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Design and construction of geotextile encased columns supporting geogrid reinforced landscape embankments; Bastions Vijfwal Houten in the Netherlands

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ABSTRACT: The demanding geometry of the architecturally designed landscape embankments forming the “Bastions Vijwal Houten”, as well as the difficult subsoil conditions required an innovative geotechnical design. Several concepts for the structure and the foundation of the embankments were analysed in the run-up of the project. Finally, a design consisting only of applications with geosynthetics was considered to be most suitable. In particular this design comprises geogrid reinforced embankments founded on geosynthetic encased columns. This project demonstrate the advantages of such a solution and also the approach to the dimensioning of the structural elements as well as to the execution of the construction work.

1 INTRODUCTION

The area of Houten-Zuid is one of the so called Vinex-locations (large-scale housing projects), which the Dutch government has targeted as a growing area for housing development in the Netherlands. In two of these areas of Vinex in Houten-Zuid, landscape embankments (Bastions) placed almost at the end of the housing projects were planned as a connection between the residential area and the natural landscape around. The landscape hills (Bastion West and East) had to be built with cohesive soils which occurred in the project areas. For these embankments on extremely soft soil, settlement calculations were performed and settlements of 1.6 m to 1.9 m for Bastion West and 0.5 m to 0.8 m for Bastion East were expected to occur. This created a problem because of the extended consolidation time estimated. In addition the considerable settlements endangered an adjacent brick-wall founded on concrete piles to potentially collapse. One other concern was the global stability of the embankments especially due to the excavation of a dewatering canal around the Bastions at the toe of the embankment.

Several options for the construction of the Bastions were analysed such as embankments on piles, anchored sheet pile walls and vertical drainage or soil replacement. However, the use of geosynthetic encased columns (GECs) was found to be the best solution with regard to the reduction of the settlements as well as to the improvement of the global stability of the embankments. The limiting of the settlements due to the GECs also reduced any induced additional load on the adjacent concrete piles to an acceptable value.

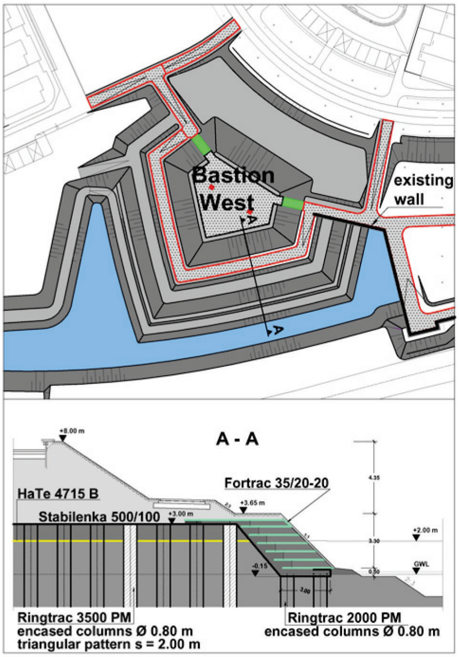


Figure 1. Bastion West.

Furthermore, the total construction period was shortened because eighty percent of the consolidation took place during the construction work. Thus, the settlements were limited to less then 10 cm after construction. Finally, these technological and economical advantages were critical in the choice of the GEC foundation system for the local authorities of Houten.

2 DESIGN

After the first ideas on the concept by Van Impe (1989), the foundation system "geosynthetic encased columns" was developed between 1995 and 2000 by the German contractor Moebius and Huesker Syn thetic. Meanwhile, it had been proven in several projects, for example, the large-scale land reclamation project for the Airbus 380 plant in the city of Hamburg in 2002.

The main idea of the GEC-System is, similar to conventional embankments on piles, to transfer the embankment load through the soft soil to a firm stratum. Thereby, the embankment load is borne mainly by the encased columns. However, the surrounding soft soil provides lateral support to the columns and bears a minor part of the vertical surcharge. The vertical deformations as well as the load distribution between the columns and the soft soil are defined by the tensile strength and the stiffness of the encasement. Since the soft soil is involved in the transfer of vertical loads, the drainage function of the GEC's, acting as vertical drains, is also important to reduce the consolidation time of the system. A design method which allows an estimation of settlements, an analysis of the required radial tensile strength of the encasement and an analysis of the distribution of vertical stress between the columns and the soft soil was presented by Raithel (1999).

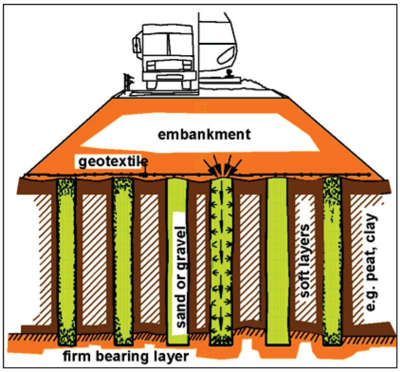
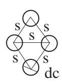
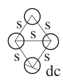


Figure 2. General GEC principle.

Following Raithels design method for the two "Bastions" in Houten different solutions with regard to the allowable settlements, the diameter and spacing of columns as well as the strength and stiffness of the encasement geotextile were analysed. Here, the solutions shown in Table 1 were determined as the most suitable ones. Comparing the design of the Bastions it must be taken into account that the allowed settlement at Bastion West was considerable larger.

Nevertheless, the more critical case at Bastion West concerning the thickness and the shear strength of the soft soil as well as the presence of ground water

Table 1. Bastion West & Bastion East: Embankment, Subsoil, GEC Foundation System.

Embankment:	Bastion West		Bastion East	
height	5.5 m		5.5 m	
fill material	$\gamma = 17$ kN/m^3/$\varphi' = 20°$/$c' = 2$ kN/m^2		$\gamma = 17$ kN/m^3/$\varphi' = 20°$/$c' = 2$ kN/m^2	
traffic load	20 kN/m^2		20 kN/m^2	
Soft Soil Layer:	organic clay & peat		sandy organic clay	
thickness	7.5 m		3.0 m	
properties	$\gamma = 14$ kN/m^3/$\varphi' = 17°$/$c' = 2.5$ kN/m^2 $E_{s,pref} = 2000$ kN/m^2 ($p_{,ref} = 100$ kN/m^2)		$\gamma = 17$ kN/m^3/$\varphi' = 22.5°$/$c' = 2$ kN/m^2 $E_{s,ref} = 3000$ kN/m^2 ($p_{,ref} = 100$ kN/m^2)	
ground water level	–2.0 m		n.a.	
Foundation System:	geosynthetic encased columns		geosynthetic encased columns	
geometry		s = 2.00 m dc = 0.80 m		s = 2.30 m dc = 0.80 m
column fill	$\gamma = 19$ kN/m^3/$\varphi' = 32.5°$/$c = 0$ kN/m^2 (sand)		$\gamma = 19$ kN/m^3/$\varphi' = 32.5°$/$c = 0$ kN/m^2 (sand)	
encasement	Ringtrac® 3500 PM	UTS = 200 kN/m $J_k = 3500$ kN/m $J_d = 2100$ kN/m	Ringtrac® 2000 PM	UTS = 130 kN/m $J_k = 2000$ kN/m $J_d = 1000$ kN/m
basal reinforcement	Stabilenka®500/100	UTS = 500 kN/m	Stabilenka®500/100	UTS = 500 kN/m
estimated settlements	≤ 0.40 m		≤ 0.15 m	

* J_k = short term radial tensile stiffness; J_d = long term radial tensile stiffness (120 years)

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results in a closer spacing of the columns and a higher strength and stiffness of the encasement. Finally, 780 columns encased with two different types of radial woven geotextiles made of high modulus Polyvinylalcohol (PVA) were planned below both Bastions.

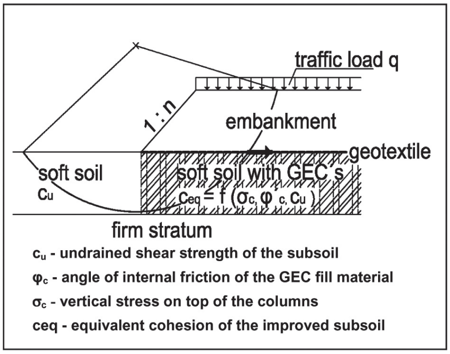

Figure 3. Principle of the global stability analysis.

Apart from the estimation of settlements and the dimensioning of the encasement, the global stability of the "Bastions" was analysed using an equivalent cohesion for the subsoil improved with the GECs. This equivalent cohesion was determined taking into account the stress distribution at the level of the column heads according to Raithels method. To achieve a sufficient global stability it was necessary to install a basal geosynthetic reinforcement layer above the columns. For both embankments a geotextile made of Polyester (PET) with a short term tensile strength of 500 kN/m was incorporated to achieve the global stability requirements. Additionally, this reinforcement layer serves to equalize settlements, to bridge the soft soil between the columns and to control spreading forces.

At the western Bastion the global stability problem adjacent to the lateral dewatering canal required the installation of additional GEC's installed at the toe of the embankment only to improve the shear strength of the soft soil. Beside the global stability of the Bastion embankments single slopes inside the structure were analysed. Since local cohesive soils were used as fill material, some of the steeper slopes required additional support. In all these sections geogrids made of PET with an ultimate tensile strength of 35 kN/m were used to stabilize the slopes.

3 CONSTRUCTION

The construction works at the Bastions in Houten was divided between two contractors. The site preparation works and the soil improvement with the GEC's were carried out by the Royal BAM Group, whilst the installation of the basal reinforcement and the construction of the geosynthetic reinforced embankments were executed by the contractor van Wyk.

The construction works started with the installation of a working platform. A nonwoven geotextile was placed on the levelled subgrade and was covered with a 1.0 m thick sand layer. From this working platform the GECs were installed, using the so called "displacement method", as shown in Fig. 4 and Fig. 5. This method used a displacement casing with a diameter of 0.8 m and twin hinged base flaps driven by means of a high frequency vibrator through the soft soil down to a firm bearing layer. After this the Ringtrac® -encasement was installed inside the casing and filled with sand. As the displacement casing was pulled out with the flaps open, the column fill was compacted by optimised vibration. Selected poorly graded sand was chosen as column fill material to achieve a sufficient compaction during the installation of the GECs.

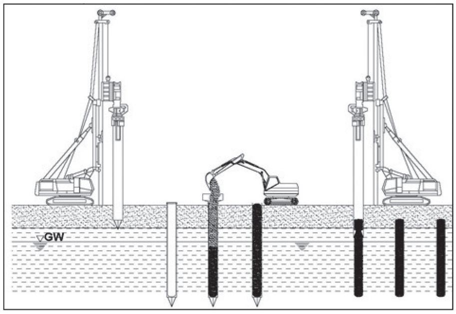

Figure 4. GEC installation with the "displacement method".

Figure 5. GEC-Installation.

The Royal BAM Group operated at both Bastions with the same equipment, a 100 t piling rig and heavy vibrators, changing only the length of the steel casing. Using this equipment up to 40 GECs per day were installed. To ensure the appropriate compaction of the column fill material and the estimated load-bearing capacity of the columns, penetration tests inside the columns and load tests were carried out. The result of a load test at Bastion-East compared to the estimated settlement behaviour is shown in Fig. 6.

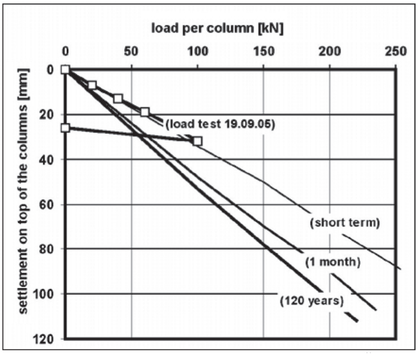

Figure 6. Estimated settlements and load tests at "Bastion East".

After the foundation work was finished the contractor van Wyk progressed with the construction. Since all GEC´s were installed from the same level the length of some columns had to be adjusted. These columns were uncovered and shortened according to the final design. Furthermore, the canals around the Bastions were excavated. After the ground surface was shaped the horizontal geotextile was installed. Finally the Bastion embankments were built on the prepared platform. After a period of consolidation of 2 months the works were planned to progress with the construction of the roads and facilities at the Bastions.

Figure 7. Installed GEC at Bastion East.

Figure 8. Bastion West during the consolidation period.

4 CONCLUSIONS

Until now the GEC-system was mainly used for large-scale projects. As an example the "Bastions" in Houten show that in the meantime this foundation system has become an interesting technological and economical alternative to conventional foundation systems also for smaller projects too. The main reason for this is the fact that the foundation system is mostly out of its developmental stage. A sufficient precise estimation of the system with regard to the prediction of settlements as well as to the required properties of the geosynthetic encasement and the basal horizontal reinforcement is possible. Furthermore, the experience with the installation of the GECs collected over the last 10 years make a better assessment of the expenditures possible.

The use of this foundation system seems to be suitable particularly if the subsoil in place is too weak (cu < 15 kN/m^2) to be treated with regular stone or gravel columns and the structure does not require completely stiff and settlement-free pile elements. Thus, the opinion of the authors is that the GECs are an appropriate supplement to conventional foundation systems.

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