A special construction of the HSL-crossing with the A15 at Barendrecht, Holland.

Kees HUISMAN
Civil Engineer
Delta Marine Consultants
Gouda, Netherlands

Piet van DUIJNEN,
Geotechnical Engineer
Holland Railconsult
Utrecht, Netherlands

Summary

Under the first span of an existing viaduct a new tunnel has to be build. Therefore a retaining wall, with a total height of 18 m and a limited horizontal displacement of 20 mm had to be designed. To overcome al the boundary conditions a jet grout wall reinforced with a sheet pile was chosen. The jet grout columns are installed in very soft soil (peat and organic clay). In this paper the design of the wall and results of a live scale jet grout test is described.

Keywords: Jet grout columns, soft soil, soil improvement, Dive under Barendrecht

1 Introduction

The crossing between the high speed link Amsterdam – Paris near Rotterdam, Barendrecht and the existing highway A15 generated a specific difficulty: a dive-under had to be build at a depth of 16 m below the first deck of an existing viaduct. The (horizontal) movements of the existing land abutment have to be kept to a maximum of 15 mm. The horizontal movement of the building pit wall has to be kept up to a maximum of 20 mm because of the existing horizontally loaded piles under the land abutment.

The deck of the existing flyover has a width of 80 m and a span of 17 m. The abutment is founded on piles and rises to approximately 8 m above ground surface. The new dive-under will require an excavation to some 8 m below ground level. This means that the embankment of de abutment has to be removed, and an additional 8 m deep pit has to be dug out. The total height of soil to be retained is about 18 m. A major issue of the works is the permanence of the horizontal stability of the abutment and the bending moments in de piles supporting the land abutment that support it, as a result of horizontal soil movements.

A retaining wall of 18 m and an allowed displacement of 20 mm do mean that a very stiff wall has to be constructed. Further more the wall was very close to the existing pile foundation of the land abutment. The solution we came up with was a wall of 16 m long jet grout columns. Over a depth of 11 m, in the tension zone, the jet grout is reinforced with steal sheet piles. To connect the sheet piles with the jet grout, steel strips (40 mm width) are added at the bottom and on the top a concrete cap. (Figure 2 and 3)
In this paper we will present the design method. At the end we will compare the measured displacements with the predicted displacements.

2 Construction stages

In figure 1 is the cross section given at the start of the project, and the cross section at the end of the project.

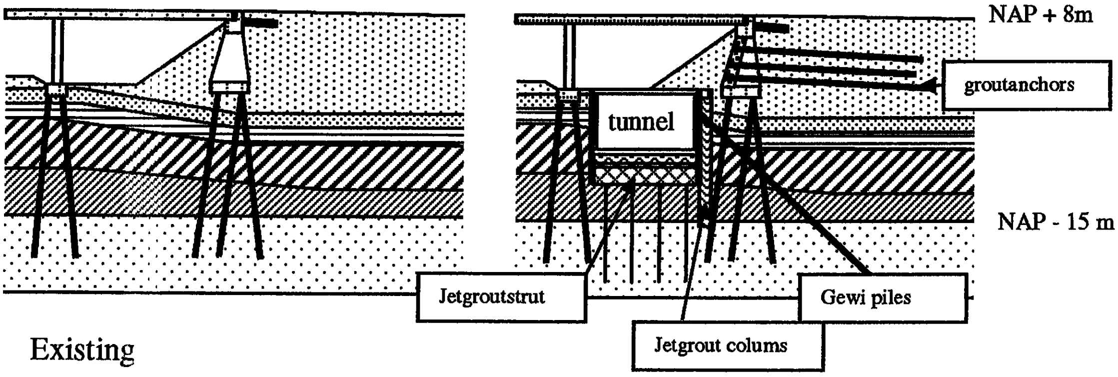

Figure 1. Cross section at the start and at the end of the project.

All the construction stages are mentioned in table 1.

Table 1. Construction stages

Stage	Description
0	initial situation
1	installation of sheet pile (Arbed AZ 48) parallel and nearby to abutment number 2 construction of the an temporary embankment up to a level of +4 m to get a work platform Installation of injection tubes and the installation of grout anchors
2-7	excavation embankment and prestress of groutanchors
8	installing of sheet pile (Arbed AZ 26) parallel and nearby existing land abutment installation of the jet grout columns behind (right side) the sheet pile AZ 26 installation of the jet grout strut at a level of -8 m to - 10 m
9	installation and prestressing the strut at a level of -1 m
10	excavation of a small trench for the installation of the GEWI piles under 45 degrees
11	installation of the GEWI piles under 45 degrees
12	wet excavation until a level of -8 m
13	installation of the under water concrete
14	dewatering building pit
15	construction of the tunnel
16	replacement of the embankment
17	calamity failure of the GEWI piles under 45 degrees [piles removed, long term influence]

3 Soil properties

The site investigation exits of cone penetration tests (CPT's) and Ackermann Boreholes. Up to a depth of 15 m below ground level the soil was made of soft peat and clay layers. Below the level there is a 10 m thick sand layer on top of a stiff clay layer. On the site soil samples where taken from the soft clay and peat layers. In a laboratory unit weight test and triaxial test where carried out on the soil samples.

In table 2 the strength parameters and table 3 the stiffness parameters are presented.

Table 2. Representative (5% lower values) strength parameters.

Soil	Model	γ_{dr}/γ_{sat} [kN/m³]	c'_{ref} [kN/m²]	ϕ' [°]	ψ [°]	OCR [-]
Sand,	HS	18/20	1	35	5	1.1
Sand, silts	HS	17/17	1	25	0	1.1
Peat	HS	10.2	13	12	0	1.1
Organic soft	HS	13	6.5	19.3	0	1.1
Clay, medium	HS	16	2	30	0	1.1
Sand, medium	HS	19/21	1	32.5	2.5	1.1

HS Hardening Soil Model

Table3: Representative (5% lower values) stiffness parameters.

Soil	Model	E'^{ref}_{50} [kN/m²]	E'^{ref}_{oed} [kN/m²]	E'^{ref}_{ur} [kN/m²]	ν_{ur} [-]	m [-]
Sand, remoulded	HS	25 000	25 000	75 000	0.2	0.5
Sand, silts	HS	5000	5 000	15 000	0.2	1
Peat	HS	2 100	1 500	6 300	0.2	1
Organic soft Clay	HS	3 600	2 600	10 800	0.2	1
Clay, medium	HS	7 400	5 300	22 000	0.2	1
Sand, medium	HS	50 000	50 000	150 000	0.2	0.5

4 Jet grout investigation

With the installation of jet grout columns in soft clay and peat there is not much experience. Nearby the building site a life scale test was done. To gain the necessary process adjustments 26 jet grout columns were installed. Each column is produced with slightly different process parameters. Direct after the installation the diameter of the column was measured, where 1.50 m was required. Five of the 26 installed columns had the required diameter. In these five columns bore holes (ø 66 mm) were made.

On jet grout samples unconfined compression tests and split tension test where carried out, total 51 tests. The average ratio of diameter/height for the compression test was 2, with a minimum of 1.5. In figure 2 the measured tension, compression and modulus of elasticity is presented.

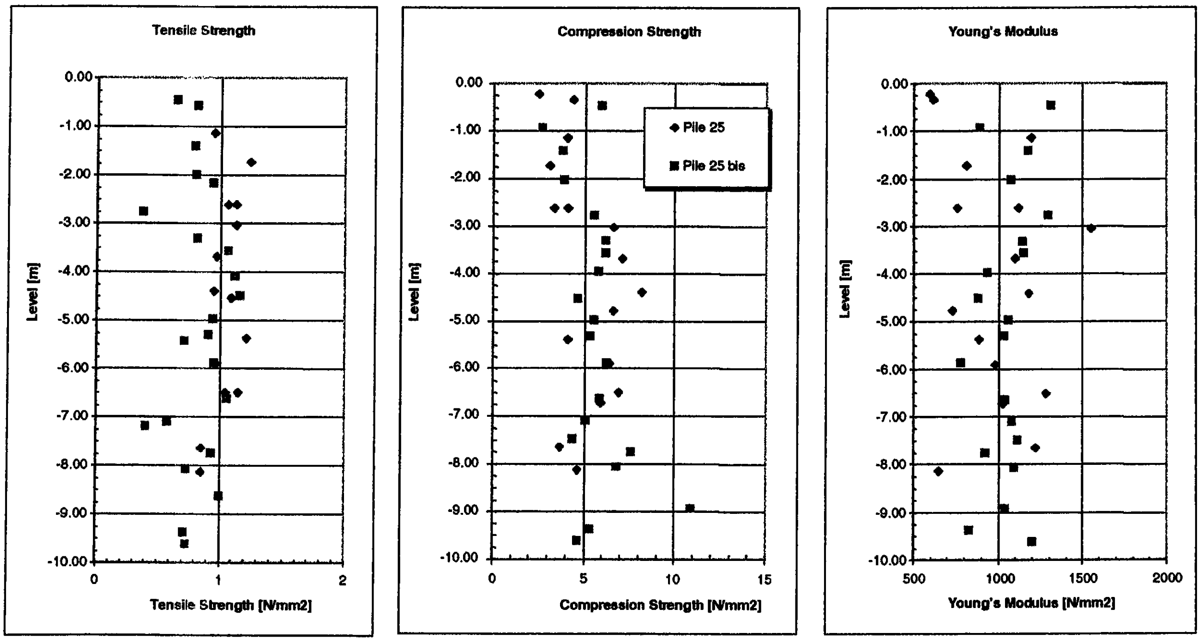

Figure 2: Test result jet grout column 25

The measured strength parameters where also statistically analysed. Al the test results between 3 and 10 below surface level where taken in one population. In table 3 the results of de statistical analyses are given. The mean compression strength was 6 N/mm^2. The tension strength is about 15 % of the compression strength.

Because of the fractures in cores the strength parameters are further reduced by 20 %.

Table 3. Statistic analyses of the compression and the tension test results jet grout

(20 to 30 days after installation)

	Compression [N/mm^2]	Tension [N/mm^2]	modulus of elasticity [N/mm^2]
Number of test	25	26	25
Mean value	6.02	0.93	1035
Standard deviation	1.51	0.19	190
Variation coefficient	0.25	0.20	0.18
Minimum measured value	3.70	0.41	649
Maximum measured value	10.93	1.16	1552
5% lower value student T [normal] distribution	3.39 [3.54]	0.60 [0.61]	704 [722]
95% top value student T [normal] distribution	8.66 [8.51]	1.27 [1.25]	1366 [1347]
Calculation value serviceability state	2.71	0.48	560 / 1370
Calculation value for ultimate limit state	1.35	0.24	1800

About 16 jet grout samples where were tested after 96 days. The mean value of the strength parameters was in the same other as the values mentioned in table 3.

5 Calculation

The calculations are made with the finite element code for soil mechanics Plaxis, version 7.2. The calculations where made in two stages. In the first stage the jet grout real scale test was still in progress. In this stage the values for the jet grout strength were taken from investigations for the North-south line in Amsterdam. In the second stage the jet grout test results were available. The strength properties which came out of the life scale test in Barendrecht were higher then in the first stage calculation, so a little optimisation was possible.

The calculations are made with 5% lower boundary values. For the safety check a phi-c reduction calculation was done. The strength control calculations were also done with the upper value (95 %) of the modulus of elasticity for the jet grout. The required factor was 1.5. In relation with the mean values of the jet grout the safety factor is more than 6.

In the calculations all construction stages were taken into account for in total three cross-sections. In figure 3 the effective stresses are given in the construction stage of a dewatered building pit.

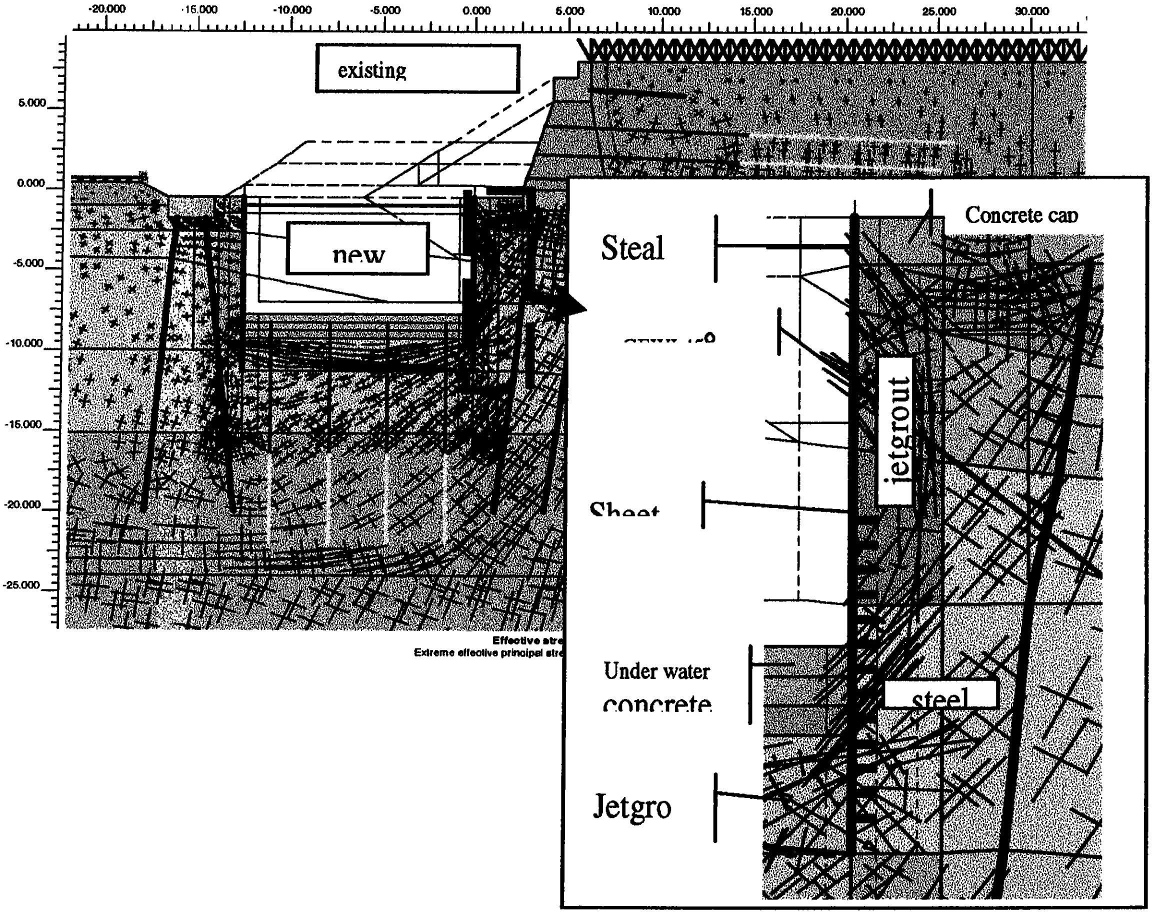

Figure 3. Calculation stage: building pit is ready for construction of the tunnel.

6 Check calamity

The assumption that the steal sheet pile and the jet grout column work together as one beam was a design risk. Therefore steal strips where constructed on the sheet pile to insure the friction between the sheet pile and the jet grout. Nevertheless calculations were made for the case that there was not any friction between the sheet pile and the jet grout column. The displacements increased with a factor of 2, but the construction would not collapse.

In a second calamity calculation the stiffness parameters of de soil were reduced by 50%. The prestress force of the GEWI anchors was increased by 50%. The calculated displacements in that case were just a little bit higher then in the earlier design calculations. Therefore, in reality 50% extra GEWI anchors were installed. When the measured displacements are larger then the calculated displacements the prestress of the GEWI anchors can be increased.

7 Monitoring

During construction of the tunnel the displacements are intensively monitored. In figure 4 the measured displacements are compared with the calculated values at the present state, April 2003.

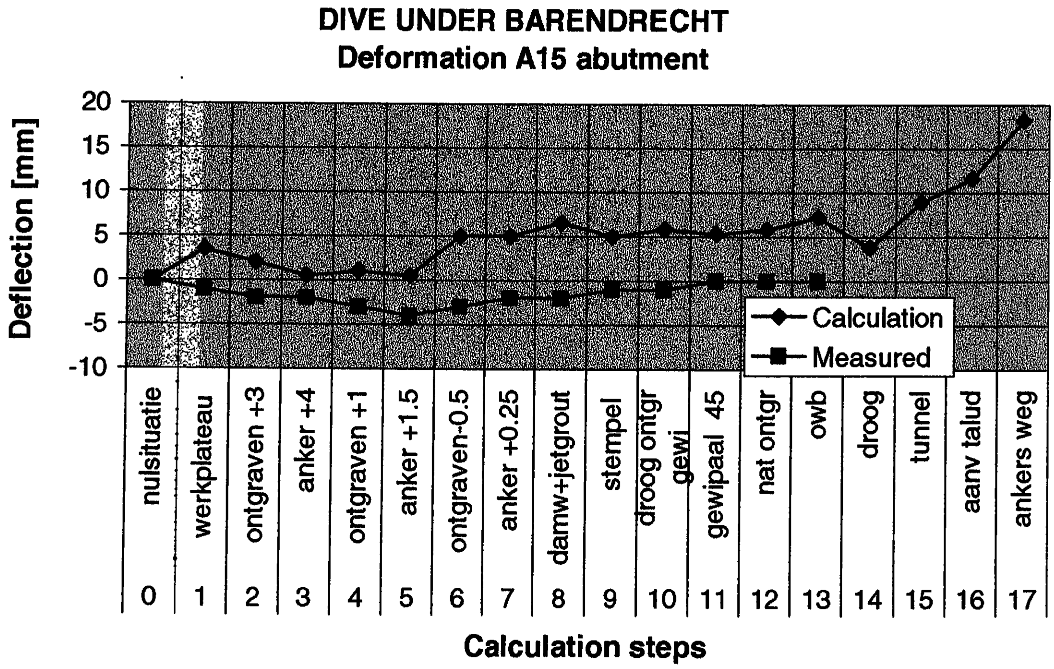

Figure 4. Comparison of calculated and measured displacements (for 1 cross section).

8 Conclusions

It is possible to constructed jet grout columns in very soft soils, such as peat and soft clays. The average compression strength is about 6 N/mm^2. The tension strength is about 15% of the compression strength. Samples where tested 20 to 30 days after installation and about 90 days after installation. No increase of strength is seen. Only the variances coefficients seems to be going smaller in time.

With the finite element code Plaxis calculations were done to predict the behaviour of a wall made of jet grout columns reinforced with sheet piles. At the middle of the project the calculated displacements are higher then the measured displacements. The calculations are done with the 5% lower limit values, so there suit be a little over estimation of the displacements. For the present stage the calculated displacement for the land abutment is 6 mm. The measured displacement is around 0 mm. At this moment it is to early the make the final conclusions, but it seems the construction can be mentioned as a solid type. Practically spoken no deformations have taken place.