Design and performance of a jet grout retaining wall in a railway embankment on soft soil

Dimensionnement et performance d'une paroi de soutènement réalisée à l'aide de la technique de jet grouting dans un remblai ferroviaire sur sol mou

Verstraelen J., Maekelberg W., Lejeune C., De Clercq E.
TUC RAIL

De Vos L.
Geotechnics Division Flemish Government

ABSTRACT: Within the framework of the regional express network around Brussels, two new railway tracks will be added besides two existing tracks linking Brussels to Ghent. The existing railway crosses the river Senne in Brussels with a geotechnical complex lithography. Beside this complexity, other project boundary conditions, such as the height of the railway embankment, the very short distance to the existing railway tracks in service, the small work platform to realize the retaining wall and safety issues linked to working next to railway tracks in service, were of great influence on the design of the retaining wall. The excavation has a total depth of 12.0m. The retaining wall consists of grout columns reinforced with steel beams. The wall is secured by grouted nails.
The jet grout columns were monitored and the resulting displacements and bending moments compared well with the design calculations.

RÉSUMÉ : Dans le cadre du projet du réseau express régional autour de Bruxelles, deux nouvelles voies de chemin de fer seront ajoutées le long des deux voies existantes reliant Bruxelles à Gand. Le chemin de fer croise la Senne, rivière de Bruxelles, dans une lithographie géotechnique complexe. Outre cette complexité, d'autres conditions limites du projet, comme la hauteur du remblai ferroviaire, la très courte distance par rapport aux voies en services, l'étroitesse de la plateforme de travail pour la réalisation de la paroi et les consignes de sécurité liées au travail à proximité de voies de chemin de fer en service, ont eu une grande influence sur le dimensionnement de cette paroi de soutènement. La profondeur d'excavation a atteint 12,0m. La paroi de soutènement est constituée de colonnes de jet-grouting armées à l'aide de poutrelles métalliques. La paroi est retenue par différents lits de clous de jet-grouting. Les colonnes de jet grouting ont été suivies par monitoring et les résultats des déplacements et des moments fléchissants ont été comparés avec les résultats des calculs du dimensionnement.

KEYWORDS: VHP jet grout columns, retaining wall, soil nails, railway embankment, alluvium, peat, monitoring.

1 INTRODUCTION

The regional express network around Brussels aims to increase the capacity of the train traffic in and around Brussels. Therefore, the existing railway lines linking Brussels to the most important surrounding cities, have to be widened from 2 to 4 railway tracks. The enlargement of the railway platform has to be done in highly urbanized zones and with restrictive project constraints. These constraints led in some cases to very complex and innovative solutions.

The retaining wall discussed in this paper is situated along the existing railway line 50A linking Brussels to Ghent, near to the Senne river at the south of Brussels.

A retaining wall is needed to create an abutment for a new integral arch bridge which is situated next to an existing bridge abutment. The excavation removes the existing embankment fill and goes up to 1 m underneath the natural ground level, as shown in figure 1.

The realisation of the retaining wall for the abutments is restricted by several constrains such as:

- Railway traffic must remain undisturbed during the whole construction period,
- Excessive movement of the railway tracks in service must be avoided and if they occur, they must be rectified directly; these movements can lead to reduced exploitation speeds and passenger delays,
- For safety reasons, the use of large foundation machinery is very much restricted next to the railway tracks in service,
- No expropriation was possible, so a working platform had to be created within the embankment contours,
- Since the embankment is situated on highly compressible alluvium, an enlargement or steepening of the embankment to create a larger working platform could not be realised.

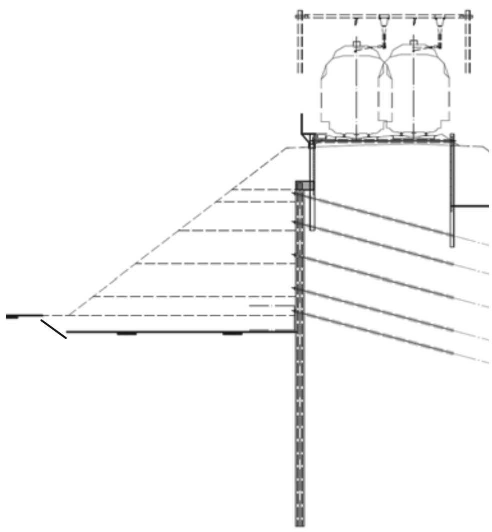

Figure 1. Cross section of the retaining wall

Due to these constraints, in a first working phase, a Berliner wall with 3 m retaining height was executed close to the tracks at the top of the embankment in order to create the working platform that will be used to install the retaining wall to the final excavation level, 12.0 m beneath rail level (see figure 1).

The use of secant piles wall, diaphragm walls, sheet piles etc was excluded for safety reasons, so a VHP-jet grout wall was chosen as retaining wall.

Since both the Berliner wall and VHP-wall are closely together and influence each other, their global design was carried out simultaneously using the finite difference program FLAC.

2 SITE GEOLOGY

The site is located within the alluvial basin of the river Senne, and contains highly compressible alluvium up to a depth of 10 m. Underneath this alluvium, a gravel layer is situated with a thickness ranging from 2 to 5 m. The deeper tertiary deposits consist of Yperian clay, an over-consolidated clay with a thickness of up to 16 m. Figure 2 shows the results of an electrical CPT together with the results of a pressiometer test at the same location. The Ménard modulus from the pressiometer test shows the different degree of consolidation in the upper clay layer from +8.0 to +4.0 mTAW and in the lower clay layer.

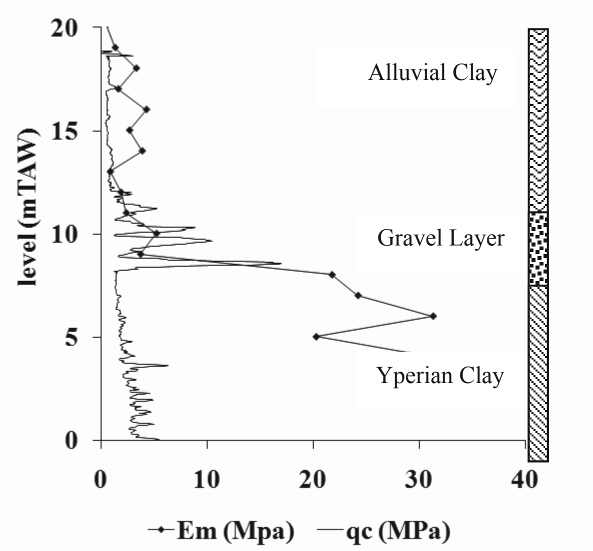

Figure 2. Cone resistance from CPT-E and Ménard modulus from pressiometer.

3 DESIGN

3.1 *Site investigation and soil parameters*

Besides the extensive in situ site testing, such as cone penetration tests (CPT's), pressiometer tests and core drillings, also extensive laboratory testing was carried out on undisturbed samples. The results of these tests were used to determine the effective strength parameters summarized in Table 1. A number of CPT's were performed directly from the train tracks and through the embankment fill. The railway embankment is a poorly compacted and silty fill.

3.2 *Finite difference model*

The geometry as shown in figure 1 and all of its construction phases was modelled with the finite difference program FLAC.

Special consideration was given to the compressibility of the alluvium. To model the stress dependant stiffness of this layer, a "double yield" soil mechanical model was used. The double yield model allows for plastic volumetric strain hardening, although independent of shear strain level. Also, unloading/reloading is taken into account with a user specified constant ratio between loading/unloading stiffness. The model is specifically designed for the use of isotropic compression tests, but the results of an oedometer can be converted to fit the input parameters. Very specific to this model is that a table of values serves as input, and the model interpolates linearly between these values. As a result, the (converted) oedometric test results can serve as direct input. To check the model, a separate load test model was used to check the input versus the modelling results (Figure 3). Since it is very difficult to combine the results of different oedometer tests, one representative oedometer was chosen as single input.

Table 1. Soil parameters.

Parameter	*alluvium*	*gravel*	*Yc clay*	*fill*
coh. (kPa)	5	0	20	4
friction (°)	22	32	25	27
E_M (MPa)	2.5	10	27	/
p_l (MPa)	0.5	1.9	1.6	/

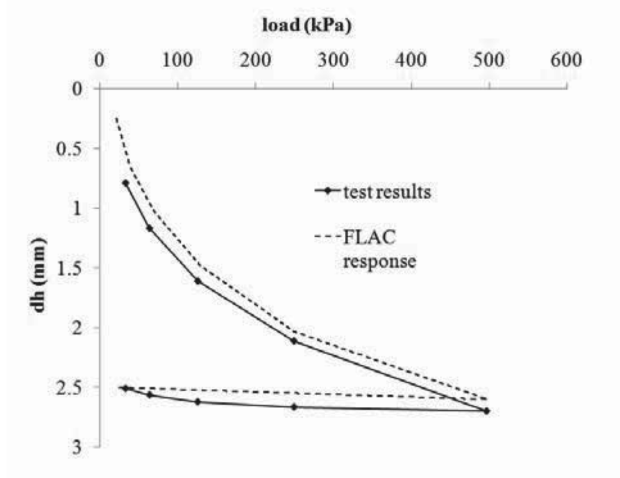

Figure 3. Comparison of model response with data from reference oedometer test.

The jet grout wall was modelled as a continuous wall with interface friction angle δ equal to the internal friction angle of the surrounding soil, and with the stiffness and strength of only the beam reinforcement of the jet grout piles. The wall is stabilized with jet grout soil nails, which are modelled as pile elements (with tensile and flexural strength) with an interface cohesion (cu = qsu based on literature values).

To limit excessive swelling of the embankment, a simple double yield model was used with constant loading and reloading moduli.

3.3 *Calculation results*

The model showed that it was necessary to install the VHP jetgrout piles till the depth of the base gravel. Otherwise, vertical settlement of the wall would reverse wall interface friction and would lead to excessive horizontal displacement. Also, squeezing of the alluvium would occur when the embedded length is further reduced.

Table 2 summarizes some results of the design calculations.

4 EXECUTION

The Berliner wall was placed with an excavator mounted vibratory pile driver and anchored to an opposing Berliner wall with tiebacks between the rail sleepers as shown in figure 1.

Table 2. Results of calculations

Bending moment embedded	63 kNm
Bending moment retaining	65 kNm
Horizontal displacement	21 mm
Vertical displacement top of wall	4 mm
Max vertical displacement behind wall	9 mm
Load in nails row 1	140 kN
Load in nails row 2	190 kN
Load in nails row 3	217 kN
Load in nails row 4	140 kN

After excavation of a retaining height of 3 m, a guide wall for the jet grout columns was casted against the berliner's soldier piles (HEB 300 beams). This guide wall also serves as temporary waler, since execution of jet grout columns decreases significantly the passive soil resistance in front of the soldier piles. To counter this effect, the installation of the jet grout columns was also carried out in a specified alternating sequence. guide wall also serves as temporary waler,

Figure 4 shows the finite difference model geometry with bending moments in the wall and axial loads in the nails.

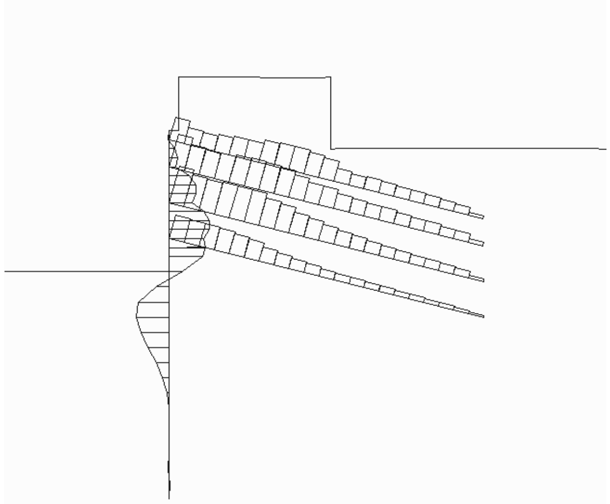

Figure 4. The distribution of the nail forces along the nails and bending moments within the jet grout wall.

The VHP jet grout columns only serve as a mean to install the beam reinforcement at depth and to transfer earth and water pressure to the reinforcement beams. For safety reasons, the 21 m long reinforcement beams (HEB 280) had to be installed in 3 m long sections which were bolted together. This installation is tedious and time consuming, and has to take place before the grout starts to harden. Due to the column length, installing the beams can only start about 2 h after commencing the (water)pre-cutting and 1 h after the (watercement) grouting. Including the bolting of the different beam sections, which takes up about 45 min in total, the last section reaches the bottom of the column 2 h after the start of the jet grouting at that depth.

Furthermore, the VHP-piles are installed in alluvial soil. Although the strength of the grout was not an issue (since it is of minor importance in the design), it is challenging to realise a reasonable sized jet grout column in this alluvium, especially when peat is encountered. Test columns were installed prior to the wall installation, in which diameter measurements were carried out with a calliper in the wet column. During these tests, chunks of more than 10 cm diameter of compacted peat were found in the spoil (Figure 5). To aid in the realisation of the required diameter to install the beam reinforcement, a reamer of 30 cm diameter was placed above the jet nozzles. Even with this reamer, the minimum diameter realized was equal to that of the reamer (Figure 6).

Figure 5. Pieces of peat found in jet grout spoil.

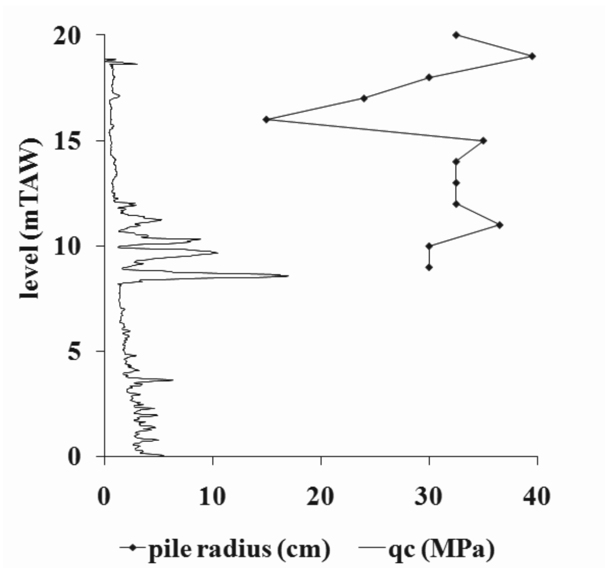

Figure 6. Cone resistance from CPT-E and measured diameter in wet jet grout column.

After testing different jetting pressures, flow rates and nozzle diameters, a suitable set of parameters was chosen. Even with this most suitable set, it was difficult to install the last few meters of the reinforcement, due to decantation of soil inclusion (clay/peat) in the grout. To ease the installation, the jet grout columns were deepened 1 m to allow for a 1 m unreinforced length. The retaining wall was executed as primary (reinforced) and secondary (unreinforced) columns with hart-to-hart distance of 1 m between reinforcements. The secondary columns serve to fill up the gap between primary columns.

Due to the nature of the fill and natural soil, a larger diameter than conventional soil nail diameters was necessary to provide sufficient bearing capacity of the nails. The soil nails were also executed as jet grout nails with a diameter of 30 cm. Pull-out tests were performed on sacrificial nails to check the design assumptions.

Figure 7 gives a view on the retaining wall after excavation and creation of a working platform for the new pile foundation.

Figure 7. Photo of retaining wall after final excavation phase, after backfill for piling rig

5 MONITORING

An extensive monitoring program was set up to measure the vertical and horizontal displacements of the wall during the different excavation stages. Specially instrumented beams were placed in the columns to measure deformations and strains in the reinforcement (L. De Vos, 2013). These reinforcement beams were exceptionally put into place in one piece and installed when the train tracks were out of service.

The measurements lie in close approximation to the calculated values. Figure 8 compares the measured and calculated horizontal displacements of the wall. Displacements are measured with an inclinometer, in which the bottom measurement is considered to remain unchanged.

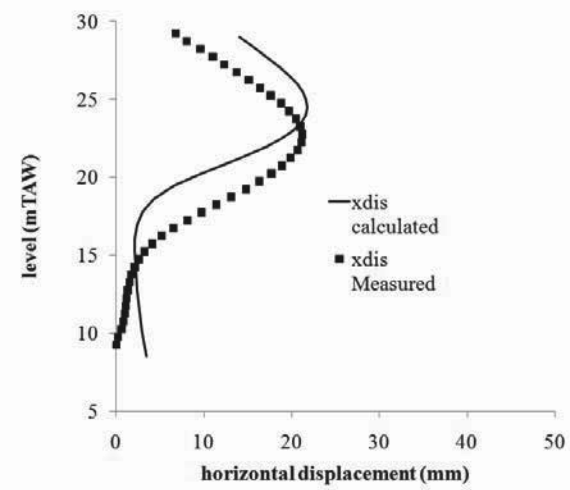

Figure 8. Comparison between calculated and measured horizontal displacements.

Based on these inclinations, bending moments can be calculated as the second derivative (Figure 9). Only the stiffness of the steel reinforcement beams was used, as was the case in the design.

Behind the wall, vertical displacements of up to 5 cm were measured, which is considerably more than the calculated values. When comparing the construction phasing with the continuous measurements, it was clear that the main part of the settlements could be related to the execution of the jet grout nails. Since the nails are realized by the jet grouting technique, soil is firstly cut away with water and further on replaced by a mixture of cementgrout and soil. This mixture takes a certain time to harden in which unconfined convergence of the drilled hole can occur. Once the mixture is hardened, the settlements stop. This effect will be investigated later in further detail.

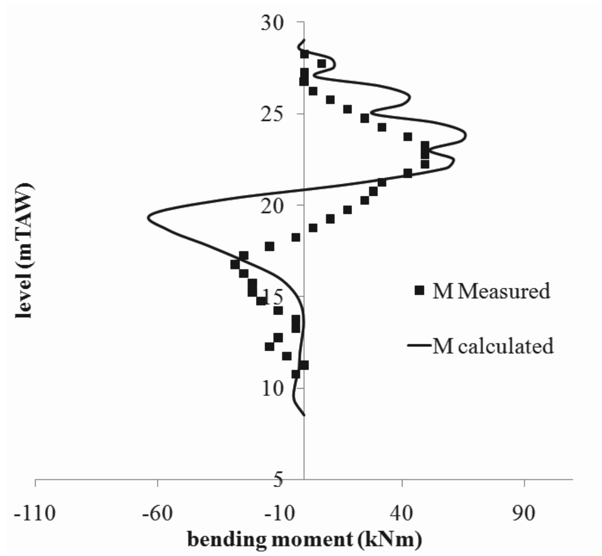

Figure 9. Comparison between calculated and measured (derived) bending moments.

6 CONCLUSION

For the construction of a retaining wall adjacent to railway tracks, the restrictions in available space and allowable height in machinery led to a combined retaining wall consisting of a small Berliner wall and deep VHP jet grout wall. The design was based on different in situ and laboratory tests, and was checked through monitoring of the excavation and performing preliminary true scale measurements. The execution of jet grout piles turned out to be difficult due to peat layers and the installation of 21 m long reinforcement beams in 3 m long bolted sections was challenging. Nevertheless, execution difficulties could be resolved by taking special measurements to ease the installation of the reinforcement beams. A monitoring campaign showed that the resulting retaining wall performed close to the design and train traffic remained undisturbed during the works.

7 ACKNOWLEDGEMENTS

The author whishes to acknowledge the Geotechnical Division of the Flemish Government, which allowed for this extensive monitoring campaign.

8 REFERENCES

De Vos L., Van Alboom G. and Haelterman K. 2013. Comparison of monitoring techniques for measuring deformations in an excavation. Proceedings of the 18th International Conference on Soil Mechanics and Geotechnical Engineering, Paris.

Verstraelen J., 2011, Green terraces for the regional express network in Brussels, EYGEC Rotterdam

Verstraelen J., Lejeune C., De Clercq E., 2012, Realisation of integrated steep landscape slopes within existing railway embankments ISSMGE- TC 211 International Symposium on Ground Improvement, Brussels, IV-169 – IV-179.

Maekelberg W., Verstraelen J., De Clercq E., 2012 Realization of a railway enlargement in unstable excavations alongside the existing line at Dilbeek (Belgium) ISSMGE- TC 211 International Symposium on Ground Improvement, Brussels, IV-107 – IV-121.

Van Alboom G., De Vos L., Haelterman K. and Maekelberg W. 2012. Innovative monitoring tools for on line monitoring of building excavations. A monitoring test site. ISSMGE- TC 211 International Symposium on Ground Improvement, Brussels, IV-327 – IV-338.