

# New Hoog Catharijne: a 5-levels challenging underground construction

## Le Nouveau Hoog Catharijne, le défi d'une construction de 5 niveaux de sous-sols

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### ABSTRACT

In the centre of the City of Utrecht, Corio project development will built the first Dutch 5 levels underground car parking. The project concerns some especially challenging underground construction topics, such as the use of prefabricated, prestressed concrete walls constructed in slurry walls, extremely highly loaded bored piles, plate pile foundation and building extremely close to nearby high rise buildings. The concept of the car parking also incorporates an integrated canal, which flows midway through the garage!

In this paper first the specific soil and environmental conditions are summarised. After that the special topics concerning the calculations of the construction sequence, pile design, influence on surroundings and groundwater flow modelling are outlined. Special attention is given to the influences caused by the displacement caused by the wall installation.

### RÉSUMÉ

En plein centre de la ville d'Utrecht, CORIO Project Development va faire construire le premier parking souterrain à 5 niveaux de sous-sols des Pays-Bas. La conception de ce projet est un vrai défi, car elle comprend des éléments tels que des parois en béton préfabriqué précontraints, installés dans une tranchée de boue, des pieux forés reprenant une charge très élevée, des fondations mixtes, ainsi que la construction extrêmement proche d'immeubles de grande hauteur. La conception du parking comprend également un canal qui s'écoulera en plein milieu de l'immeuble!

L'article commence par un résumé des conditions spécifiques du sol et de l'environnement. Ensuite sont décrits la modélisation et les calculs hydrogéologiques, le phasage de la construction, la conception des pieux et les effets sur les constructions adjacentes. Il s'agit notamment de l'influence du rabattement de la nappe, des vibrations causées par la construction et des déplacements du sol causés par la réalisation des parois.

Keywords : underground construction, prestressed concrete walls, bored piles, piled raft foundation, groundwater lowering

## 1 INTRODUCTION

Right in the city centre of the town of Utrecht, the Netherlands, CORIO Real Estate Development is planning to build one of the largest and deepest car parking garages in the Netherlands. The garage is part of a much bigger plan, restructuring a large shopping mall and entertainment area called *Hoog Catharijne*.

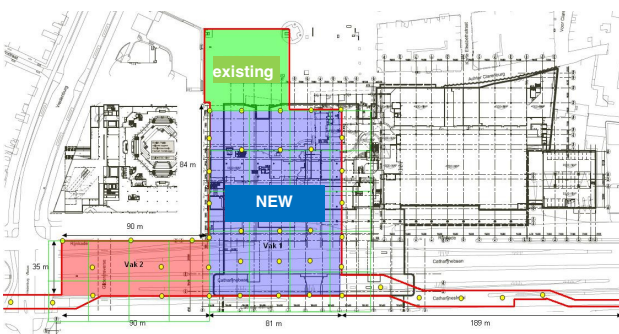


Figure 1. Situation car parking

Because building activities will take place in a densely build and populated area, much attention must be given to the environmental impact of the project.

This paper deals with the constructions as shown in Figure 1. An artist impression of the finished project is given in Figure 2.



Figure 2. Artist impression of finished project; canal and building above 5 levels car parking

## 2 SOIL INVESTIGATION (SI)

An extensive SI program has been performed, consisting of, among others, 45-65m deep CPTs, a 63m deep boring including sampling, oedometer tests and triaxial test. Because part of the construction still has to be demolished, also a CPT was performed from within the existing car-parking. Figure 3 shows the location of the CPTs.

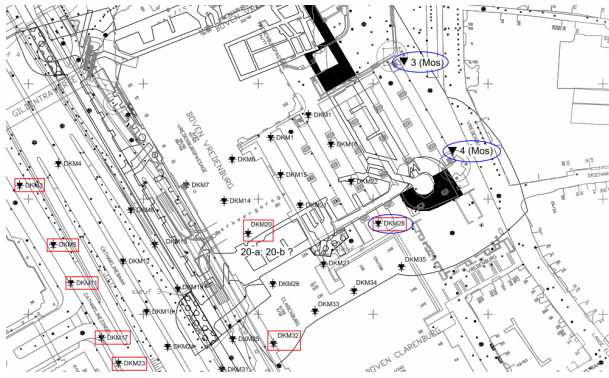


Figure 3. Situation: CPTs - grid

Special attention is asked for the Cone Test. Some test-results can be found in this conference proceedings (Ali et al, 2009) and more extensively in Van der Stoel et al. (2009)

The soil basically consist of a 5m thick top layer of clay, under which a apr. 50m thick, (very) dense, mostly coarse sand layer containing clay lenses is situated. At 55m an apr. 5m sandy loam layer forms a water-resistant barrier, under which, finally a continuous layer of fine, dense send is found.

### 3 ENVIRONMENTAL CONDITIONS

The new car parking is situated just between three existing structures, as can be seen in Figure 4. North of the site lies a high rise building (MP) including a basement founded on piles, east of the site (Vredenburgplein) lies an existing 2 level car parking, south lies a high rise building including a basement with an unknown foundation (VD) and west lies a road including many services (Catherijnesingel). Because there is extremely limited space between the newly to be realised deep car parking and the existing structures, much attention has to be paid to the (differential) displacements that may occur as a result of construction activities. Therefore a FEM analyses was performed for the project, of which one typical cross section is illustrated in this paper.

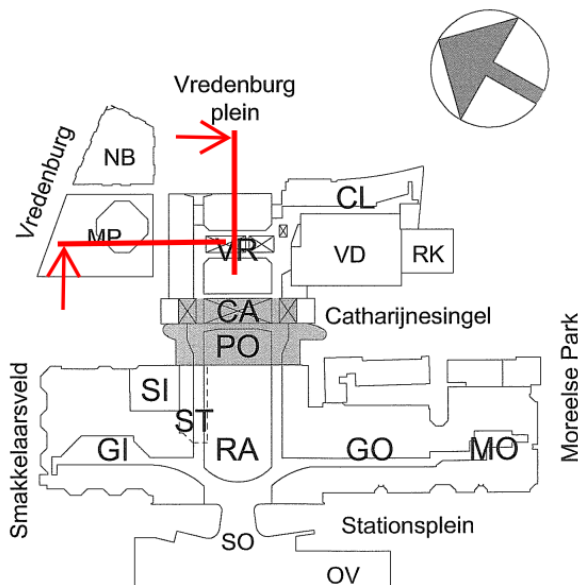


Figure 4. Location of two typical cross sections

The construction of the building pit basically consist of constructing prestressed, prefabricated concrete walls (so called Spanwand) which are placed incement-bentonite / slurry walls.

Excavation is performed per parking level, in which the floors function as struts. The concentrated loads (up to 21.000 kN!) form the high rise building that will be placed on top of the car parking are transferred using a special pile foundation. Because also a canal is integrated in the car park, special attention has to be paid to horizontal and vertical load transfer, see Figure 5.

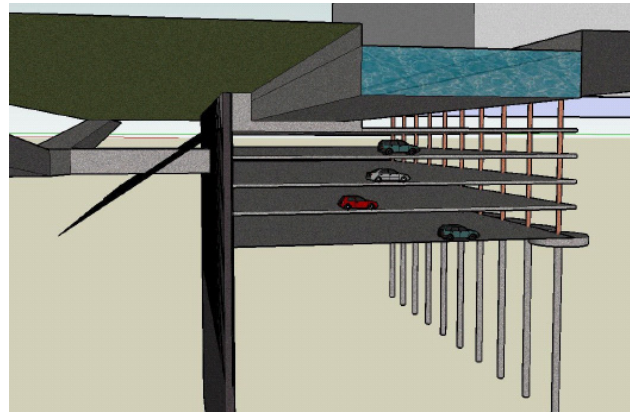


Figure 5. Artist Impression: car parking, Spanwand, (one row of) piles and canal.

### 4 GEOMETRY OF THE CAR PARKING

The existing 2 layer car parking will be partially demolished and connected to the new 5 layer parking. This paper deals with the cross section at this specific location. In Figure 6 the cross section of the FEM PLAXIS model is shown. Calculation have been performed using the 2D Hardening Soil model.

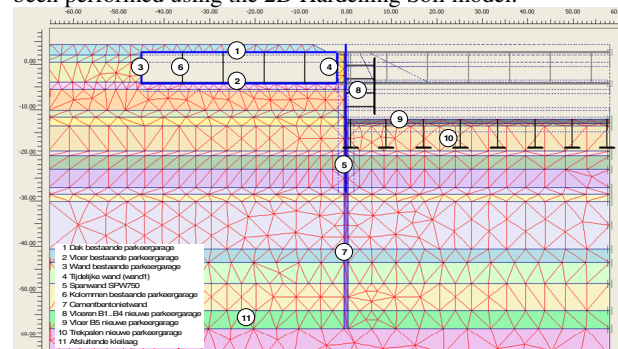


Figure 6. Cross section at existing parking

Groundwater level is situated at NAP+0,6m, calculation have been performed for the drained situation (because the sand(y) soils). The cconstruction sequence has been modelled as follows (measurements in metres to NAP):

- Construction of existing car park (1,2 plate elements,8 anchor elements)
- Placement of temporary wall (4, plate element)
- Inundation existing parking
- Under water demolition existing parking
- Stabilisation sand (4)
- Cement bentonite (slurry) wall -58,0m (6,7, volume element and plate element)
- Spanwand -28,0m (6, plate element)
- Excavation floor B1 (8, anchor element); groundwater (gw) -4,5m
- Floor B1 (8); excavation to -3,4m B2 (gw still -4,5m)
- Floor B2 (8); excavation to -6,4m B3; gw -6,5m
- Floor B3 (8); excavation to -9,4m B4; gw -9,5m
- Floor B4 (8); excavation to -13,0m B5; gw -13,5m
- Groundwater level back to normal
- Possibility (not used) of modelling continuous concrete floor B5 (9, volume element) & anchors (10)

In Figure 7 the results of the total displacements are shown for the stage of total excavation (NAP-13,0m).. These results were used to determine the differential displacements at the existing 2 levels car parking.

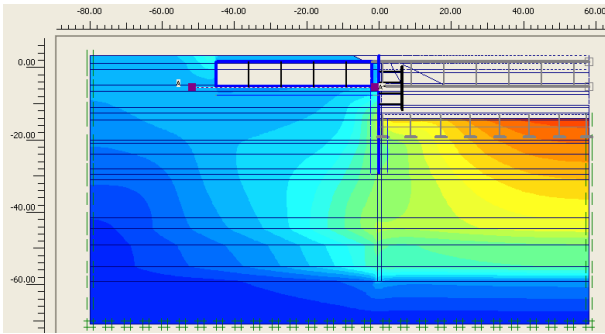


Figure 7. Indicative contour plot of total displacements after excavation NAP -13m (VR)

The horizontal displacements for a number of stages of the *Spanwand* are shown in Figure 8. The maximum displacement is 52mm.

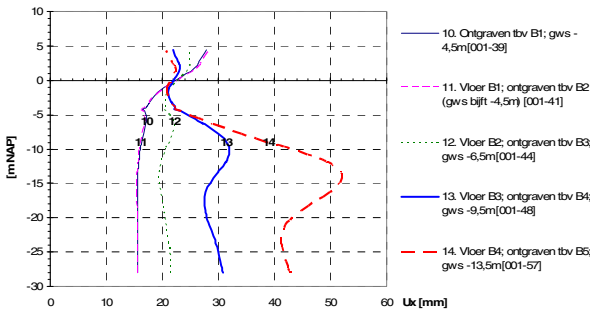


Figure 8. Horizontal displacements *Spanwand* P&C

5 DAMAGE PREDICTION

To be able to predict the possible damage caused to the existing parking garage, a conservative summation of the maximum possible deformations is projected on the construction, being:

- 100% of the horizontal displacements at NAP-13,0m at excavation;
- 100% of the vertical displacements at NAP-13,0m at the inundation stage;
- 100% of the settlement caused by the slurry wall construction (not presented in this paper).

The calculated horizontal displacements and the sum of the vertical displacements in the floor of the existing garage, are shown in Figure 9 and Figure 10 respectively.

Based on these calculation results, a prediction has been performed for the estimated damage category of the structure, the result of which is shown in Table 1. There is a change of very slight damage in the existing parking garage, which is considered to be acceptable.

Table 1 Damage prediction existing carpark P&C

L/H	rotation	deflection ratio	horizontal strain	Max. strain	Damage class
(-/-)	(-/-)	(-/-)	(-/-)	(%)	
1.08	0.0016	0.0003	0.0003	0.102	Very slight

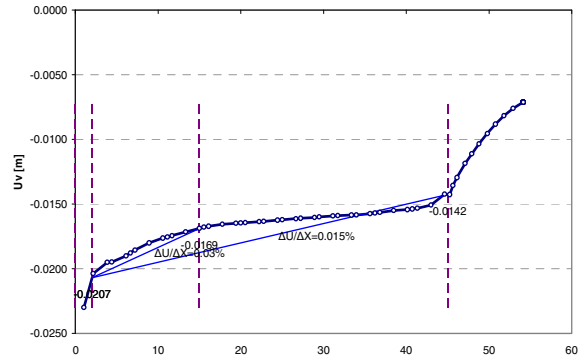


Figure 9. Horizontal displacements basement existing car-park

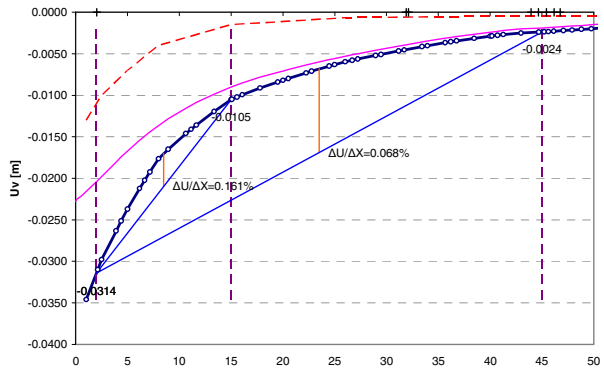


Figure 10. Vertical displacements basement existing car-park

6 PILE DESIGN

Another special condition is formed by the foundation piles. Because of the extremely high column loads, varying between 9,000 and 21,000 kN,. High loads have to be transferred to the subsoil via pile foundations. Inside the garage however, parking space has to be optimised. Therefore the columns have to be as slender as possible. Because the structure is build top down (garage) and bottom up (high-rise tower) the piles also function as columns and have to transfer a load up to 9000kN in the construction stage. The solution that has been chosen consist of Tubex piles with a dowel, so that about 5000kN can be transferred via the pile, and the rest via the dowel.

Pile dimensioning has been based on the assumptions that:

- Maximum excavation level NAP -12.8m
- Load on pile circa 5000kN,
- No negative skin friction.
- Positive skin friction from NAP -12.8m tot pile toe level.
- A thinner tube is placed on the thicker lower pile section (beneath excavation level); a transition peace (*trumpet*) is placed in-between.

Calculation have been made using both the Dutch national codes (NEN6740, NEN6743) as well as PLAXIS 3D FEM. The biggest issue was to fit the load-settlement behaviour of the pile in PLAXIS tot the load settlement behaviour as prescribed by the NEN7643 code (based on a series of trials). The best fit was eventually found by increasing the Young's Modulus of the soil in a 4 times the diameter area around the pile toe, combined with an increase in the able of internal friction of the sand in the bearing layer. The principle of the 3D Axial symmetric model is shown in Figure 11.

Because pile bearing capacity according tot NEN6743 is 5500 kN, only results up to 5000kN are used. The deformations

found in PLAXIS are then bigger than based on the NEN6743, which is accounted for in the stiffness calculations of the new car parking and the high rise building.

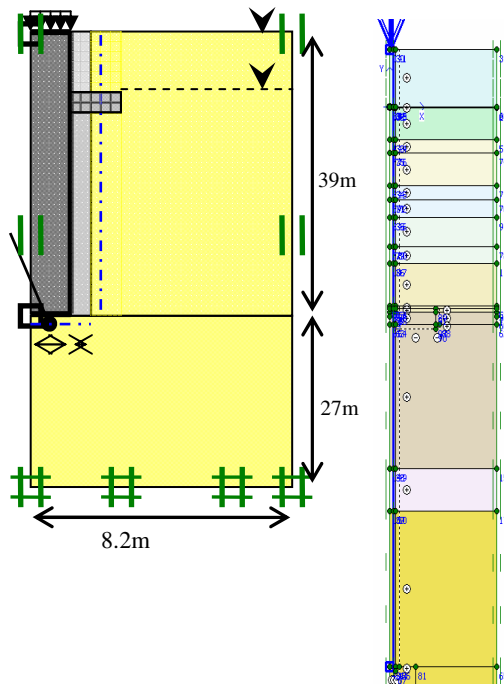


Figure 11. PLAXIS 3D axial symmetric pile model

The results of some simulations are shown in Figure 12.

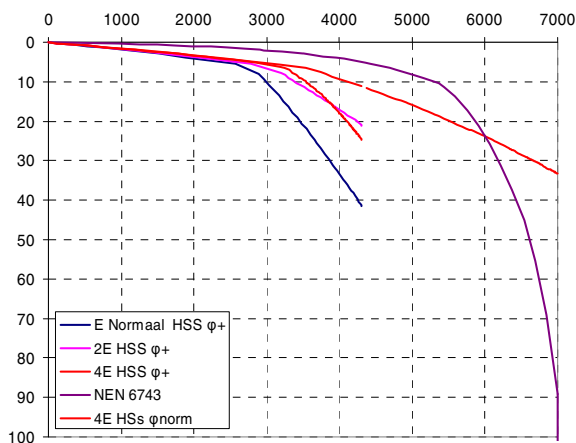


Figure 12. Result of prediction using PLAXIS 3D axial symmetric pile model, compared to NEN6743; Force (kN) vs. settlement (mm).

## 7 GROUNDWATER FLOW MODELLING

The construction of the underground car parking will possibly have an impact on the local groundwater level in the utilization phase. E.g., the underground construction will form an obstruction to groundwater flow. At the up-stream side of the construction the groundwater level could be raised, whereas it could be lowered at the other side due to a reduced groundwater flow. In addition, groundwater will be continuously abstracted at the construction-floor level. The groundwater level between the slurry walls will be lowered by as much as about 13m. Although the groundwater level drop outside the slurry walls will be less due to the high hydraulic resistance of the wall, the groundwater abstraction possibly inflicts migration of surrounding contaminated groundwater plumes.

Groundwater flow modeling is used to assess the influence of the underground construction and groundwater abstraction on

the groundwater system. Steady-state calculations were conducted with the semi-3D finite-element code MicroFEM. The present hydro geological situation was simulated, after which the slurry walls, car parking and the groundwater abstraction were inserted into the model. The recalculated groundwater levels were compared to the present levels. Results indicate that the low hydraulic conductivity of the slurry wall reduces the groundwater level drop outside the walls effectively. It is concluded as well that the groundwater flow is not obstructed enough to cause considerable groundwater level changes. The computed lowering of the groundwater table directly outside the slurry walls caused by groundwater abstraction and obstruction to groundwater flow is less than 5 cm. The calculations show that the construction of the underground car parking will have a negligible effect on plume behavior.

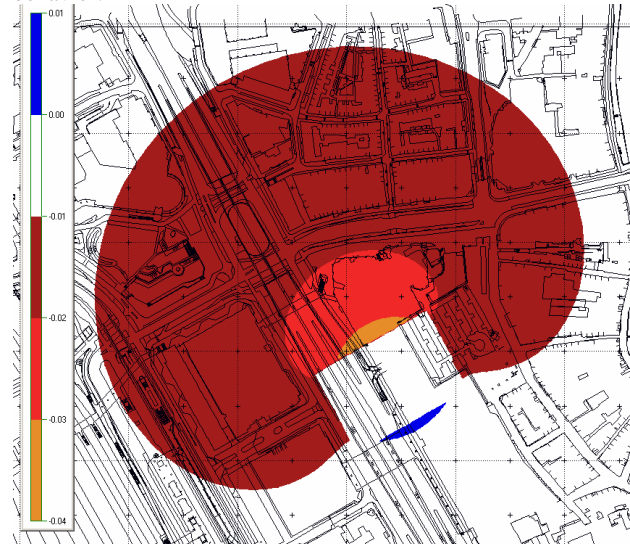


Figure 13. Groundwater lowering (m) as a result of drainage and groundwater flow (grid 100mx100m)

## 8 CONCLUSIONS

In the preliminary design of this projects, challenging new design aspects were encountered. Examples of the analysis of FEM deformations, pile bearing capacity calculations and groundwater flow and damage prediction approach were shown to illustrate the chosen design approach. The conclusion can be drawn that using state of the art design tools, even in the challenging conditions that are encountered here, it is possible to create a safe and consistent design.

## ACKNOWLEDGEMENTS

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