Anchored sheet pile wall for a 13m deep construction pit along an operational railway line.

JAN MAERTENS and FRANK THEYS
TUC RAIL, Brussels, Belgium.

INTRODUCTION

As part of the construction of the High Speed Railway line between France and Brussels an old brickwork bridge of the line L96 over the river Senne at Halle had to be replaced. Since the EUROSTAR train uses this railway line until completion of the new High Speed Railway line it was quite impossible to interrupt the traffic for the demolition of the old bridge and construction of a new one at the same location.
It was decided that close to the old bridge a 13 m wide by 11 m high tunnel was to be jacked underneath the existing railway, after which the river Senne was to be deviated into this tunnel and backfill placed under the old bridge. At that moment the old bridge could be demolished and the tracks put into service in a very short period.

Problem was the very limited space available for the prefabrication of the tunnel so that the front of the jacking pit had to be realised extremely close to the operational railway track (at a distance of only 2m). The back of the jacking pit, on which about 3200 tons of horizontal force would be exercised during the jacking, would be very close to the river embankment (at about 8-10m distance). See figure 1.

For this presentation we will be concerned only with the front of the jacking pit.

SUBSOIL

Due to the vicinity of the river Senne it is not surprising that alluvial soils, having very low resistances, are encountered. This is clearly visible in the Cone Penetration Test diagram in figure 2, showing a cone resistance q_c = 0.4-0.6 MPa between levels +31.50 and +25.00. The cone resistance q_c in the fill of the railway embankment itself is about 1-2 MPa, which indicates a fill of very mediocre quality and of insufficient compaction.
Underneath this fill and the alluvial layers the primary bedrock (early Cambrian) is encountered, at about + 22.50. Previous experience attained during the site investigations and subsequent construction of the secans pile walls of the High Speed Train tunnel at Halle (at only a few kilometers distance) show that the bedrock layers are inclined at a steep 75° angle almost perpendicular to the railway axis and exhibit a very irregular nature, with hard sandstone, siltstone en phyllite (schist) layers alternating with completely weathered layers over only a few meters distance [1].

The watertable is situated at about +33.00, requiring a water lowering towards +27.50 before construction of the pit.

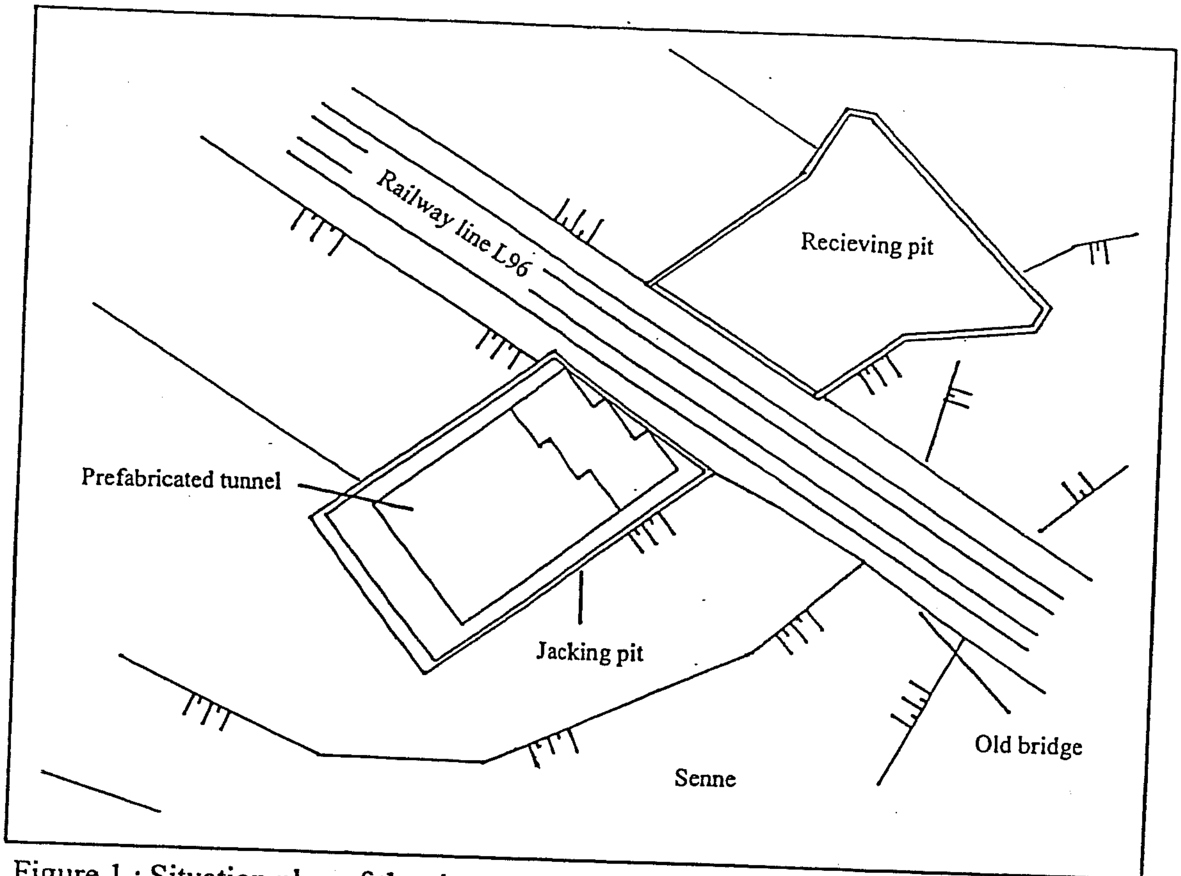

Figure 1 : Situation plan of the river Senne, construction pit, railway and old bridge.

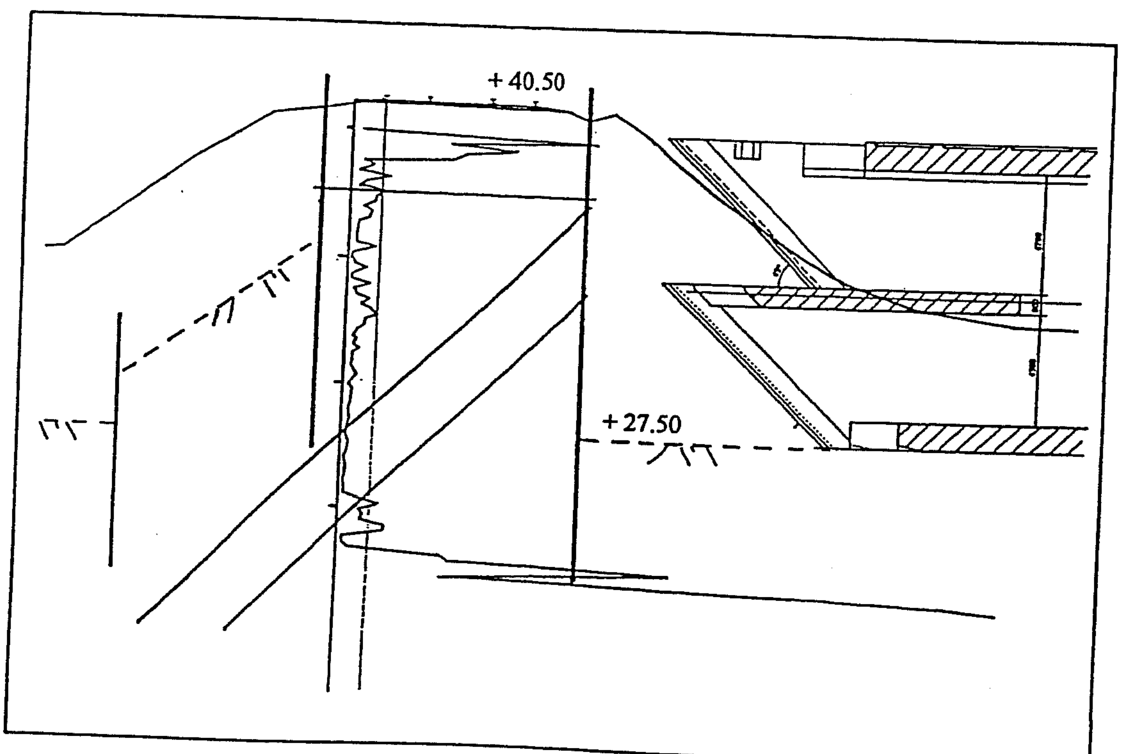

Figure 2 : Prefabricated tunnel, sheet pile walls of the jacking and recieving pits and CPT.

DESIGN OF THE RETAINING WALL

To construct the 13m deep pit, the best adapted and practical solution was found to be a sheet pile wall whose total length is determined by the depth of the underlying bedrock (+22.50). The sheet piles would have to be quite stiff and have more than one row of prestressed anchors in order to limit the displacements.

The initial design is done by use of an elasto-plastic spring model program. Since in this case the design will be determined by the amount of deformation of the wall, it is important that the program used should have at least the following features :

- choice of the horizontal subgrade reaction modulus k_h,
- ability to perform phased calculations,
- algorithme that takes account of reversibel displacements, i.e. reinitialisation of the force-displacement curve at the moment of reversal of the displacements.

If these features are not supported by the software, unrealistic values of the displacements will be the result. This may seem obvious, but in everyday practice a lot of retaining walls are designed by use of these simpler software programs. As long as the designer is aware of its limitations and does not attempt applying it to retaining walls with more than one anchor row and/or with prestressed anchors and in cases where the displacements are indeed very critical, no harm will be done. This is unfortunately not always so.

At TUC RAIL the software ESA-SCIA [2] was used for the calculations, resulting in a retaining wall with 2 prestressed anchor rows at 45° inclination and Larssen 4S sheet piles, see figure 2. The obtained maximum horizontal displacements are 7-10 cm (depending on the soil stiffness) and the maximum anchor forces are 310 kN and 630 kN/linear metre of wall, for the first and second row respectively, this with anchors prestressed at 50% and 75% of their maximum service load (anchors of 56 tons at 1.5 m interval for the first row , 85 tons at 1.0 m interval for the second row).

Because of the significant heigth of the wall (13m of earth to be retained) and the nearness of the tracks of an important railway line, a more refined calculation was needed for the horizontal and also the vertical displacements. To this end the finite difference program FLAC [3] was used, with Mohr-Coulomb modeling of the soil.

The soil parameters used in the calculation are presented in figure 3, while a typical output is presented in figure 4 which shows the bending moments in the sheet piles and the zones of soil that have undergone plastic flow or are still at yield. Figure 5 shows the calculated horizontal displacements and anchor forces during consecutive construction phases, with anchors prestressed at 50% and 75% of their maximum service load. The obtained values are more or less similar to those obtained in the initial design calculations, the anchor force in the second row (727 kN/m) being a bit larger.
The most critical phase seems to be phase 3 (with 1 row of anchors and excavation to +32.50) during which the maximum displacements will occur.

The vertical displacements have been calculated for different sets of soil parameters (bulkmodulus, friction and cohesion). The resulting vertical displacements of the railway track varie between 5 and 10 cm (figure 6).

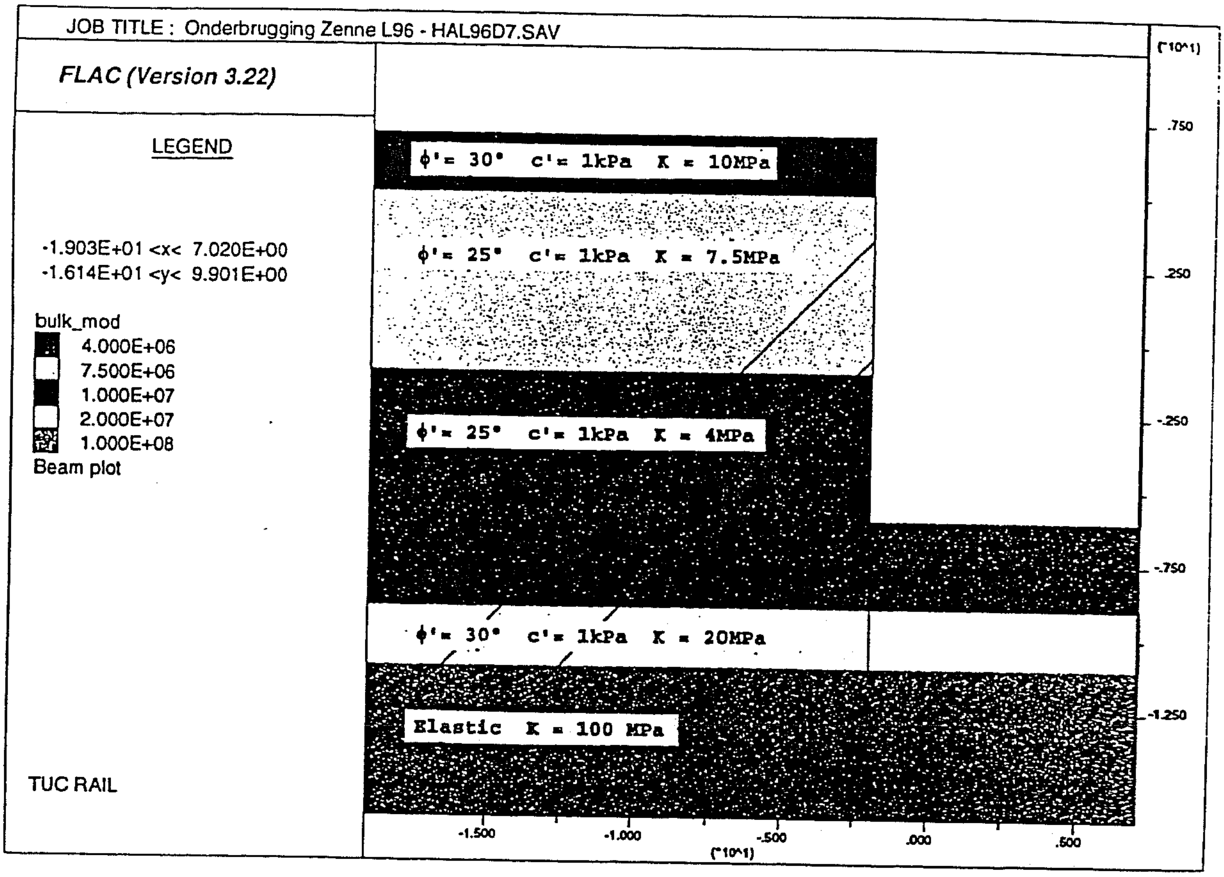

Figure 3 : Example of soil parameters used in the FLAC calculations.

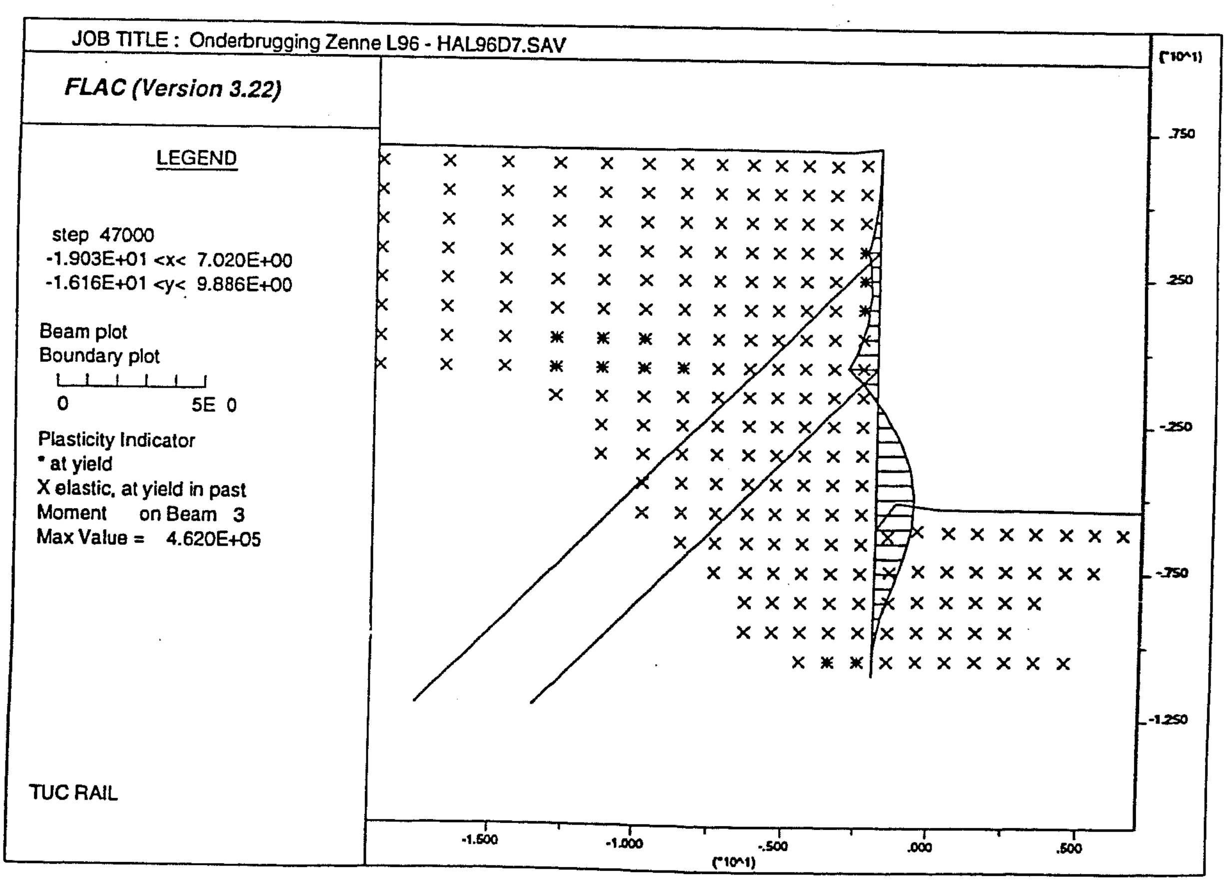

Figure 4 : Typical output of FLAC calculations.

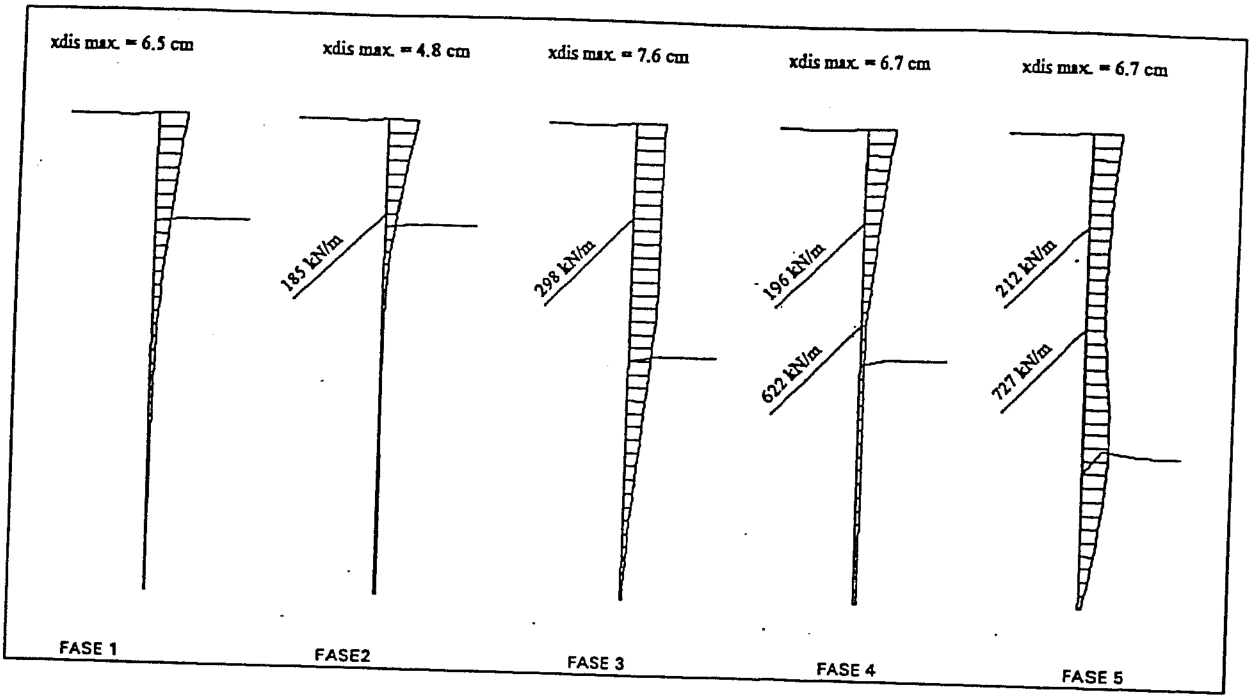

Figure 5 : Calculated horizontal displacements and anchor forces during consecutive construction phases with pretensioning to 50% and 75% of service load.

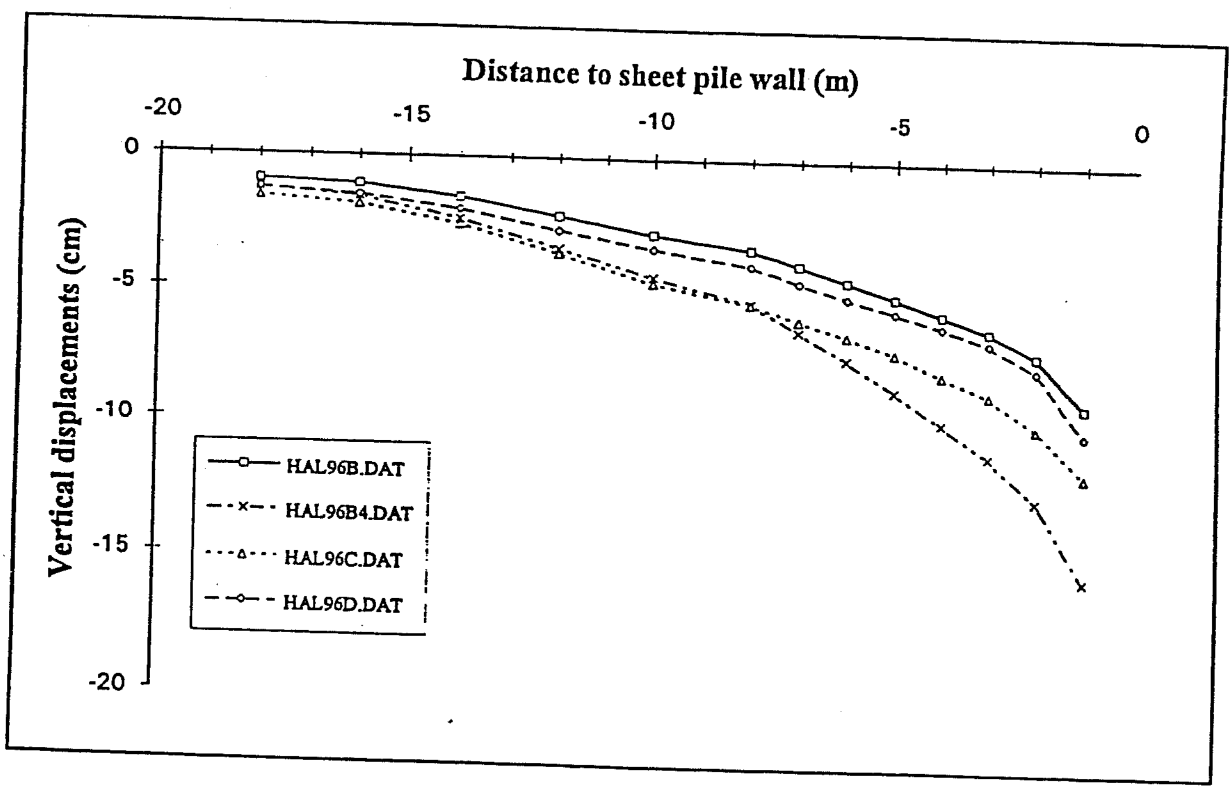

Figure 6 : Calculated vertical displacements behind sheet pile wall.

All the obtained results enable us to conclude that the proposed design can be considered acceptable on the following conditions :

- the anchors are pretensioned at a higher load, f.i. at 90% of their service load,
- a speed limit (40 km/h) is imposed during the construction of the pit and the jacking,
- regular measurements of the railtracks, the horizontal displacements of the wall and the anchor loads are made,
- when the measured deformations of the track become too important, the track can be raised on short notice.

DESIGN OF ANCHORS

As already mentioned, the anchors of the first row have a service load of 56 tons and are placed at 1.5m interval, the anchors of the second row have a service load of 85 tons and are placed at 1.0 m interval. Their inclination is 45° in order to reach the underlying bedrock with a minimum free length. They are fixed into this primary bedrock.

The length of the anchor root in the bedrock is determined according to the method of BUSTAMANTE [4]. A friction of 650 kPa at the grout-rock interface is obtained, resulting in root lengths of 4.0 m for the 56 ton anchors and 6.0 m for the 85 ton anchors. This implies the 'rock' to be of good and constant resistance.
As already mentioned in a previous paragraph the bedrock exhibits a very irregular nature, with hard sandstone, siltstone en phyllite (schist) layers alternating with completely weathered layers over only a few meters distance . This means that, since the anchors had to be bored nearly parallel to the rock layers it couldn't be avoided that some anchors had to be installed in softer layers, while others had to be bored in very hard rock layers.

To overcome this problem it was agreed with the contractor that the length of the anchor root would depend on the resistance of the rock encountered during the boring. If no, or very little, consistant rock is encountered the root length would be increased to 6.0 m and 8.0 m respectively for the 56 ton and 85 ton anchors.

In any case, during the pretensioning every anchor was to be preloaded to 1.3 times the service load.

MEASUREMENTS DURING AND AFTER EXECUTION

Since there was much uncertainty about the nature and quality of the fill and of the alluvial layers, load cells were installed on 4 anchors (2 on each row) .
These cells were equipped with a clearly visible measuring gauge (Glötzl type with manometer gauge [5]) so that at every moment the anchor forces could be known on the spot.
If at any time the anchor forces should inexplicably increase and come very close to (or even surpass) the anchor capacity, the necessary measures (additional anchors, placement of support members,...) could still be taken on time to prevent further load increases.
It is certainly reassuring for everyone concerned with the project if the anchor forces do not increase up to the critical values.
In figure 7 we see the evolution of the anchor forces in time, starting at the moment the anchors of the first row are prestressed. Also given are the theoretical, calculated anchor forces, this for pretensioning at 50% and 75% of the service load respectively for the first and

second anchor row (as shown already on figure 5) and also in the case of pretensioning to 90% of their service load, as corresponds more closely to the final execution.

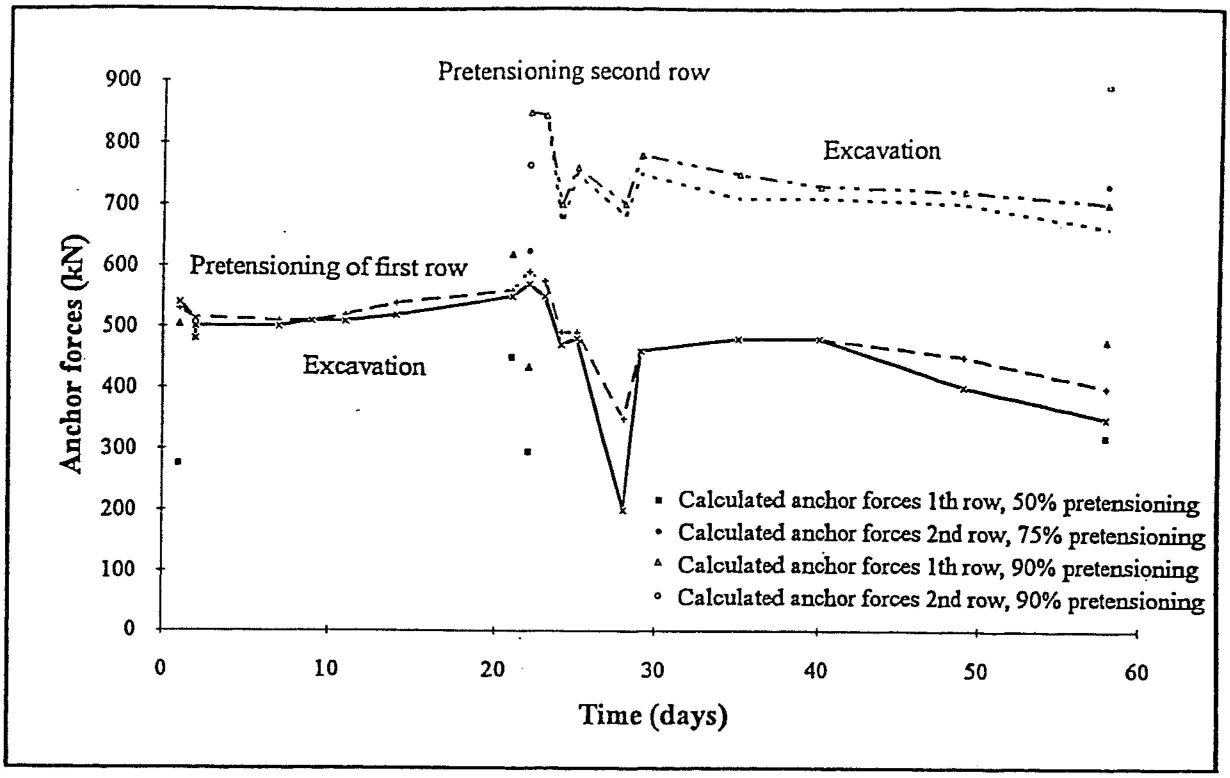

Figure 7 : Calculated (FLAC) anchor forces and measured anchor forces as function of time.

Observations :

- The measured anchor loads present a steep drop of the measured anchor forces after about 26 days. This is due to the tensioning of the horizontal anchors of the sheet pile wall of the recieving pit at the other side of the railway (see figure 2). Indeed, in order to speed up the execution, this wall and its horizontal anchors connected to the present wall, has been installed earlier than envisaged during the design.
This decrease of the anchor load due to the prestressing of the horizontal anchors is observed mostly in the first row and, as can be seen on the graph, the original anchor loads are recovered after a few days. This is probably due to a small rotation of the soil volume between the 2 walls, indicating that this soil volume contributes very little to the overall horizontal stability. Due to the very low stiffness of the soil (confirmed also by the decrease of 12 cm in the distance between the two walls during the pretensioning of the horizontal anchors), this is not astonishing at all.

- The anchor forces in the first row increase less during the excavation of phase 3 than the calculated increase, this is even more the case with the anchor forces in the second row during and after the final excavation. This is probably caused by the creep of the anchors and/or soil, a phenomena that is not modelled in our calculations.
The decrease of the anchor forces in the first row during and after the final excavation is probably also due to this same phenomena.

- The decrease in the anchor forces of the first row during the pretensioning of the second row corresponds more or less with the calculated decrease (with 90% pretensioning).

- During the passage of the trains no increase in the anchor loads is observed at all, even for very heavy transports. A logical question is then at what stage, and for what amount, the traffic loads have to be taken into account in the design of retaining walls with pretensioned anchors.
This may also be a reason for the overestimated final anchor forces obtained in the calculations.

CONCLUSIONS

With the use of the finite difference method (FLAC) reasonable estimates can be made of the horizontal and vertical displacements of a retaining structure with prestressed anchors.
The anchor forces can also be reasonably estimated although they tend to be slightly overestimated for the final construction phase. Creep in the anchors and/or overestimation of the traffic loads seem to be the cause.

The installation of anchor load cells of the type used (with manometer gauges) is to be recommended for all retaining walls close to existing structures. Their installation is simple, they are not very expensive, and they can easily be recuperated for future use on similar walls. All the data thus obtained can be very valuable for an increase in the understanding of the interactions between soil, wall and anchors and the influence of their installation methods.

These measurements can enable us for example to do further research on the values of the traffic loads that have to be taken into account for the design. Research on the modelling of the creep of the anchors would also be useful.

ACKNOWLEDGMENT

The authors wish to thank Mr.Couchard of TUC RAIL for the permission to use the results of the calculations and the observed data for this publication.

REFERENCES

1. DE SCHRIJVER P., MAERTENS J., LIEVENS G., DE GEYTER G. and DE VOS W. : NMBS, Railway tunnel, Halle, Belgium. Proceedings XI ECSMFE, DGF-BULLETIN 11.
2. User's Manual ESA, Release 3.01, Scientific Application Group (SCIA), 1990.
3. User's Manual FLAC, Version 3.2. Itasca Consulting Group Inc., 1992.
4. BUSTAMANTE M. and DOIX B. : Une méthode pour le calcul des tirants et des micropieux injectés. Bull. liaison Labo. P. et Ch., 140, nov.-déc. 1985, pp. 75-92.
5. Glötzl, technical information on hydraulic loadcell, type KN 1000 A 75(105) M 4.