Soil nailing for the realisation of excavations along existing railway lines

Frank THEYS
Civil Engineer
Tuc Rail / Tractebel
Brussels, BELGIUM

Frank Theys, born 1964, received his engineering degree from the Free Brussels University

Jan MAERTENS
Civil Engineer
Geotech Consultant / Tuc rail
Brussels, BELGIUM

Jan Maertens, born 1949, received his engineering degree from the University of Ghent. He is associate Professor at the Cath.Univ.Leuven since 1991

Wim MAEKELBERG
Civil Engineer
Tuc Rail
Brussels, BELGIUM

Wim Maekelberg, born 1974, received his engineering degree from the University of Ghent

Summary

For the construction of a tunnel-crossing at Herent a retaining wall had to be realised along the existing railway line. Initially a secant pile wall with pre-stressed anchors was chosen in order to limit the displacements. Finally preference was given to a secant pile wall with grout nails because of the later advantages during the construction of the concrete tunnel structure. Since most design methods for soil nailing walls do not permit an accurate estimation of the horizontal wall displacements, a finite difference modelling was performed to estimate those displacements for the serviceability limit state. During and after the realisation of this nailed secant pile wall the displacements were monitored through the use of extensometers enabling a comparison between estimated and measured displacements.

Keywords: excavations; secant pile wall; soil nailing; finite difference modelling.

1. Introduction

For the construction of the high speed railway line between Brussels and Liège the existing railway line between Brussels and Leuven will be upgraded for the THALYS trains and the capacity extended by adding 2 extra tracks for local trains, one on each side. At Herent, near Leuven, the two central tracks leave the existing line needing a tunnel-crossing. In order to build this tunnel-crossing a temporary retaining wall had to be constructed close (i.e. 2 meters at its minimum) to the existing railway line.

This closeness to an important existing railway line in exploitation with a speed limit of 100 km/h called for the design of a retaining wall with minimal risk towards instability of the railway track, a limited horizontal and vertical displacement (10-15 mm max.) and the possibility to use the wall as a lost formwork for the construction of the concrete tunnel wall.

2. Geology

The subsoil consists of a quaternary silt of 4.0 – 5.0 m thickness with a gravelly base covering the tertiary sand formation of Brussels. This sand formation consists of fine and loosely packed sand with clayey layers and sandstone layers. The groundwater table is situated at 5.0 m depth.

A representative cone penetration test is shown in figure 1.

IABSE Congres Antw 2003

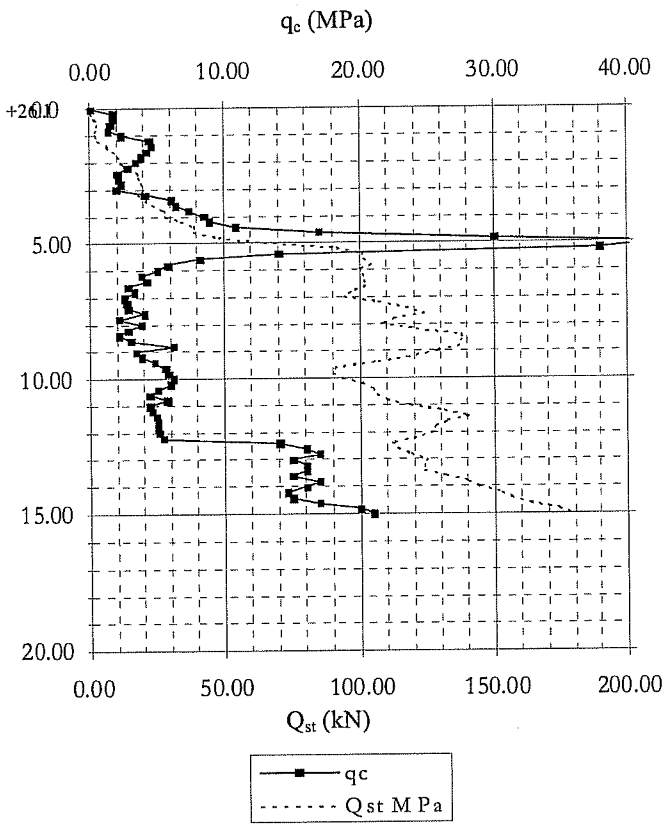

Fig. 1 Representative cone penetration test.

3. Design

The imposed restrictions and the geology of the site led to a design of a secant pile wall with 2 rows of pre-stressed anchors, this was imposed in the tender documents. Since horizontal girders were necessary to transfer the significant anchor forces to the pile wall and because the wall was to be used as a lost formwork, it would be necessary to do the concreting of the definitive tunnel wall in 3 phases to allow the intermittent removal of the girders.

In order to avoid these 3 phases it was proposed by the contractor to execute a nailed secant pile wall. Because of the greater number of nails, the force per nail would be much lower. So it was not necessary to provide girders to transfer the nail forces to the pile wall. Instead, small steel plates could be used to connect the nails to the pile wall, allowing the concreting of the definitive tunnel wall in one single phase. A possible disadvantage of this design is that in general the displacements of nailed walls are higher than those of walls with pre-stressed anchors. Furthermore, for nailed retaining walls the displacements are difficult to predict with the normally used design methods. This is contrary to the design methods for walls with pre-stressed anchors which permit a more accurate prediction of the displacements, provided an adequate calculation algorithm is used that takes into account possible reversible displacements i.e. reinitialisation of the force-displacement curve at the moment of reversal of displacement [1].

The initial design by the contractor was made using the French “Recommandations CLOUTERRE 1991” [2] in which the partial safety factors on the material characteristics and on the loads are dependent on the type of wall (“courant” or “sensible”) and the type of loading (“combinaison fondamentale” or “combinaison accidentelle”). In this case a wall of the type “sensible” was used and the loading of the type “combinaison accidentelle”. Then, for a given geometry, length and diameter of the soil nails, the most unfavourable failure surface taking into account the stabilising effect of the soil-nails needs to have a safety against failure of 1.125. Non-circular failure surfaces

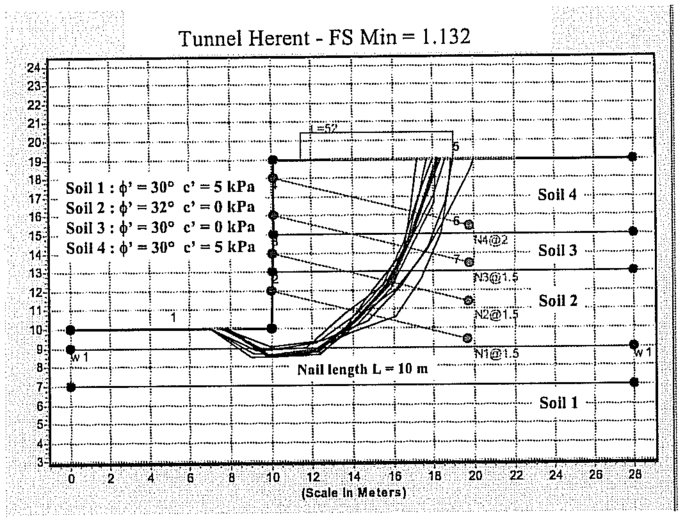

Fig. 2 Soil characteristics, geometry and most unfavourable failure.

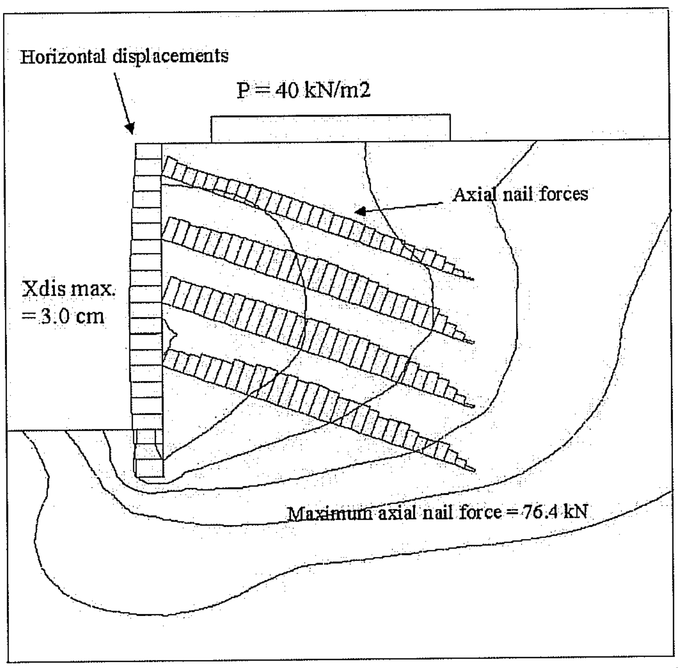

Fig. 3 Horizontal displacements of the wall and axial forces in the nails

and the JANBU method are used (software STABL for Windows, v2.0 [3]). This resulted in the design with 4 rows of nails shown in figure 2 for the most representative wall height of 8.0-9.0 m, with nails of 10 m length and horizontal distances of 2.0 m (upper row) and 1.5 m (second to 4th row). Locally, a pumping chamber needed to be constructed. For this, a retaining wall having a height of 11.5 m had to be constructed, requiring 6 rows of nails of 10 m length with horizontal distances of 2.0 m (upper row), 1.5 m (second to 5th row) and 1.0 m (6th row).

The nails used are of the jet-grouting type with a 30 cm diameter and theoretical limit pull-out force of 51 kN/m. To verify this pull-out force 14 pull-out tests have been performed on the nails. These tests confirmed the theoretical value.

To determine the displacements of this nailed pile wall a calculation was performed through modelling using the finite difference code FLAC [4]. The soil model used is the Mohr-Coulomb model, the value of the bulkmodulus for the different soil types (from 1 to 4) is taken as 100 MPa, 25 MPa, 50 MPa and 35 MPa respectively. For the lower elements of the model the elastic model was used with a bulkmodulus of 500 MPa. The nails are modelled as cable elements with grout bond shear strength Sbond = 51e3 N/m and grout bond stifness Kbond = 3e9 N/m/m. The resulting horizontal displacements of the retaining wall and the axial forces in the nails (per meter wall) are given in figure 3, the resulting displacements at the top of the wall and at the level of the second nail row during the different excavation and construction stages are given in figure 4.

For the interpretation of the obtained results it has to be considered that in general the measured displacements of temporary retaining walls are lower than the calculated displacements; this is because in calculations longterm, conservative values for the cohesion are used. Furthermore, it is often observed (see also [1]) that the passage of a train behind a retaining wall does not give rise to the displacements that are theoretically predicted. This is probably due to the high damping characteristics of most soils, resulting in high dynamic stiffness and cohesion.

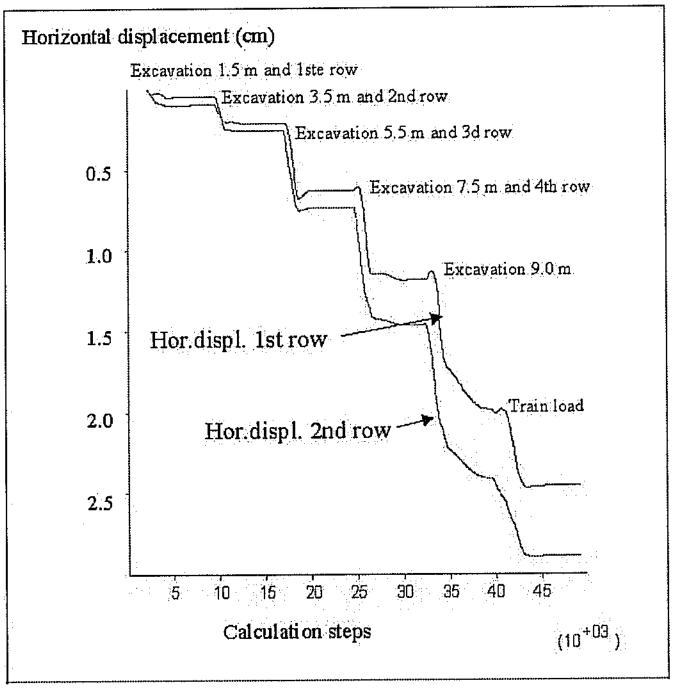

Fig.4 Predicted horizontal displacements during the different excavation stages.

Furthermore, in the calculations the train load is applied in the last calculation step, cfr. Fig.4. This is a safe assumption compared to a calculation whereby the load is applied at the beginning of the calculation so that part of the deformations due to the application of the load have occurred before the installation of the piles.

It was judged that the displacements would probably be within the proposed 10 – 15 mm range. Only locally, for the construction of the pumping chamber where the retaining wall is designed to have a height of 11.5 m, these displacements could be higher.

The design was thus accepted on condition that the wall displacements would be extensively measured topographically and through the use of extensometers.

4. Execution and measurements

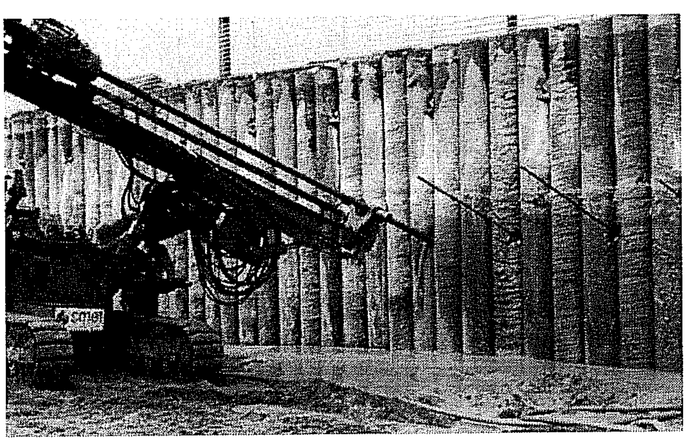

Fig. 5 Execution of soil nails

The piles used have a diameter of 53 cm, placed at 49 cm distance. The primary non-reinforced piles of the secant wall were executed as normal CFA-piles, the secondary reinforced piles were executed as CFA-piles with casing, the reinforcement consisted of IPE100 steel profiles. For the latter the auger and the casing are screwed in at the same time, rotating in opposite directions. Once the required depth is reached, concrete is pumped through the central tube of the auger and the auger and casing are withdrawn progressively and simultaneously.

The casing is provided with drilling bits, allowing to cut into the concrete of the primary piles. This process allows a fast execution of the pile wall, the total construction time of the nailed wall with a length of 350 m, including the necessary excavations, nail testing (14 pull-out tests) and installation of extensometers was about 4 months.

5. Conclusions

A secant pile wall with 2 rows of pre-stressed anchors has been successfully replaced by a nailed secant pile wall. When designed using the method of the "Recommandations Clouterre", with wall type 'sensible' and with loads of the type 'combinaison accidentelle', the displacements of this type of nailed wall are rather low. This is confirmed through modelling of the wall with a finite difference code and through the on-site measurement of the horizontal displacement of the wall during and after construction.

References

[1] MAERTENS J., THEYS F., "Anchored sheet pile wall for a 13 m deep construction pit along an operational railway line", *Proceedings of symposium on Ground Anchorages*, London, 20-21 march 1997.

[2] "Recommandations CLOUTERRE 1991 pour la conception, le calcul, l'exécution et le contrôle des soutènements réalisés par clouage des sols", Presses de l'école nationale des Ponts et chaussées, 1991.

[3] Software STABL for Window v2.0, Geotechnical Software Solutions.

[4] Software FLAC (Fast Lagrangian Analysis of Continua), Itasca Consulting Group, Inc.