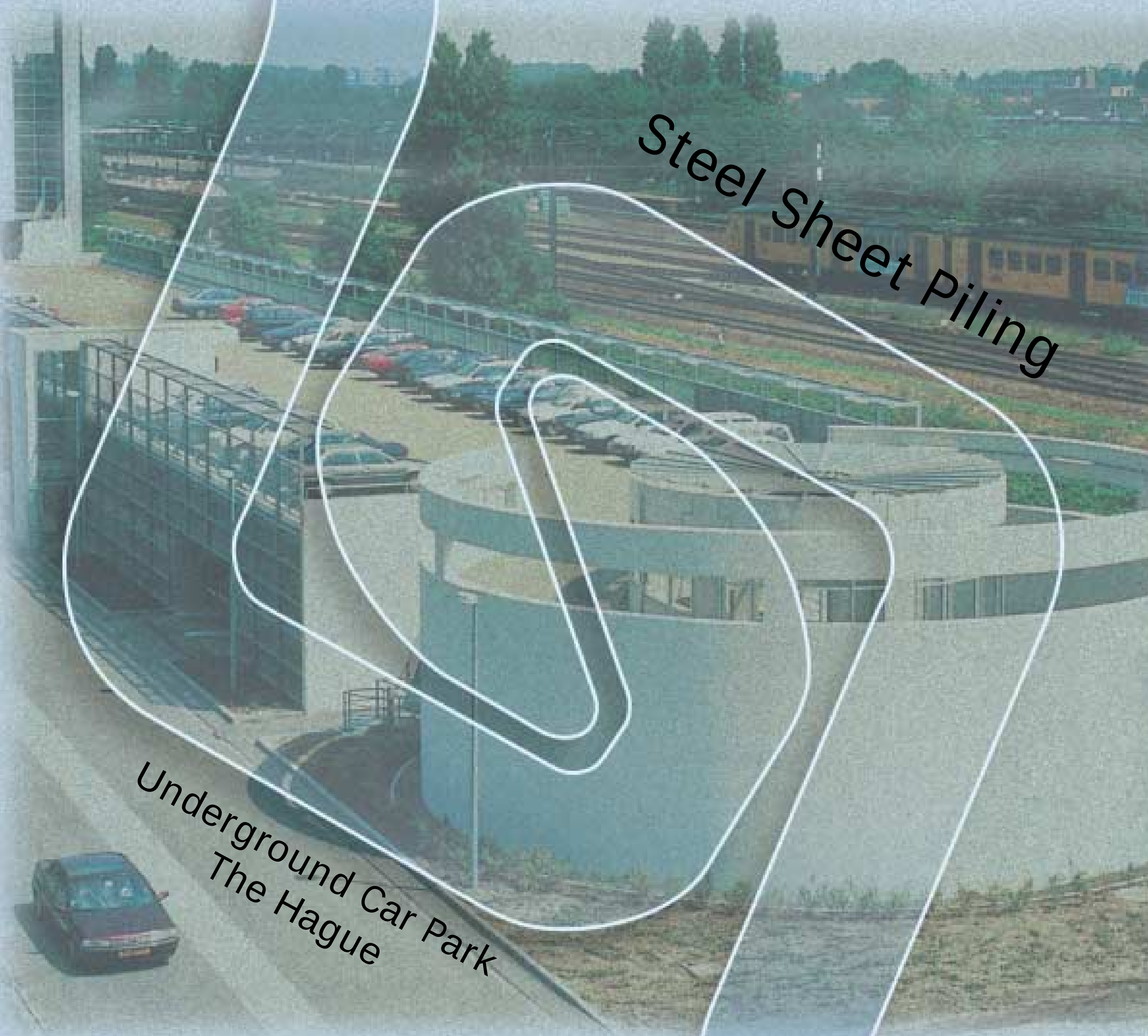
Steel Sheet Piling



Underground Car Park
The Hague

PROFILARBED S.A.
Arcelor Group

CERTIFIED ISO 9001

Introduction

1.

This case study considers the design and construction of a multi-storey car park in which steel sheet piling was used as an integral part of the load bearing structure.

The car park was built as an extension of the head office of Siemens Nederlands N.V. in The Hague and lies adjacent to the railway linking The Hague to Amsterdam. The complex comprises 12,000 m^2 of office space and an underground car park for more than 550 cars.

The car park is constructed partially below ground level. The part above ground consists of the ground floor, first floor and roof park. The underground part comprises two levels of parking which extend beneath the upper levels and the adjacent road. The design is rectangular in shape, being 138 m long by 16 m wide on the surface and 32 m wide below ground. The deepest basement level is approximately 5.4 m below ground level, whilst the top level is approximately 5.4 m above ground level. The vertical distance between each level is 2.7 m but the usable height is 2.2 m due to the thickness of the floor members. (Fig. 1)

Vehicular access to each level is by means of two carousels, one at each end of the car park.

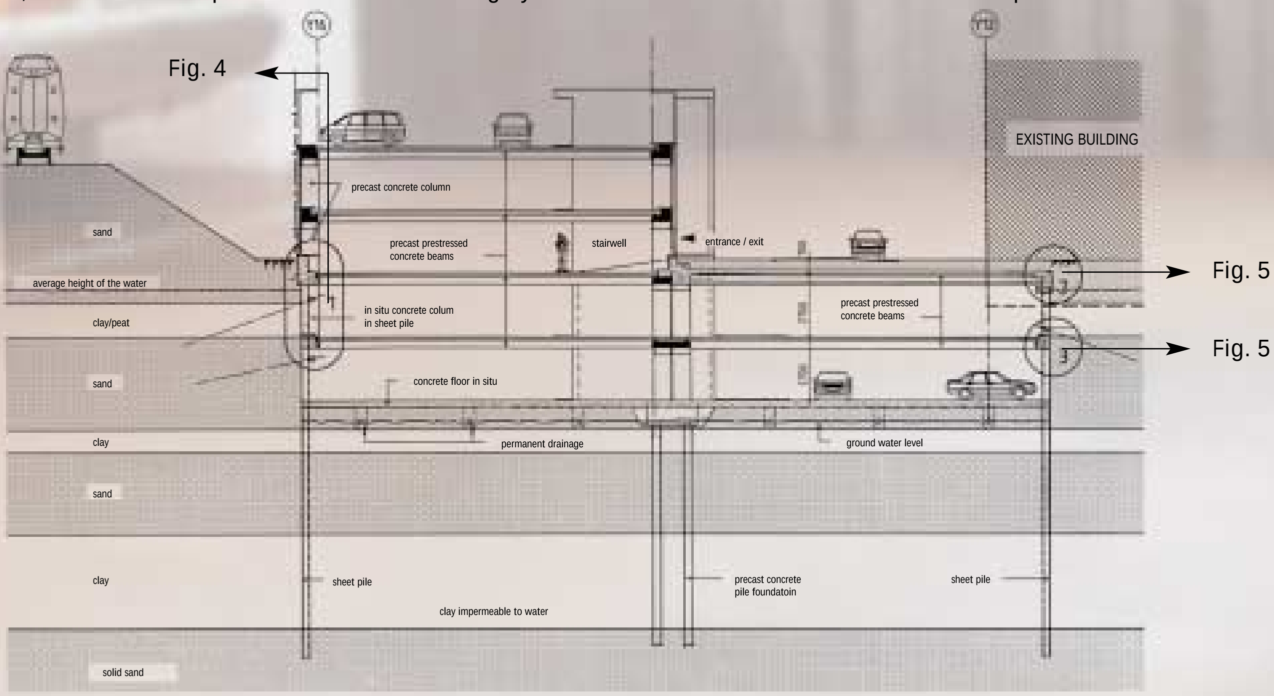


Fig. 1

2. Site conditions

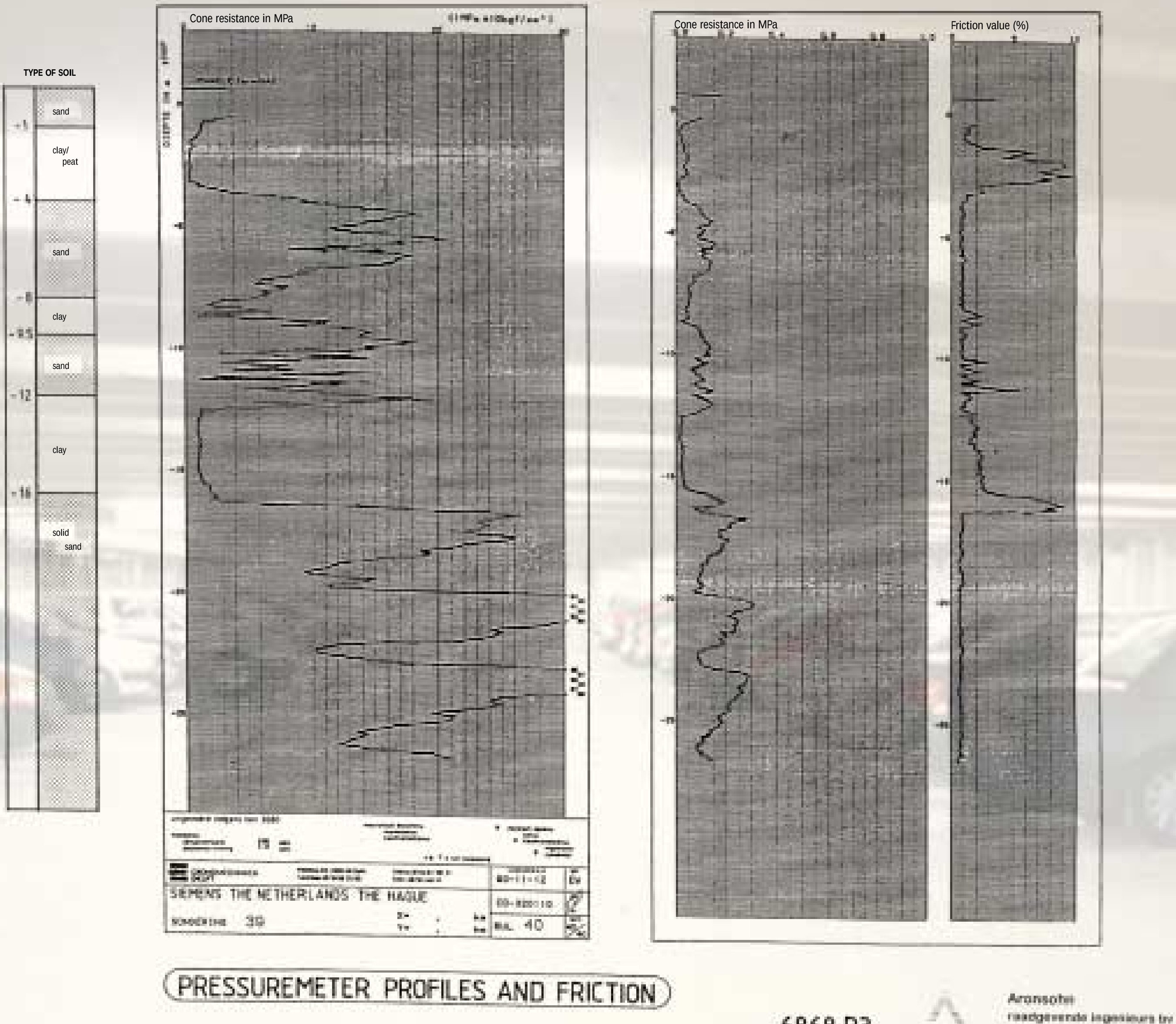


Fig. 2

2.1. Location

Since existing buildings were close to the proposed site it was necessary to take measures to limit the noise during pile installation.

Railway embankment

The design requirements specified that the subsidence of the rails had to be minimised as far as possible. Special care was taken with regard to subsidence of the railway embankment during the construction phase, particularly when driving the piles and when digging and draining the excavation. It was necessary to phase the piling work and use low vibration installation methods together with an extremely rigid piling system in order to minimise the effects on the railway.

Finally, it was necessary to include measures to avoid increased corrosion of the piles as a result of any stray currents in the ground coming from the adjacent electric railway.

Existing public road

A public road existed on the site before construction started and once the car park was completed the road would be re-installed on the top of the underground part of the car park. The road was not in use during the construction phase but would be used for access on completion. The design, therefore, had to take account of the normal urban traffic load expected to use this road.

2.2. Ground conditions (Fig. 2)

The nature and the characteristics of the soils are of great importance when designing a foundation. During the initial design process the ground conditions were determined on the basis of earlier soil analysis carried out for the adjacent building. The results were subsequently confirmed by soil analysis at the site location. This consisted of a permeability study and a geotechnical study of the excavation, together with a bearing capacity study of both bearing and sheet piles. The ground consists of a post glacial sequence approximately 16 m thick, overlying a Pleistocene sand sequence. The post glacial sequence consists of the following:

0 to 3.5 m An impermeable layer with fine sand on top and clay and peat below.
3.5 to 7.5 m A permanent water bearing sand strata.
7.5 to 9.0 m A second impermeable, slightly cohesive layer.
9.0 to 13 m The second permanent water bearing sand strata.
13 to 16 m Finally, an impermeable clay which varies in thickness from 3.0 to 3.5 m.

Below this post glacial layer, the pleistocene sequence consists of a very compact sand. The ground water level is 1.5 m below the ground surface.

2.3. Groundwater drainage

The aquifer below the deepest impermeable clay is used as a drinking water reservoir for The Hague and must not be affected by drainage. The regional and local authorities have stipulated that drainage of groundwater must not exceed 1.5 m^3/h for this project. Thus, it was necessary to ensure that the car park was made as impermeable as possible. During the hydrogeological study an estimate was prepared of the expected seepage into the sheet pile supported excavation. It became apparent that to ensure that the groundwater seepage remained below the stipulated levels it would be necessary to take additional precautionary measures.

Since the aquifer would be under hydrostatic pressure, the design needed to take into account the possibility of ground heave in the lower impermeable layers.
The excavation was limited to 6 m below ground to provide sufficient vertical stability.
Heavy drainage of the upper layers, which are prone to subsidence, would result in subsidence of the buildings adjacent to the car park. So, for this reason, it would be necessary to use a steel sheet piling cofferdam in the construction of the foundations.

3. Design considerations

Two alternative designs were considered when designing the car park. A closed concrete structure and the chosen option, an open steel piling structure. (Fig. 3)

3.1. Closed concrete structure

A conventional closed concrete structure would consist of a concrete basement cast in-situ. The thick concrete floor would be set on concrete bearing piles and provision would be made at the bottom of the structure to prevent lifting.
A variant of the same structure with only one level below ground was not an attractive proposition because of the increased floor area needed.

Both of these concrete solutions would also require extensive use of sheet piling in the form of temporary cofferdams.

3.2. Open structure constructed using steel sheet piling

Since an impermeable clay layer 3.5 m thick exists above the very dense sand, an open structure was considered as a viable option. This structure consists of a car park supported on all sides by steel sheet piling that had been driven through the clay into the sand. In the middle, a separate system of bearing piles is also driven into the dense sand.

In this case, the clay layer and the piling form a near watertight seal to the basement of the garage and have sufficient vertical stability to resist heave due to hydraulic uplift. As there is the possibility of

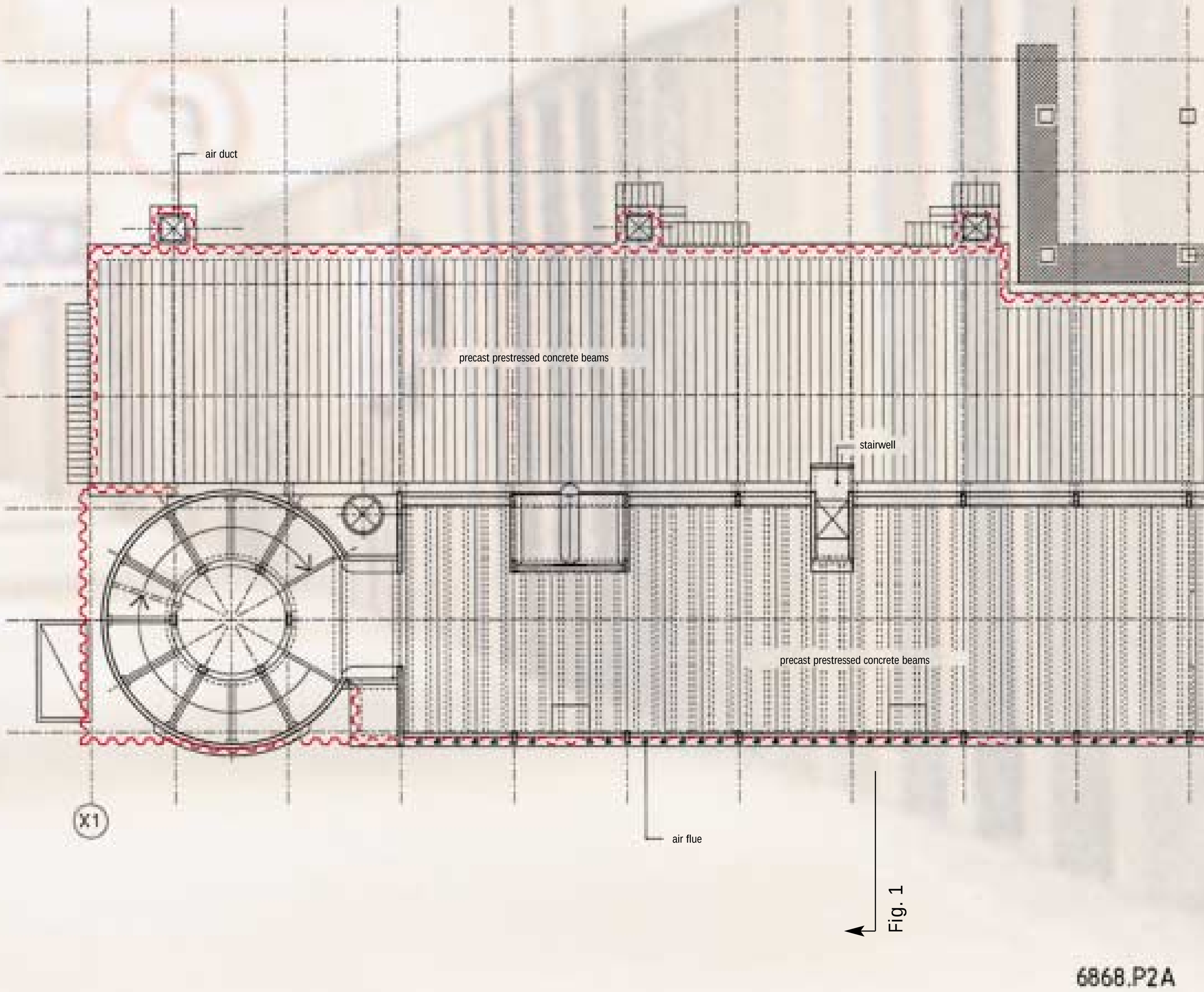


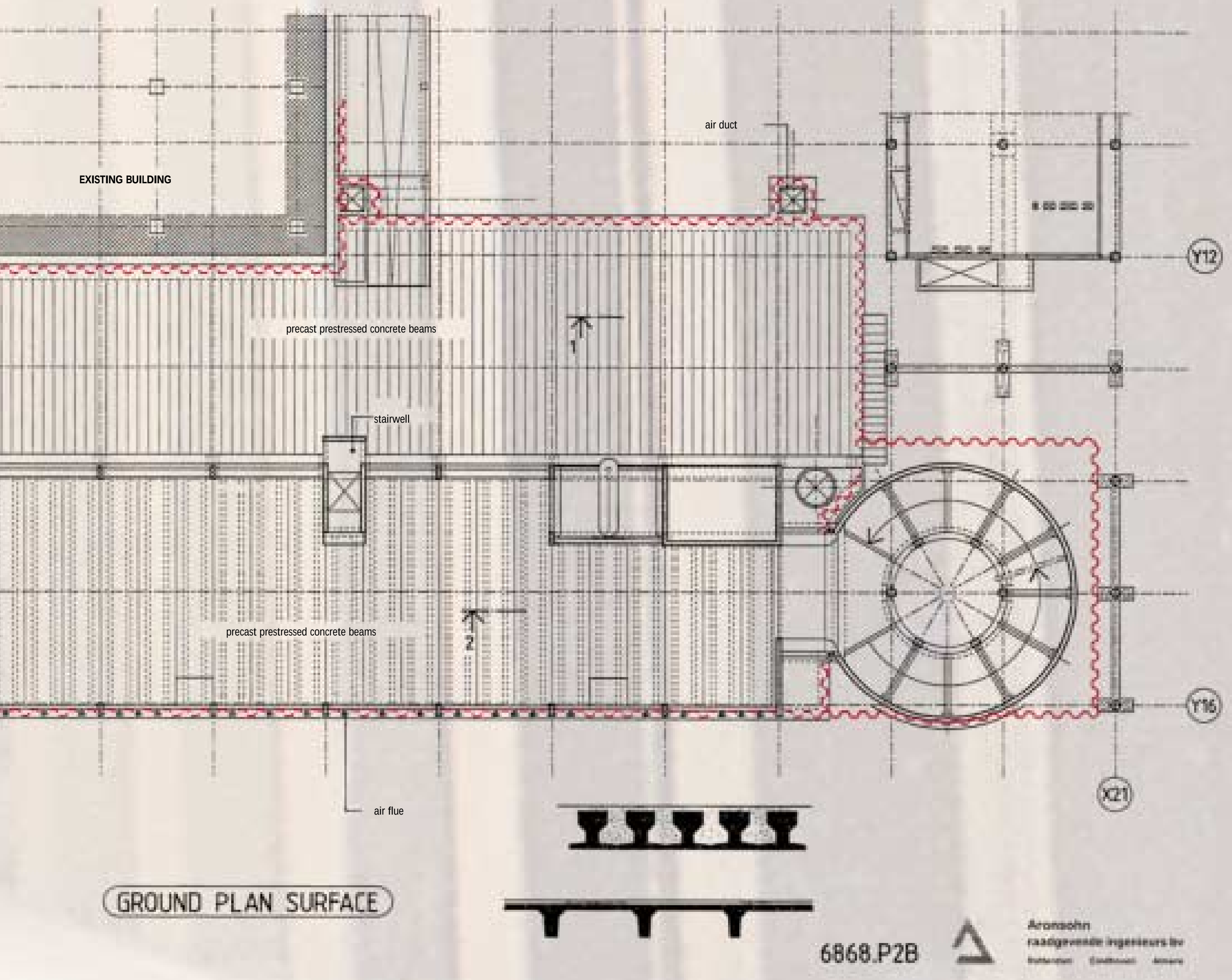
Fig. 3

a slight amount of leakage along the interface between the piles and the clay, a permanent drainage system has been installed approximately 0.5 m below the deepest car park level.

The floor for the deepest level was designed as a thin concrete strut. This floor has a series of openings in it, in the form of small pavement sections set on sand. These allow water to pass through in the event of the car park flooding and prevent the floor becoming distorted due to water pressure in a flood situation.

When comparing the two alternatives on the basis of cost and speed of construction, the open structure, employing steel sheet piling, proved to be approximately 15% cheaper than the conventional concrete option.

The clients' design consultants had recommended that consideration be given to remedial measures needed in the event of higher water inflow than expected. This would only become apparent during excavation and could originate from the piling interlocks or from the pile to clay interface. If needed, the remedial measures foreseen are grouting behind the piles or into the floor.



4. Loads to be considered

Horizontal loads

The horizontal loads on the structure include:

- Wind load on the superstructure in accordance with NEN 3850.
- Soil pressure against the substructure.
- Lateral pressure from the railway embankment.

Vertical loads

The vertical loads consist of:

- Self weight.
- Live load on the floors in the garage.
- Live load on the garage roof.

Load transmission

These loads are transmitted to the foundations in the following way:

4.1. Vertical load transmission

On the railway side (Y16)

The vertical load of the superstructure is transmitted through the floor beams onto precast concrete columns which are sited at 7.2 m centres. The columns in turn rest on a capping beam cast onto the sheet piling which redistributes the point loads of the columns into the sheet pile wall. (Fig. 4)

The underground floors of the car park are supported directly by beams that bear directly onto the sheet piling. The deepest floor of the car park is founded directly on the subsoil and is not supported by the sheet piling.

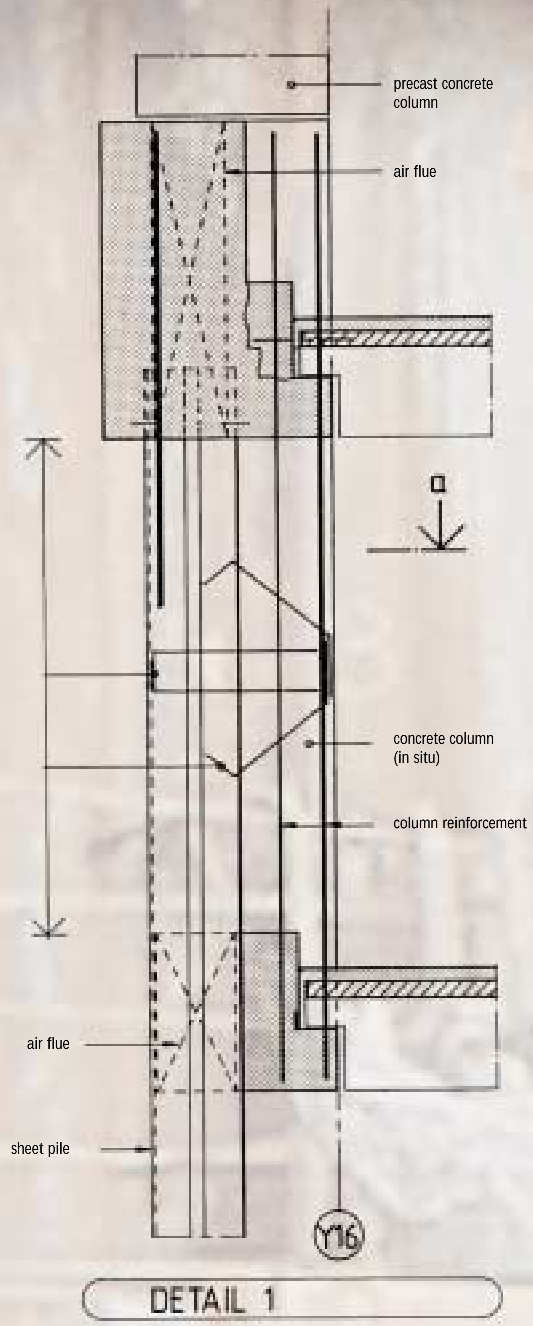


Fig. 4 - Vertical load transmission

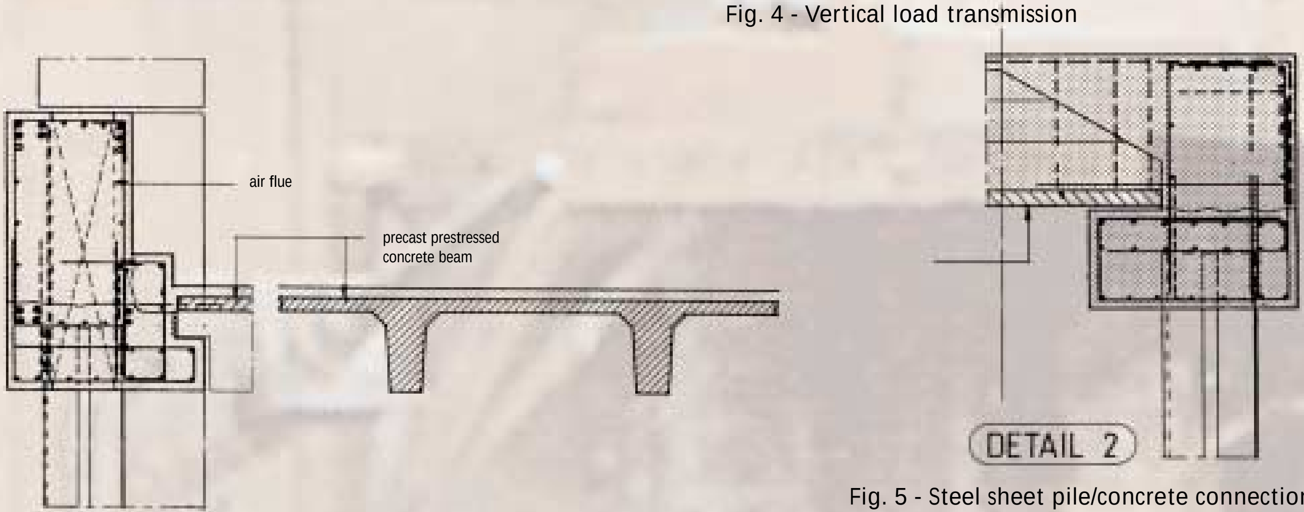


Fig. 5 - Steel sheet pile/concrete connection

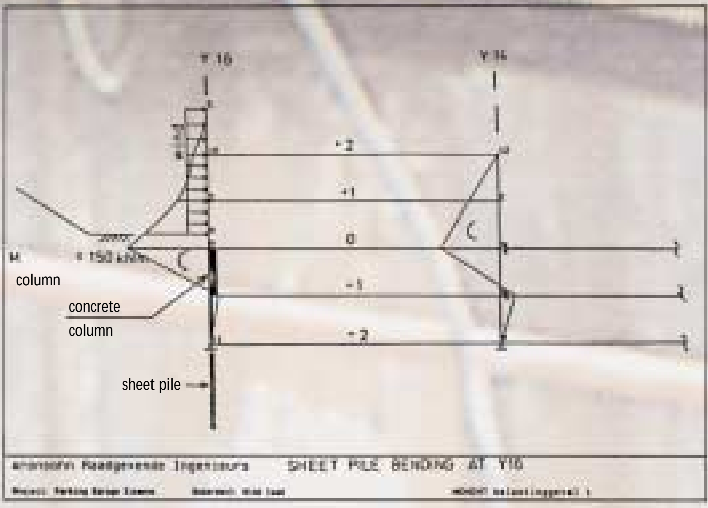


Fig. 6 - Sheet pile bending at Y16 due to wind load

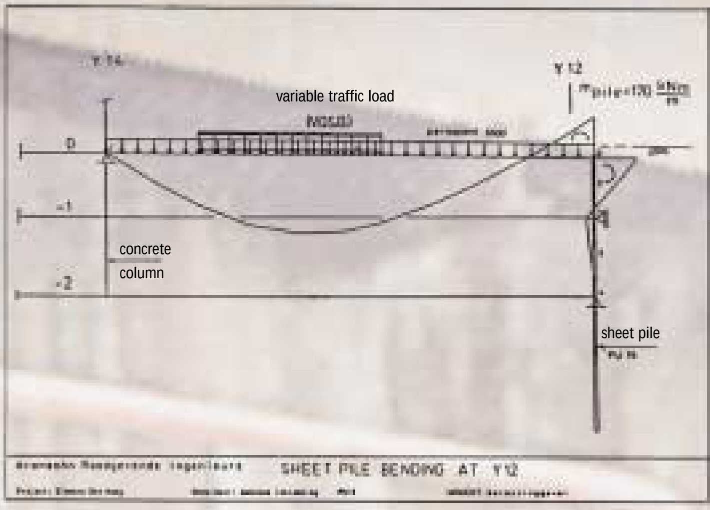


Fig. 7 - Sheet pile bending at Y12 due to variable traffic load

On the central axis

A double row of columns on the central axis of the structure is supported on bearing piles, which are founded in the dense sand 18 m below the surface level.

On the office side (Y12)

The vertical load due to traffic on the office side of the garage is transmitted to the supporting sheet piling as an evenly distributed load. The roof comprises 16 m long girders which rest on a capping beam cast onto the sheet piling. The basement floors are constructed adopting the same method used on the railway side of the building. (Fig. 5+7)

4.2. Horizontal load transmission

Horizontal load transmission of the superstructure (Fig. 6)

The design of the structure is such that the horizontal wind load is not transmitted directly to the sheet piling, but is transmitted to the ground floor and the basement floor beneath it, forming together with the in-situ concrete columns a stiff frame and so absorbing this additional moment.

The load bearing system of the lower structure

The sheet piling supports the ground pressures in both the construction and working phases of the structure. During the temporary stages, ground anchors and wallings were used for support, where as the floors of the completed structure supported the walls in the long term.

in situ casted concrete beam with reinforcing bars welded to steel sheet pile; Anchorage

5. Calculations

The main calculations used in the design of the steel sheet piling

The sheet piling serves as both the support to the ground and the vertical loads from the structure above.
The profile chosen was the PU 16 type of sheet piling (in steel quality PAE 250 in accordance with Euronorm quality Fe340 B).

Stresses as a result of vertical load

The stresses in the sheet piling resulting from vertical loads comprise a normal compressive stress and a local bending stress where the capping beams are formed at the top of the piling and where the underground floors are fixed to the walls.

Normal vertical force

This consists of the vertical component of the ground anchor force in the temporary case and the load of the structure and its contents in the permanent case.

The bending stress in the steel

This falls into two parts:
• The localised bending in the piles due to the connection of the floor members and the transmission of the vertical load.
• The bending moment due to the ground pressure.

Bending of the railway side wall on line Y 16 (Fig. 8)

The sheet piling showed little or no bending due to the vertical or floor connection loads transmitted to it.

Bending of the office side sheet piling line Y12, due to vertical load (Fig. 9)

The ground floor caused major bending moments at the head of the sheet piling. During the construction phase this was due to the load of the garage roof and, in the permanent condition, from the heavier load from traffic on the road on top of the garage roof.

Deflection of the sheet piling due to the soil loading on the railway side

The deflection of the sheet piling due to soil loading has been calculated using a programme which is based on bi-linear ground springs against the sheet piling.

The railway load has been calculated as an additional horizontal load using the Culmann method. The ground pressure coefficients have been based on assumed failure surfaces.

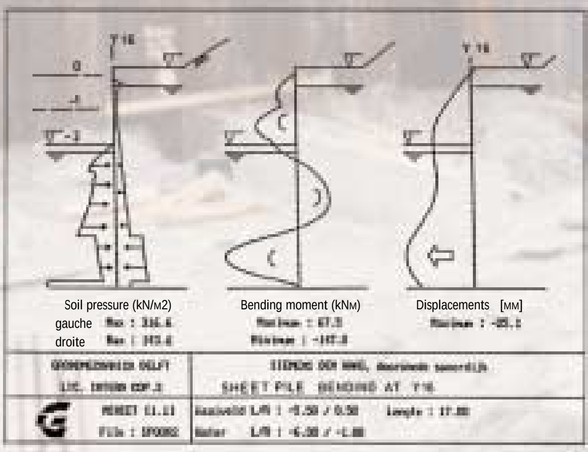


Fig. 8 - Sheet pile bending at Y16 due to soil and water pressure

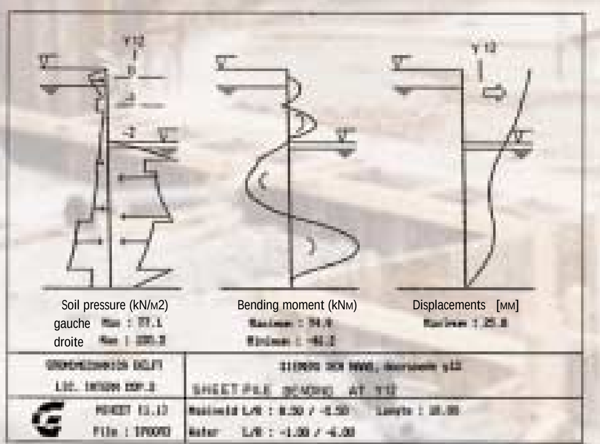


Fig. 9 - Sheet pile bending at Y12 due to soil and water pressure

6.1. Surface treatment

The exposed parts of the steel sheet piling were treated with a layer of zinc-rich primer, then a coat of epoxy primer and finally a coat of epoxy paint.

6.2. Fire protection

No specific measures were taken with respect to fire protection of the steel since the exposed surfaces were backed by saturated soil, which would act as good thermal conductor.
In use, the steel stress in the sheet piling is very low at 40 N/mm^2, which is approximately half of the maximum value.

A slight decrease in the yield point of the steel due to the effects of temperature would not affect the bearing capacity of the sheet piling significantly.

6.3. Corrosion of steel sheet piling by stray electrical currents

In view of the location of the garage, with its steel sheet piling close to an electrified railway line, a study of the possible effects of stray currents was undertaken. Stray currents occur as a result of using the rails as the return for the electricity used by the trains. The voltage of these stray currents depends on the proximity of substations and the type of ground. The corrosion effects can be minimised by ensuring good conductivity between the individual piles and by welding on steel rods at certain points to act as electrical earth pathways, which lead the stray current back to the rails.
By welding on rods in certain spots, it was possible to perform a controlling measurement afterwards. The location of the garage was so favourable that no risk of corrosion due to stray currents was found.

6.4. Impermeability

A sealing product was applied to the interlocks at the factory and the piles were driven into predrilled holes filled with bentonite cement slurry, down to the clay layer. This pre-drilling was carried out to reduce the vibration and subsidence effects on the surrounding ground and structures. However it was thought that piling into bentonite cement slurry would have a beneficial effect on sealing the interlocks. Once the excavation was complete the sheet piling wall was grouted to complete the sealing process.

6.5. Ventilation provisions

The ventilation of the underground part of the garage was dealt with in two ways:

- On the office side of the structure, 5 ventilation shafts were formed using sheet piling. Each shaft was 2.5 m x 2.5 m and extended down to the underground levels from ground level. The top of each shaft is protected with a grill
- On the railway side, mechanical ventilation was provided via small vertical ducts made as part of the vertical columns. (Fig. 10)

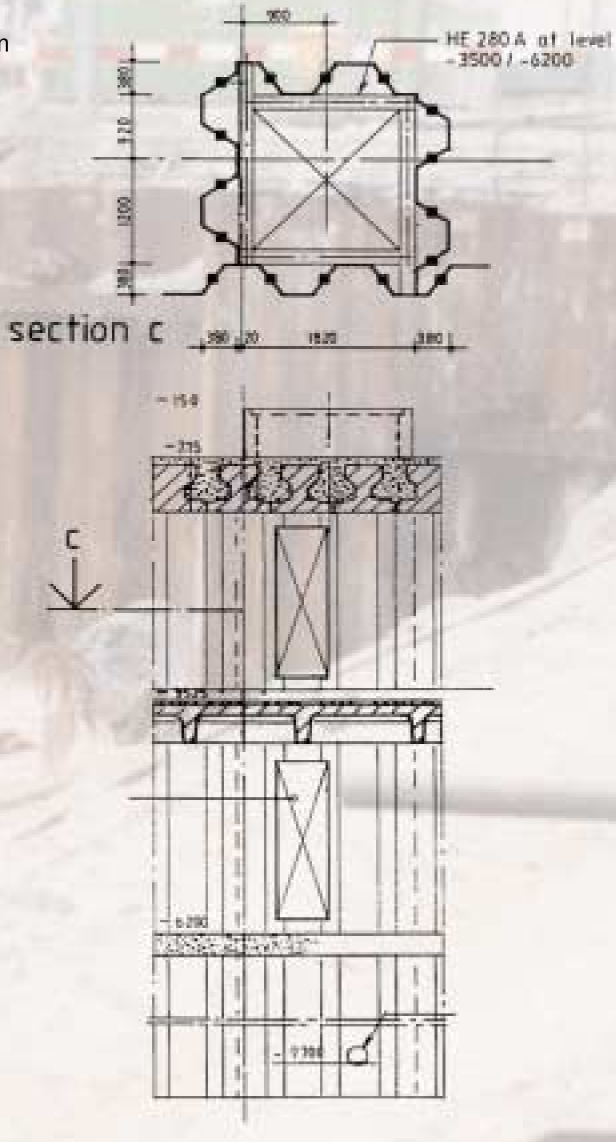


Fig. 10 - Ventilation shaft

7. Phasing of excavation construction

1st Phase: Pre-Drilling of Bentonite Cement filled holes

Holes of 30 cm ø were drilled at 1.2 m spacing (driving width of the paired piles) and filled with a bentonite mix prior to driving the piles. The pre-drilling was necessary to reduce the ground vibrations in order to minimise the potential for subsidence during pile driving and to improve the quality of the sheet pile installation.

2nd Phase: Pile Driving

The piling was driven using a piling hammer with an impact energy of 120 kN/m per blow. The piling was driven in crimped pairs between the pre-drilled holes such that each free lock that had not been previously treated was placed in a bentonite hole. The composition of the bentonite cement mixture was such that it was considered to be extremely watertight with respect to the sheet piling. The centre interlocks of the paired piles have been treated with a bituminous sealing product.

3rd Phase: Excavation to first ground anchor level

During construction, before the car park levels were constructed it was necessary to support the piling by temporary ground anchors and steel walling on the inside. On the side adjacent to the railway, to ensure that track subsidence was kept to a minimum, 2 rows of temporary ground anchors were used. The positions of the anchors correspond to the ground floor and the first basement floor. The third phase of the work involved drainage and excavation to the top anchor level and installation of the ground anchors. In each row, the anchors lay alternately at an angle of 20 degrees and 27 degrees to the horizontal. The top row of anchors had a length of 20 m.

4th Phase: Excavation to lower ground anchor level

The excavation was then taken down to the lower anchor level. In order to reduce the possibility of subsidence a supporting berm was left against the sheet piling adjacent to the railway until the piles on the central axis had been driven. Once the piles on the central axis had been driven, the temporary berm was removed and the lower row of ground anchors was installed, these having a length of 14 m.

5th Phase: Completion of excavation

The excavation is completed and drained to the base level.

reinforcing bars welded to steel sheet pile supporting the in situ casted concrete beams

8. Evaluation

8.1. Impermeability

The requirements stipulated with regard to permanent drainage were amply met. However, some moisture had entered the structure near the sheet piling interlocks which made surface treatment less easy. This seepage was virtually stopped by means of grout injection.

The source of the moisture was believed to be due to capilliary action along the inside of the interlocks from the water bearing aquifer; as the sealing product had been applied on the outside (landside and waterside) of the locks the ground water could only seep out into the garage.

The impermeability of the piling may have been further improved by applying a sealing product inside the entire sheet piling interlock.

8.2. Drainage during construction

Once the excavation had been pumped dry, further drainage was minimal because of the impermeability of the sheet piling. No influence on the surroundings has been observed since the excavation has been drained.

8.3. Inconvenience on the surroundings

As a noise screen was used around the piling hammer during driving, minimal inconvenience was caused to the direct surroundings. The only exception to this was whilst driving the short stretch of piling immediately adjacent to the existing office block.

8.4. Subsidence of the railway embankment

The vertical and horizontal movements of the railway were measured at regular intervals during the various stages of construction. Measurements taken later confirmed that no significant subsidence was measured during the installation of the ground to the final level.

8.5. Maintenance

The drainage pipes are positioned below the ground water level which will reduce the risk of blockage due to drying out. Maintenance is limited to periodic purging of the drainage pipes to facilitate the flow of water.

9. Parties involved in this project

Management: Bouwkundig Adviesbureau Derks b.v., Leiden

Architect: de Jong, Hoogveld, de Kat architecten, Utrecht

Design Consultant: Aronsohn Raadgevende Ingenieurs b.v., Rotterdam

Contractor:
DURA BOUW b.v., Rotterdam

Piling Subcontractor: van Splunder Funderingstechniek b.v., Rotterdam and Visser & Smit Bouw b.v., Papendrecht

Soil Analysis: Grondmechanica Delft, Delft

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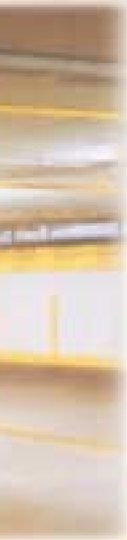

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10. References of underground car parks

Court	Münster	D	picture 1
Congress Centre	Amsterdam	NL	picture 2
House for dentistry	Münster	D	picture 3
Malieveld	Den Haag	NL	picture 4
KLM	Amstelveen	NL	picture 5
City hall	Rouen	F	picture 6
Münsterstrasse	Düsseldorf	D	picture 7
Marketsquare	Coesfeld	D	picture 8
World Trade Center	Amsterdam	NL	picture 9
Haute ville	Rouen	F	picture 10
Royal Christiana Hotel	Oslo	N	picture 11
VROM	Den Haag	NL	picture 12
Zwolsestraat	Scheveningen	NL	picture 13

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