HANZELIJN – LICHTWEIGHT EMBANKMENTS BEHIND ABUTMENTS

Milan Duškov
InfraDelft BV, The Netherlands (milan.duskov@infra delft.nl)

Jos Hogerwerf
BAM Infraconsult, The Netherlands (j.hogerwerf@baminfraconsult.nl)

Abstract

The planned Hanzelijn-railway to be constructed crosses the motorway A6 near Lelystad at chainage 7.450 km. At that location the roadway is situated above the railway. Another 200 m north of this the roadway crosses the canal Noordertocht. The motorway A6 and the corresponding access and exit roads are situated high on the bridge structures due to bridging the canal. Due to compressible peat and clay layers present in the ground the construction of high embankments with heavy sand could undoubtedly cause considerable settlements. These settlements could likewise result in horizontal loads on the land abutments and constitute a risk for the stability of the structures. A cause oriented solution with lightweight EPS-blocks stands for minimizing the loads on compressible subsoil. A second advantage is that the extreme reduction of horizontal stresses on the mounds (otherwise risk on sliding without additional measures) and the land abutments (otherwise high top moments on the foundation piles) will influence the stability positively.

INTRODUCTION

The planned Hanzelijn-railway crosses the motorway A6 near Lelystad at chainage 7.450 km. At that location the roadway is situated above the railway. Another 200 m north of this the roadway crosses the canal Noordertocht. The A6 and the corresponding access and exit roads are situated high on the bridge structures due to bridging the canal. The same is applicable for the elevations to the relevant structural works as can be seen in Figure 1.

Due to compressible peat and clay layers present in the ground the construction of high embankments with heavy sand could undoubtedly cause considerable settlements. These settlements could likewise result in horizontal loads on the land abutments and constitute a risk for the stability of the structures. The use of traditional sand embankments would cause difficulties. MStab calculations performed by the Combination ‘Hanzelijn’ in the past indicated the possibility for a cause oriented solution with lightweight EPS-blocks. The deadweight reduction achieved this way stands for a minimisation of the loads on compressible subsoil. A second advantage is that the extreme reduction of horizontal loads on the mounds (otherwise risk on sliding without additional measures) and the land abutments (otherwise high top moments on the foundation piles) will influence the stability positively.
DESCRIPTION OF SITUATION

As can be seen in Figure 1, bridge KW176 over the Noordertocht canal is planned on the west side and bridge KW178 at the east side of the A6. The situational position of the structural works prescribes indirectly the necessary elevation height behind the abutments and the slopes in the longitudinal direction. That heights and slopes together with the local soil structure and ground water levels are representative for the design of the lightweight structures.

The embankment on the west side of bridge KW176 (W) is different from the embankment on the east side (E). The height of the western embankment W decreases rapidly with the distance from the bridge, because this embankment connects the structural works with the lower lying minor road. Therefore the bridge is build with a substantial slope in the longitudinal direction (from -1.68 m above sea level to ASL-2.42 m) as can be seen in Figure 2. The factual measurements of the viaduct in the longitudinal direction apply for the midpoint of the abutment. From the bridge towards the motorway the height of the eastern embankment E increases less rapidly.

Figure 1
Situation drawing with access and exit roads (including bridges kw176 and kw178 over Noorder tocht canal) of the motorway A6 north of the crossing with the Hanzelijn-railway
In contrast to KW176, the embankments of KW178 are connected to the motorway and stay at the same height during the whole length. KW178 is situated between ASL-0.035 m (N) and ASL-0.613 m (S) as described in Figure 3. The height of embankments N and S decreases in a restricted way due to the fact that the bridge height over canal Noordertocht prescribes the local position of the motorway A6 and KW178. This is important for the assessment behaviour of the local compressible subsoil. If the height of the embankment does not decrease radically, their dead-weight barely changes and the embankments provide vertical loads on the subsoil over the whole length.

The thickness of the lightweight material (EPS package) in the embankments is not (or hardly) allowed to change, if we purely choose a policy based on sufficient weight reduction. If consolidation acceleration measures are taken into account at a certain distance from the abutments as f.e. preloading, local assessment behaviour of the underground may, however, alter with less lightweight material. Due to the lengths and heights of the embankments there are many significant EPS-blocks needed for an adequate weight reduction. It is economically reliable to find out which dimensions of the EPS-package (in prolongation of the sand embankment) are the minimum to safeguard the stability of the whole embankment structure and the abutments.

The soil structure is characterized by a 2.5 m thick sand layer followed by a ca. 4 m thick weak peat and clay package. Such thick compressible layers indicate a high sensitivity to settlements in the subsoil under the access and exit road embankments. The Pleistocene sand package starts only from ALS-10.5 m.
The ground level varies from ASL–4.32 m to –4.00 m. The polder water level is at ASL-6.20 m just like the water level in the Noordertocht canal. Maximum lifting height of the ground water level has been determined on ASL-4.91 m with a recurrence of 2000 year.

Although a lifting height of ASL-4.91 m is unlikely and only possible in theory, the client insists that the stability of the (lightweight) embankments should also be safeguarded under such extreme circumstances. It is important to emphasize that in fact the soil structure is representative for the subsoil of canal banks. This statement is important for the modelling of the behaviour of the embankments by extreme lifting heights.

LIST OF DEMANDS

For the geotechnical design of the structural works KW176 and KW178 the following starting points and boundary conditions have been employed:

- Representative ground level on ASL–4.3 m;
- Polder water level on ASL–6.20 m;
- maximum lifting height of the ground water table has been determined as ASL-4.91m (with a recurrence of 2000 year);
- with reference to negative adhesiveness, the remaining settlements of the local piles under the abutments on both sides of the structural works have to be restricted to maximum 100 mm;
- the water braking function of the Holocene package (peat and clay) should be maintained; the water span is interpolated linearly over the water cut-off layer identical to the previous calculations of the client;
- to reduce costs the client prefers the implementation of purely minimized lightweight structures just behind the abutments or with restricted dimensions to safeguard the stability; adequate reduction of remaining settlements should be secured during available construction time by means of sand preloading.

ANALYSES WITH PLAXIS 2-D MODELS

To minimize costs Combination ‘Hanzelijn’ preferred a lightweight structure just behind the abutments and a minimum amount of EPS to secure stability. Adequate reduction of the remaining settlements should be secured during available construction time by means of sand preloading. Therefore the final analysis is concentrated on the stability aspects of the embankment of KW178 and KW176 in exclusive combination with minimized lightweight construction dimensions.

For a global analyse in the exploration phase the Mohr-Coulomb model (MC) has been used. Further refinement of the models has resulted in the implementation of the Hardening-Soil model (HS). All settlement calculations have been performed drained and undrained for a safety factor with regard to stability.

One of the problems was generated by the piles under the abutment. In a two dimensional model the piles should act as sheet pile walls. The effect of the piles has been modelled by defining the abutment as weightless. This way the abutment build on piles does not influence the settlement
of the embankment and at the same time the piles does not lock possible horizontal deformations.

**Influence of lifting height of the groundwater table on stability**

In the first instance the implementation of the groundwater level on ASL-4.91 m resulted in instability of all models. To find out why the results differ from the analysed models we investigated the cause by printing an output. This output is shown in Figure 4. The arrows show where instability occurs first by the crack at the toe of the slope in the water.

![Figure 4](image-url)

*Figure 4 – Development of water stresses under and behind the abutment of structural work KW178*

Due to the lifting height in the Pleistocene layer the structure is not stable. This can be solved if we replace a part of the Holoceen layer by a more solid kind of clay. (In fact the borings are only representative for the subsoil of the canal banks). After all the theme of the analysis is the macro stability of the abutments. The unstability (crack up) of the canal is a different problem. This problem has been isolated by modelling an even, strong and rigid clay layer on the bottom of the canal. The calculations are presentable because of the small (positive) effect on the macro stability. When there is no local collapse in the modelled clay layer, the calculation is interrupted. The models of KW178 and KW176 have been calculated with the method described above.

**Development of water stresses**

In order to create consistent calculations during the total design process of the embankment the water stresses of the water isolation layer has been interpolated linearly in the stability calculations. In the figures 5 and 6 the modelled development of KW178 is shown.
Influence of EPS-package on horizontal stresses

It is relevant to investigate how the EPS-package influences the horizontal stresses. This could be of importance for the design of the piles under the abutment. Our expectations that the use of EPS-blocks just behind the abutments result in a reduction of the horizontal stress are shown in figures 7 and 8. In the elevation part behind the EPS-package (Figure 7) the average horizontal stresses are higher than in the transverse cross section in the EPS-package (Figure 8) just behind the abutment. This is created by a lower Poisson’s coefficient ($\nu=0.1$) of the material.
Figure 7 - Value of stresses in the horizontal direction just behind the abutment of structural work KW178 according to Plaxis calculations

Figure 8 - Value of stresses in the horizontal direction behind the EPS-package at a distance of 16.0 m w.r.t. the abutment of structural work KW178

**OPTIMIZED LIGHTWEIGHT ELEVATIONS**

The Plaxis-model of the embankments behind bridge KW178 with HS-model for the subsoil is shown in Figure 9. A relatively large amount of elements, both under and behind the abutment, are used to model this with alternating EPS-package dimensions in the exploration analyses. We were able to imitate situations both with variable thickness and length and with or without EPS-blocks build-in under the abutment. This is important, because the calculations demonstrated that horizontal deformations on the front side under the abutment are critical for the stability of the total structure.

The optimized total EPS thickness is 4.0 m. The lowest EPS layer is 8.5 m long and the upper layer has a length of 16.0 m. The grey and pink elements represent the EPS blocks.
De stresses and strains in the EPS-package are verified with the allowable values for type EPS100 (with a density of 20 kg/m³). The relevant stresses caused by deadweight of the hardening layers and distributed top loads of 15 kN/m² do not result in permanent deformations in EPS100.

The stability calculations point out a stability factor of the relevant optimized lightweight embankment of 1.51. Figure 10 shows the calculated total movement created by sliding stresses behind and under the abutment of bridge KW178. Doing so, the sliding surface in the embankment is visible according to the total incremental displacements.

REFERENCES