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Bridge abutment foundation on a basal reinforced piled embankment

Fondation de culée de pont sur une digue sur pilotis armée à la base

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ABSTRACT The application of piled embankments and reinforced earth structures for infrastructure projects is more and more widespread in the Netherlands. For the - generally soft - soil conditions in the western part of the Netherlands, piled embankments offer an efficient building method for settlement-prone roads. Within the large scale A15 motorway widening project, which comprises the widening of the motorway A15 in the Rotterdam harbour area, piled embankments and reinforced earth structures were constructed at a number of locations. The most notable one was constructed at the motorway interchange 'Vaanplein'. For this interchange (connection of motorways A29 and A15) the abutment of one of the overpasses was founded on an embankment of geosynthetic reinforced bottom ash. The reinforced embankment itself was subsequently founded on a reinforced mattress on piles. The abutment was originally designed as a stub abutment supported on piles. By changing the design of the base plate of the abutment, tilting of the abutment and related peak stresses were reduced and the foundation stresses below the base plate were spread more evenly. This enabled a foundation directly on the embankment of reinforced bottom ash and the piled mattress below. Strength and stiffness properties of the bottom ash proved to be favourable as settlements of the abutment during and after construction remained negligible. Close coordination between geotechnical and structural possibilities resulted in a durable construction that could be built efficiently. The application of bottom ash in the embankment adding both a cost-effective and sustainable component to the construction.

RÉSUMÉ L'emploi de digues sur pilotis et de structures en terre armées pour des projets d'infrastructure est de plus en plus répandu aux Pays-Bas. Pour les sols généralement meubles de la partie occidentale des Pays-Bas, les digues sur pilotis offrent une méthode de construction efficace pour les routes sujettes aux affaissements. Sur le projet à grande échelle d'élargissement de l'autoroute A15 dans la zone portuaire de Rotterdam, des digues sur pilotis et des structures en terre armées ont été construites à plusieurs endroits. Le plus intéressant à été construit à l'échangeur autoroutier 'Vaanplein'. Pour cet échangeur, (liaison des autoroutes A29 & A15), la culée d'un des viaducs repose sur une digue de mâchefers armés de géosyntétiques. La digue armée elle-même reposait ensuite sur un matelas armé sur pilotis. La culée était au départ conçue comme culée de tronçon supportée par des pilotis. En modifiant la conception du socle de la culée, l'inclinaison de la culée et les contraintes maximales relatives ont été réduites et les contraintes de la fondation sous le socle ont été réparties de manière plus uniforme. Cela a permis une fondation directement sur la digue de mâchefers armés et du matelas armés dessous. Les propriétés de solidité et de rigidité des mâchefers, qui ont été favorables pour être employés comme fondations de la culée pendant et après la construction, sont restées négligeables. Une coordination étroite entre les possibilités géotechniques et structurelles a débouché sur une construction durable qui a pu être érigée efficacement. L'emploi de mâchefers dans la digue a ajouté une composante à la fois durable et rentable à la construction.

1 INTRODUCTION

The main thoroughfare to and through the Rotterdam harbour area, the motorway A15 is currently being adopted to relieve current and future traffic congestions. The large scale project comprises the widening and construction of the road embankments for the motorway, a large number of fly-overs and a new lifting bridge over the river Oude Maas. At one of the interchanges a new fly-over will connect the motorway A29 from the southern direction to the A15 to the western direction (Figure 1). The north-western abutment of this fly-over was originally designed as a stub abutment founded on piles. The connecting road embankment was designed to be founded on a reinforced mattress on piles. For the connection of the abutment to the road embankment a number of technical solutions were considered, comprising adaptations of the foundation of both the embankment and abutment. An integral innovative design, founding the abutment directly on the reinforced embankment and piled mattress turned out to be the most efficient and cost-effective. In this article details of the design and construction of the abutment are discussed.

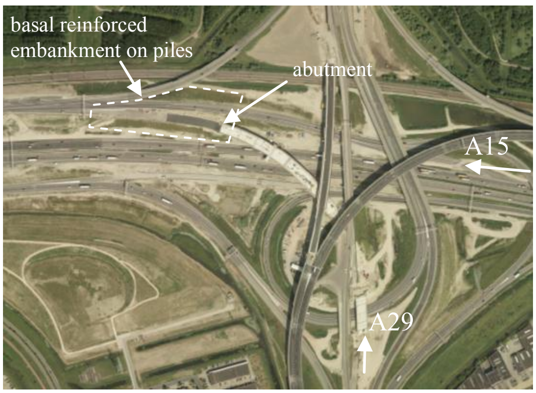

Figure 1. Situation of the intersection A15 with the A29

2 PROJECT CHARACTERISTICS

2.1 Soil stratigraphy

The project location is characterized by highly compressible clay and peat layers up to approximately 15 m below ground level. The soil stratigraphy is presented in Table 1 below.

Table 1. Soil stratigraphy at project location

Top of layer [m+NAP]	Soil description
-0.50	Sand, loose
-4.00	Peat, very soft
–7.50	Clay, very soft to soft
-13.50	Peat, soft
-14.00	Sand, dense

2.2 Geometry and settlements

The design level of the road at the location of the embankment and the connection to the flyover is located at 8 m above ground level (approx. NAP +8.0 m). Settlement calculations for a traditional embankment indicated a settlement of approximately 2.5 m. The available time for construction of the embankment and abutment proved to be too short in order to meet the project requirements. In order to meet the settlement requirements within the available time limits for design and construction, a reinforced mattress on piles proved to the best solution. As stated before, the original design of the abutment of the connecting fly-over consisted of a sub-abutment founded on piles (Figure 2).

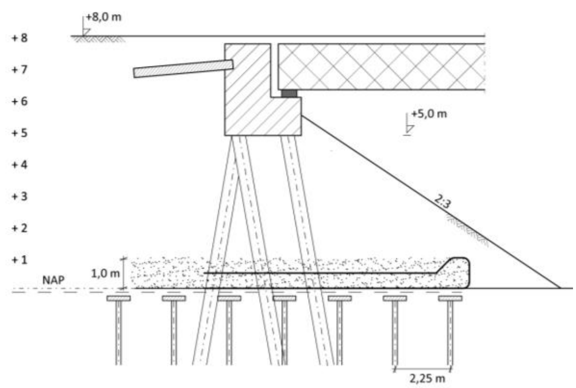

Figure 2. Longitudinal section of original design of embankment and abutment

2.3 Trade-offs

As can be seen in figure 2, the piles supporting the reinforced mattress conflict with the piles supporting the abutment. Furthermore, the geosynthetic reinforcement has to be 'interwoven' with the piles of the abutment. Although similar constructions were realised successfully for other projects, a more efficient design was deemed possible.

A number of alternatives were considered:

a. construction of the road embankment under and directly behind the abutment with expanded polystyrene;
b. construction of the abutment as a full height abutment (pile head levels of abutment equal to those beneath the reinforced mattress);

c. construction of the abutment as a shallow foundation placed on successively a reinforced embankment and the reinforced mattress on piles.

Trade-off analyses weighing the main project goals and critical risks in terms of time, costs and quality resulted in a clear preference for alternative c. In terms of overall weighed costs alternative c represented an optimization of roughly 25% relative to the other two alternatives and the original design.

The main risk in terms of quality of alternative c, relative to a and b concerns the deformations of the abutment, as the abutment is not founded directly on piles. Figure 3 gives the major outlines of the design solution.

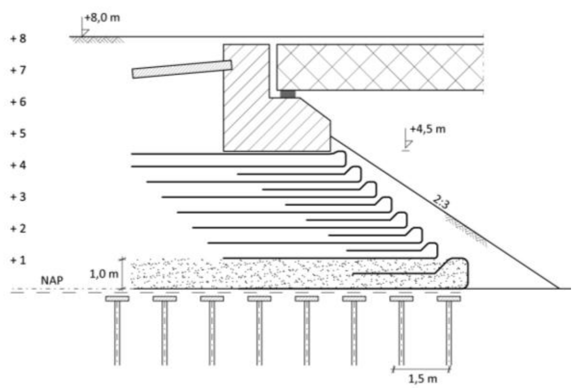

Figure 3. Longitudinal section of optimized design of embankment and abutment

3 DESIGN OF THE CONSTRUCTION

3.1 *The abutment*

The bearing pressures of the original design of the abutment, which was to be supported by piles, turned out to be too unfavourable for a spread foundation. The geometry of the abutment was optimized by enlarging the width of the base of the abutment and centering the bearing point of the beams of the flyover. By doing so, both the bearing pressures and the eccentricity of the load on the abutment were reduced. Resulting maximum bearing pressures were thus reduced from 470 kPa to 217 kPa. The latter value falling within the range of bearing pressures generally allowable for a spread foundation on top of a reinforced soil slope.

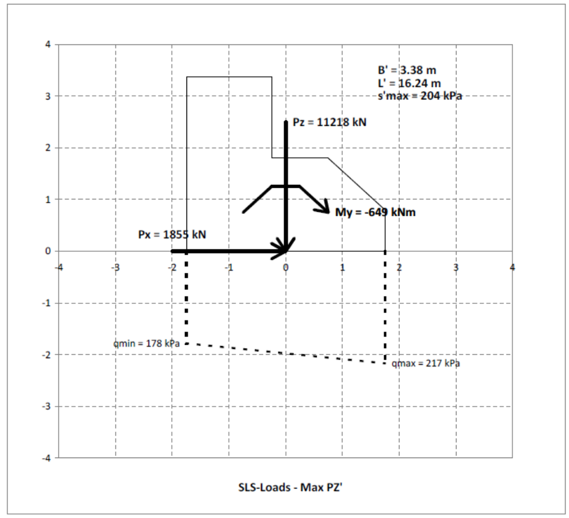

Figure 4. Bearing pressures after adaptation of the abutment design

3.2 *The reinforced soil slope*

The reinforced soil slope was designed according to the EBGEO (2011) and CUR 198 (2000). Internal- and compound stability of the reinforced soil slope was checked for all possible sliding planes (circular Bishop- and wedge analyses). The basal reinforcement for the piled embankment (refer to §3.4) was disregarded during the internal- and compound stability analyses of the reinforced slope. The overall (external) stability was checked with FEM calculations that included the piles and basal reinforcement of the piled embankment. In Table 2 the design for the reinforced slope is summarized.

Polyvinyl alcohol (PVA) grids were applied for the reinforced slope below the abutment because only small strains are allowed to minimize deformations of the abutment. Furthermore the PVA grids have a better chemical resistance, which is required for the application of the grids in combination with the bottom ash as fill material.

Table 2. Summary of design of reinforced slope

Parameter	Value
Height of slope between abutment and basal reinforcement	3.5 m
Layer thickness	0.5 m
Unit wt. of fill material	19 kN/m^3
Int. fric. angle fill material	32.5 deg.
Required char. Strength reinforcement*:	
Directly below abutment	Fortrac R (PVA-grid) 400 kN/m ‘
Layers below	Fortrac R (PVA grid) 300 kN/m’

* Reinforcement was applied in two orthogonal directions below the abutment (lateral and longitudinal).

3.3 *Pile design*

For the piled embankment connecting to the flyover, relatively slender piles with a cross section of 290 x 290 mm were applied. The additional pile loads resulting from the abutment proved to be normative for the pile bearing capacity and the pile spacing.

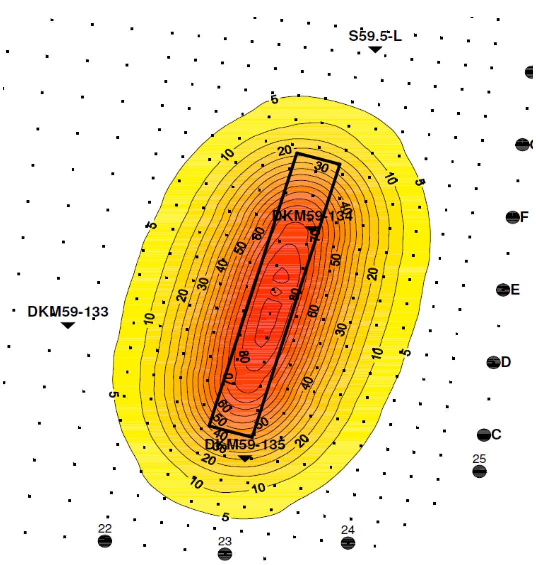

Figure 5. Additional soil pressure from abutment at level of pile caps

To determine the increased bearing pressures resulting from the abutment at the level of the pile caps, analytical (Boussinesq approximation) and finite element calculations were performed (Figure 5).

As, based on economical and logistical arguments, preference was given to the application of the same pile and pile cap throughout the embankment and under the abutment, the pile spacing was decreased within the zone of increased bearing pressures resulting from the abutment.

3.4 *The basal reinforcement*

The basal reinforcement was designed according to the Dutch design guideline CUR 226 (2010). The loads at the level of the reinforcement originating from increased total loads from the abutment (both the static and dynamic traffic loads) were incorporated as vertical static loads in the calculations. According to the CUR 226 (2010) this is acceptable for a relatively large thickness of the embankment and associated sufficient spreading of the loads. In Table 2 the reinforcement design is summarized.

Table 2. Summary of design of basal reinforcement

Parameter	Value
Centre-to-centre distance piles*	1.5 x 1.5 m
Size of pile cap	0.75 x 0.75 m
Embankment height	8 m
Add. load from abutment	68.2 kPa
Unit wt. of fill material (avg.)	19 kN/m^3
Int. fric. angle fill material (avg.)	40 deg.
Required char. Strength reinforcement:	
Longitudinal	Fortrac T (PET-grid) 450 kN/m ‘
Lateral (incl. spreading forces)	Stabilenka (PET-woven) 1000 kN/m’

3.5 *Bottom ash and deformations*

The bottom metre of fill material in the basal reinforced embankment consists of hydraulic granular fill material. For the embankment itself bottom ashes were used as fill material. The main environmental concern for the application of bottom ashes is a possible contact of the material with groundwater, which results in pollution. For a piled embankment settlements are characteristically small. The construction is therefore very suitable for the application of bottom ash, provided the top of the embankment is sealed with a foil construction adequately.

Road engineering properties of properly processed bottom ash are comparable to those of natural sand or gravel (Arm 2003). The major difference between sand and bottom ashes in mechanical terms is that the latter may show cementation after construction of the embankment, which may prove problematic when differential settlements are expected (Halter 2002), again underlining the piled embankment as a suitable construction for application.

Up to today there has been relatively little experience or measured data of long term deformability of bottom ashes. Provided compaction of the bottom ashes during construction is performed adequately up to proctor densities of 98% or higher, deformations due to settlements will be kept to a minimum. It is assumed that bottom ashes may show some chemical decomposure over long periods of time of 1.5% resulting in a possible settlement of the abutment over its service life of 50 mm.

4 CONSTRUCTION MONITORING

The basal reinforced embankment and reinforced slope with the abutment were constructed between March 2012 and Octobre 2013. Milestones during the construction works are indicated in Table 3 below.

Table 3. Milestones during the construction works

Description	Date
Pile driving	February - April 2012
Installation of basal reinforcement	May - June 2012
Reinforced Embankment under abutment	July – August 2012
Construction of abutment	November 2012 – February 2013
Installation of decks	May– August 2012
Traffic	October 2013

As the main uncertainties concerned the deformation of the bottom ashes and related possible settlement of the abutment, monitoring of the abutment was started directly after its construction. The figure below shows the settlement of the abutment over the period of time between completion of its construction up to six months after realization of the flyover. Measurements show negligible settlements of maximum 15 mm between completion of construction of the abutment up to nine months after the initial traffic loads (start of operational lifetime) on the flyover. Monitoring of the abutment will be continued at regular intervals in the coming years.

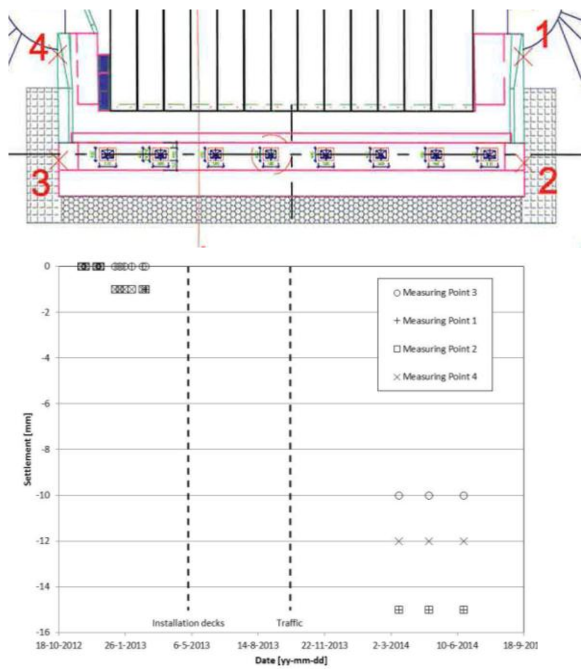

Figure 6. Layout of measuring points and settlement measurements of abutment

5 CONCLUSION

By combining recent developments and techniques in reinforced soil structures (basal reinforced piled embankments and reinforced soil slopes) an innovative solution was found for the foundation of a bridge abutment. The solution proved to be more efficient and economic than the more commonly applied traditional solutions.

The application of bottom ash as embankment fill on top of basal reinforced piled embankments adds an economical and sustainable component to the construction. Measurements show that mechanical properties (deformations) of the bottom ash seem adequate even when applied as fill in a reinforced slope under a bridge abutment.

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