properties of the fill material and interaction of the fill material with the geogrids. A number of analytical models are available in literature, which model the arching effect. To compare the effectiveness of arching according to the different models, two parameters have been defined. The pile-efficacy (E_P), which is defined as the proportion of embankment weight carried by the piles (Hewlett and Randolph, 1988):

$$E_P = \frac{F_{s;pile}}{F_{s;tot}} \qquad (1)$$

And the stress reduction ratio (S_{3D}), which is defined as the ratio of the average vertical stress carried by the reinforcement to the average vertical stress due to the embankment fill (Russell and Pierpoint, 1997):

$$S_{3D} = \frac{\sigma'_{v;g}}{\sigma'_{v;t}} \tag{2}$$

The following models available from literature were analysed:

3.1.1 *Terzaghi (1943)*

Terzaghi's model (1943) has been derived for a plane strain semi infinite sand mass (2D). The method of analysis of the arching effect is based on the redistribution of stress on a stationary soil mass (soil mass above piles), by a soil mass, which is subsiding. The stress-redistribution is caused by a shear stress between the stationary mass of soil and the subsiding soil mass.

3.1.2 *Hewlett and Randolph (1988)*

Hewlett and Randolph concluded from lab experiments, that the top of the arch between piles in a square configuration should be more or less spherically shaped. Analysis of the arching effect consists of an assessment of limiting equilibrium of the soil stresses in the arches. Boundary conditions for the limiting equilibrium have to be met either at the top of the arch of at the pile caps.

3.1.3 *British Standards 8006*

British Standards 8006 propose a method, with which complete modelling of the reinforced soil mattress on piles can be carried out. Assessment of the arching effect of the fill material is mainly based on Marston's formulas for passively loaded subsurface conduits.

3.1.4 *Guido*

Guido's method has been developed by Bush (1991) and Jenner (1996). The model is mainly empirical and is based on a number of plate loading tests, which were carried out by Guido (Guido et al., 1987). The main assumption, which lies at the basis of this method is, that the situation of Guido's plate loading tests (footing on soil reinforced with geogrids) can be inverted by 180 degrees.

3.1.5 *Comparison of design methods*

Using the methods mentioned above, the proportion of load that is transferred directly to the pile caps by arching and the proportion of the load which will be carried by the soft subsoil

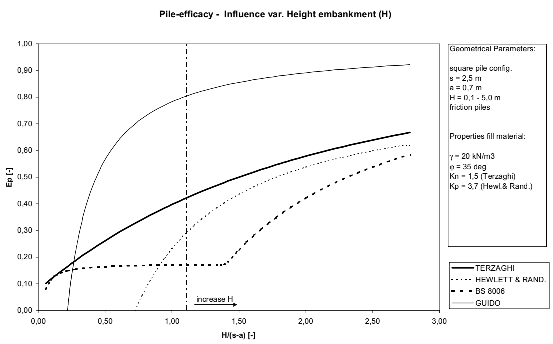

figure 2 Comparison of design methods

can be determined. By comparing the methods in terms of pile-efficacy and stress reduction ratio, a comparison can be made between the analytical methods. A study has been carried out in which a number of parameters, including height of the embankment (H), distance between the piles (s) and size of the pile caps (a), were varied. An example of the results of the comparisons is shown in figure 2. The figure shows the effect of varying the height of the embankment. It can be seen, that the five methods yield very different results with respect to stress reduction at foundation level (level of pile caps) due to arching.

In general BS8006 and Hewlett and Randolph yield conservative results. Terzaghi and Guido yield more positive results. The relevant design requirements per method and limitations of the different design methods are listed in table 1.

Design method	Design requirements	Limitations
Terzaghi	none given	3D-effects are not taken into account; only applicable for embankment on single grid layer; variation of K in embankment is not constant.
Hewlett & Randolph	none given	only applicable for embankment on single grid layer; design method only applicable for cohesionless material
BS 8006	height (H) embankment >t 0,7(s-a); max. initial strain in grids allowed of 6% max. strain during design lifetime of (additional) 2% no large settlements of piles allowed	only applicable for embankment on single grid layer; properties of fill material are not taken into account.
Guido	geogrid and fill material should be chosen such that interaction is optimal; for optimal performance three grid-layers are required.	method is only applicable for Tensar-geogrids.

table 1 Design requirements and limitations of the various design methods

Choice of the design method has a considerable impact on the design loads on the geogrids, the number of required layers of geogrids, spacing and configuration of the piles and size of the pilecaps. After an extensive parameter study, in which all methods were applied, it was found that Guido's method was the method, which was most apt to model the reinforced mattress for the N247 case.

3.2 *Analytical design*

Prior to designing the geogrid reinforced soil mattress for the N247 Bus lane, a number of requirements were defined in co-operation with the client. The requirements that had to be met by the construction are listed below:

1. settlements after construction should be less than 0.1 m;
2. differential settlements should be less than 0.02 m;
3. factor of safety against instability of the construction should be larger than 1,3;
4. soil parameters should be determined in accordance with Dutch standards (NEN 6740);

5. design parameters for loads on the construction should be determined in accordance with Dutch standards (NEN 6702).

Using the Guido method a preliminary design of the construction was carried out. By changing the configuration of piles, size of the pile caps and levels of the geogrids, the 'desired' distribution of loads between piles and subsoil was determined. The layout that was found using the method described above, consisted of a triangular pile configuration with a spacing of 2.5 m distance. The soil mattress consists of three layers of Tensar SS30 grids. As fill material granulate was chosen, with a grain diameter that would interact optimally with the grids.

Parameter		Value
Configuration of piles	[-]	triangular (60°)
Pile-distance (s)	[m]	2,5
Size pile-caps (a)	[m]	0,7*0,7 (square)
Height embankment (H)	[m]	1,55
Pile size	[m]	0,29*0,29 (square)
Number and types of Geogrids	[-]	3 layers Tensar SS30
Distance between bottom Geogrid and pile caps	[m]	0,10
Distance between individual grid layers	[m]	0,25

table 2 final design configuration

Based on the required pile and geogrid configuration and the required size of the pile caps, the construction was further designed, using analytical methods. Analytical methods included pile capacity, settlement and stability calculations according to a number of Dutch standards. The analytical design resulted in a complete design, which fully met the requirements as posed by the client. A summary of the design is given in the table 2 and figure 3:

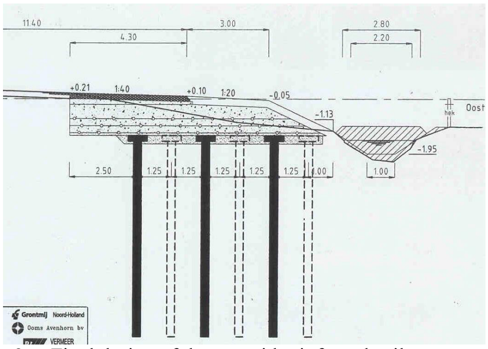

figure 3 Final design of the geogrid reinforced soil mattress on piles for bus lane N247

3.3 *Deformation and behaviour of the construction*

As the construction is of a complex nature, with a lot of interaction between subsoil and the construction, a number of finite element calculations were carried out using PLAXIS. The PLAXIS calculations were carried out to assess induced forces from deformations (and vice versa) within the construction and to gain more insight in the possible behaviour of the construction in general. To model the 3D behaviour of the geogrid reinforced soil mattress using the 2D finite element equations, two types of calculations were carried out using PLAXIS, which were:

- axi-symmetrical calculations of a "unit-cell" in which the axis of the pile served as the axis of symmetry;
- plane-strain calculations perpendicular to the existing road-axis.

The behaviour of the construction is best modelled using the axi-symmetrical calculations, whereas the embankment slopes could only be modelled with plane-strain calculations. By using conversion factors, the results of the axi-symmetrical calculations could be integrated with the plane-strain calculations.

Verification with PLAXIS confirmed the sound analytical design of the geogrid-reinforced mattress on piles. Results of the PLAXIS-calculations have been summarised in figure 4 and table 3.

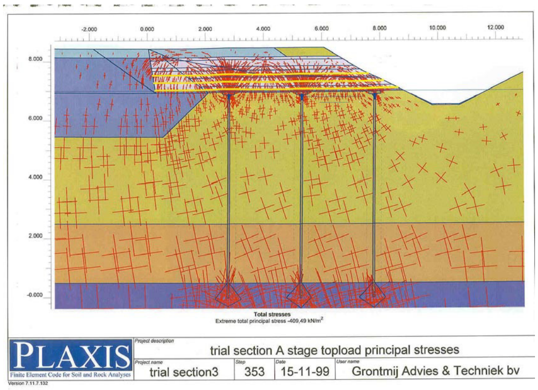

figure 4 Graphical presentation of the results of the Plaxis calculations

Pileno.	Pile-forces		Areano.	stresses in soil at pilecap level	
[-]	constr.phase 1 [kN]	constr.phase 2 [kN]	[-]	constr.phase 1 [kPa]	constr.phase 2 [kPa]
1A	32,1	-	I	9,3	17,5
2A	32,5	-	II	9,1	21,9
3A	12,2	-	III	9,4	13,8
1B	31,1	105,6	IV	9,9	16,5
2B	28,2	54,2			
3B	5,9	7,1			

table 3: calculation results using PLAXIS

4 TRIAL SECTION

4.1 *introduction*

Because constructions including a geogrid reinforced mattress on piles had not been realised in the Netherlands previously, a trial section of 50 m length was set-up. The section was set-up both to verify the design according to the posed requirements and to assess if the construction would behave as expected based on the designs. To determine the forces, stresses, strains and displacements in the various parts of the construction and in the soil, an extensive monitoring programme was set up. Monitored parameters included the following:

- pile forces;
- settlements;
- tensions in geogrids;
- strains in geogrids;
- soil and water pressures;
- inclination of piles and pile caps;
- shortening of the piles;
- shearing of geogrids over pile caps;
- damage of geogrids.

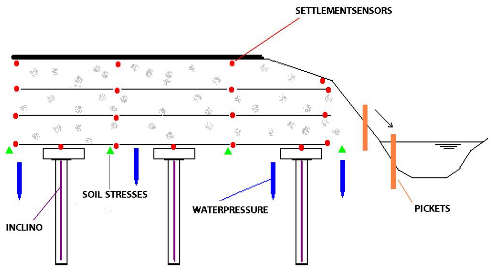

figure 5: Overview of monitoring program

4.2 *Monitoring Results*

Construction of the trial section and monitoring set up commenced in June and July, 1999. Monitoring of the construction was carried out during construction phase 1 (august and September 1999), which comprised construction of the geogrid reinforced soil mattress itself. Upon completion of construction phase 1, construction phase 2 was initiated, which included application of a surcharge on top of the soil mattress of 1,2 m of granulate (approx. 20 kN/m^2). The following figures present the results of the monitoring of the trial section. Figure 6 shows the pile forces plotted against time. The figure clearly shows an increase of pile forces in time. This can be explained by the fact that the arching effects are taking place and the piles gradually start carrying more and more of the loads. A second feature that can be seen is the application of the surcharge on the soil mattress. The loads of the soil mattress are transferred directly to the piles (days 85 to 115, figure 6). Figure 7 shows the soil stresses between the pile caps. Here the opposite takes place, the stresses gradually reduce in time, a clear indication of arching taking place.

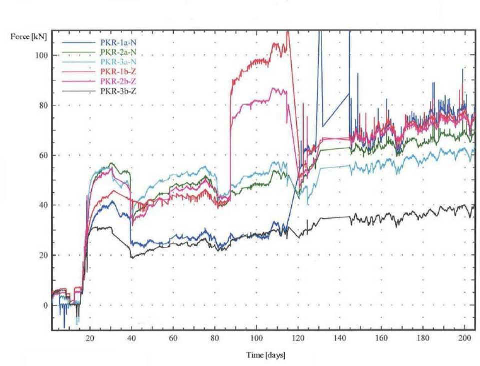

Figure 6 Monitoring results – Pile forces

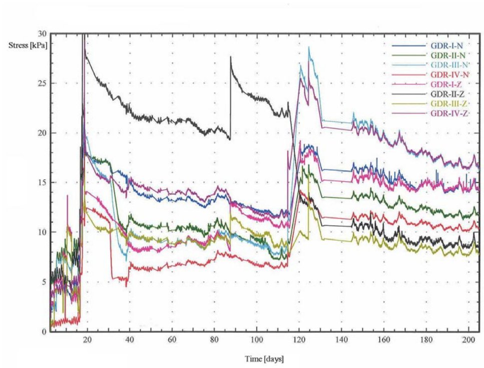

Figure 7 Monitoring results – Soil stresses between pile caps

5. CONCLUSION

Based on the monitoring results, it can be concluded, that the design of the geogrid reinforced mattress on piles for the N247 road widening behaves according to expectations. In spite of the limited availability of measurements of long term behaviour of the construction in this project, given the long term experiences in similar constructions in other projects, this type of construction seems promising for a future in which durable roads will have to be constructed reliably in a short time span.

Based on a comparison of the trial section data and the results of the analytical design methods, it could be concluded that for the N247 case the Hewlett and Randolph method and BS8006 method underestimates the arching effect. Results of the methods of Terzaghi and Guido were reasonably in line with the monitoring results. Modelling the geogrid reinforced mattress on piles in 2D-Plaxis yields reasonable results by combining axi-symmetrical calculations with plane-strain calculations. For a firmer grip on the 3D-effects in the construction it is recommended to investigate the possibilities of modelling in 3D-Plaxis.

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List of symbols

a	width of the pile-cap
c	cohesion of the fill material
C_c	arching-coefficient
E_P	pile efficacy
$F_{s;pile}$	load due to embankment weight carried by piles
$F_{s;tot}$	total load due to embankment weight
H	height of the embankment measured from pilecap level
$h1$	distance between top of pile cap and first gridlayer
$h2$	distance between first and second gridlayer
$h3$	distance between second and third gridlayer
K	empirical constant for horizontal coefficient of earth pressure (method Terzaghi)
K_p	Rankine's coefficient of passive horizontal earth pressure (method H & R)
p'_c	average vertical stress on pile caps (method BS8006)
q	surcharge
s	pile distance
S_{3D}	stress reduction ratio
$2B$	distance between edges of pile caps (method Terzaghi)
w_T	distributed vertical load on grid between two adjacent pile caps
γ	volumetric weight of fill material
δ	ratio a/s
φ	angle of internal friction of fill material
σ_v	vertical soil stress
σ_h	horizontal soil stress
$\sigma'_{v;p}$	average vertical stress on pile caps
$\sigma'_{v;g}$	average vertical stress at pilecaplevel carried by the reinforcement (geogrid directly over pilecaps)
$\sigma'_{v;t}$	average vertical stress at pilecap level due to the embankment fill