Risks related to CFA- pile walls

Risques liés aux rideaux de pieux de CFA

M. Korff
GeoDelft, Delft, The Netherlands

A.F. van Tol
Delft University/GeoDelft, Delft, The Netherlands

E. de Jong
VolkerWessels Stevin Geotechniek, Woerden, The Netherlands

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ABSTRACT

Walls consisting of CFA-piles are often used for vertical cut offs for building pits. Several methods of installation and geometry may be used and sizes, depths and strengths of walls necessary vary widely. Based on experience with CFA-pile walls in The Netherlands, requirements for this type of wall can be set with a risk management view to it. This paper describes those requirements, based on specific local conditions. Furthermore this paper shows how contractor Volker Wessels Stevin Geotechniek used their own experiences to establish a “decision model” in order to choose the most suitable pile wall type depending on soil conditions and client demands.

RÉSUMÉ

Des rideaux se composant de pieux de CFA sont souvent utilisés pour des puits de construction. Plusieurs méthodes d’installation et de géométrie peuvent être employées et les tailles, les profondeurs et les forces des murs nécessaires changent considérablement. Basé sur l’expérience avec les rideaux de pieux de CFA dans les Pays Bas, des conditions pour ce type peuvent être placées avec une vue des risques à elle. Cet article décrit ces conditions, basées sur des conditions locales spécifiques. En outre cet article montre comment l’entrepreneur Volker Wessels Stevin Geotechniek a employé leurs propres expériences pour établir un “modèle de décision” afin de choisir le type de rideaux de pieux le plus approprié selon des conditions de sol et des demandes de client.

1 INTRODUCTION

In many cities (also in The Netherlands) the application of building pits for the realisation of underground spaces (such as car parks, shops or cellars) or infrastructure is becoming common practice. That however does not mean that the construction of underground projects in building pits always follows the schedule. To limit damage to buildings and nuisance for neighboring residents all kinds of measures are taken. That the desired result is not always achieved becomes clear from examples mentioned in this paper.

2 DUTCH SOIL AND SITE CONDITIONS

Conditions in The Netherlands can be characterised as soft soils. The Western part of the country consists mainly of soft clays and peats for up to 15 m, overlaying Pleistocene sand deposits. The Eastern part of the country and some river and estuarine areas consist of fine to coarse, often silty sands.

Building pits are often situated in densely built areas, so noise and vibrations due to installation of e.g. sheet piles are restricted in many cases. In those situations low or non vibrating wall types such as diaphragm walls or piled walls are used, which each have specific characteristics.

3 WALL TYPES FOR BUILDING PITS

Diaphragm walls have a large bearing capacity and stiffness, so that they can also act as permanent construction. A disadvantage of the application of diaphragm walls is the level of costs, certainly in case of a building pit with relatively small dimensions, for example for medium sized underground car parks. In such cases the use of a piled wall can become attractive with regard to costs. A piled wall commonly consists of CFA piles, which overlap in case of a secant pile wall.

Such CFA-pile walls are designed generally as a soil - and water retaining structure, whereas in practice it has become clear that this type of walls is not 100%

watertight. Sometimes this leads to large problems, but in other cases this type walls is successfully applied. How can we prevent that a piled wall has negative impact on our project ? The answer is found in a risk management approach and experience based decision making for choosing the optimum wall type.

4 RISK ANALYSIS

Almost all (in-situ) foundation techniques have a relatively large chance that imperfections occur in the end product. With "relatively" is meant in comparison with for example above ground cast concrete. In that case by visual control during production and of the end product imperfections are identified and thus being improved. That is clearly very different for constructions made ín the soil. During the past years for example it has become common knowledge that injection layers are not entirely impermeable. Even with state of the art techniques it is not possible to make a 100% impermeable injection layer. Those layers are now more commonly named as "water restraining" layers. Also other constructions made in the soil are not fully impermeable, such as sheetpiles and pile walls. During installation of sheet piles interlocking may fail, and piles for closed walls are possibly positioned wrong or deviate in diameter. In short, imperfections in foundation techniques occur easily and in many cases. In itself this does not have lead to problems, as long as in the project such deviations are anticipated for.

5 CFA- PILE WALLS MORE CLOSELY EXAMINED

To be able to predict risks when using a pile wall, information is necessary on how a piled wall is constructed. At making a traditional secant CFA-pile wall CFA piles, with or without casing, are applied, with a certain amount of overlap. Firstly the non-reinforced, primary pile is installed and consequently the secondary piles are constructed between the primary ones. The secondary pile is reinforced with a steel profile or cage. Also other techniques are available, which make use of for example bentonite cement piles instead of concrete primary piles. (Suckling 2005) uses the term hard/firm walls for the secant pile walls described above, with reinforced secundary piles and non reinforced primary piles and hard/soft for secant pile walls with bentonite cement piles. In the decision model explained below contractor Volker Wessels uses the type C as indication for hard/firm walls and type D for hard/soft walls. Type A walls are used for contiguous pile walls, whereas type B represents a combination of contiguous reinforced primary piles with spacing, filled with jetgrout coloms. See Figure 4.

So, in case a piled wall is used, the designer must anticipate that the retaining wall will not be 100% impermeable, depending on the type of wall as design

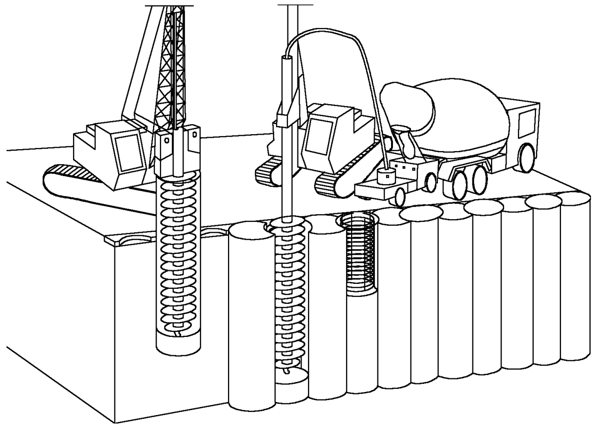

Figure 1. Secant CFA-pile wall principle type C/D.

Figure 2. CFA-pile wall type B (Arnhem 2004).

Figure 3. Anomalies in CFA-pile wall.

and constrution details. A common measure is that after the excavation or after pumping in case of a building pit with an underwater concrete floor, leakage is repaired by means of injections. The question is: are such injections a reliable counter measure in case of imperfections ? This question should be answered by the designer, as integral part of the design process, in a risk analysis. The impact of such leakages must be assessed: is it possible to control the leakage, is the leakage not only transporting water but also soil particles, is there a risk of sinkholes, what is the impact of scour on the building pit and on the neighboring buildings, is it realistic to repair by means of injection, etc. Depending on the risks assessed the designer should examine the possibilities of using different types of piled walls and/or other wall types.

6 DUTCH EXAMPLES

In The Netherlands several building pits with CFA-pile walls have been constructed in the last 10 years.

In Table 1 a list is given of some Dutch projects with conditions and information about the experienced leakage (or absence of it). The examples are only incidentaly published in technical papers, but mainly taken from the experience of the authors from second opinions, arbitrations and construction. In all cases the piles are made with casing.

In more detail Case Middelburg 2003 involves a three storey deep building pit in fine sands.

An 8 m deep building pit is constructed with secant CFA-piles. During construction several leakages and bad spots were discovered. This even caused some sinkholes behind the wall and damage to buildings in the area due to settlements.

In this case it appeared that the unfavorable combination of: a large retaining height in sandy subsoil conditions, a high groundwater table and shallow foundations at short distance is difficult to control.

Case The Hague 1995 involved a hard/firm secant piled wall (type C) in a sandy subsoil. The wall is made with a pile diameter of 560 mm and an overlap at ground level of 70 mm. During excavation several leakages were discovered. In order to finish the project and to stop the leakage through the CFA pile wall, the wall had to be injected on numerous locations for several times. The intensive injections had to take place which cost around 6% of the tendersum.

In other situations CFA-pile walls have been, however, successfully applied, also in sandy soils with high groundwater tables (see Table 1). Such cases are not impossible by definition, but a risk management approach is clearly needed in all cases.

7 RISKS RELATED TO SECANT PILE WALLS

The risk analysis must be made case by case and will lead to different results depending on specific conditions. Factors which can be decisive:

1. Retaining height (especially distance of ground water level to deepest excavation level):
   - At increasing retaining height the risk for lack of sufficient overlap between the piles increases as a result of deviations in the verticality of the piles
   - The water pressure difference over the wall determines the possibilities for control of leakages;
2. Soil conditions behind the wall:
   - In cohesive soil leakage will not directly be problematic, because the amount of water coming in will be small and scour does not occur;
   - In saturated sands leakage will almost directly introduce inflow of a sand water mixture with scour and sinkholes behind the wall as a consequence;
3. Use of the soil behind the wall:
   - In case of roads, pipelines or shallow foundations scour can have very serious impact
   - In case of piled foundations, depending on the size of the scour, the distance/situation of the piles and the piletype the impact could be less.

By taking into account the above named factors it is possible to prevent imperfections in the walls of underground constructions, and more in particular of piled walls, to lead to severe consequences in time and budget of the project and quality of the surroundings.

Based on these risks and experiences such as the The Hague 1995 project contractor Volker Wessels decided to develop a decision model for CFA pile walls that is presented in Figure 4 With this model an appropriate wall type can be selected based on the above named decisive factors. In certain cases this contractor even does not make an offer. With the use of this model, VolkerWessels hascarried out 12 CFA pile walls projects in the Netherlands without leakage problems. The building pit Middelburg 2003 was not tendered for, as followed from the decision model.

These risks make clear that especially for control of leakage the wall characteristics are very important. But not only leakage is important, also structural effects have to be taken into account.

8 CONSEQUENCES OF INSUFFICIENT OVERLAP

Let's take a deeper look at the risk for lack of sufficient overlap between the piles at increasing retaining height as a result of deviations in the verticality of the piles.

The verticality of the piles is an important input parameter for the amount of overlap between the piles. (Suckling 2005) describes the vertical tolerance of different wall types to be between 1,3% and 0,5%. The requirements in EN code 1536 for the installation of CFA-piles are 2% deviation of the vertical. For a secant CFA-pile wall such deviation would clealry be not acceptible. The achieved verticality influences the possibilities for leakage directly by the amount of overlap needed to guarantee a certain amount of water tightness, but it also influences the amount of leakage which is to be expected due to structural problems in two different ways, as described in more detail below.

The first structural effect that occurs in a secant pile wall is the combined bending of the reinforced

Table 1. Examples CFA-pile walls

Location (NL)	Year	Type	Storeys	Subsoil	Result; measures
Arnhem	2006	C	1-2	Sand	Ok, no water
The Hague	2005	D	1-2	Sand, peat	Ok
Tilburg	2004	D	2	Sand	Ok
Arnhem	2004	B	2	Sand	Ok
Middelburg	2003	C	3	Sand	Leakage
Amsterdam	2003	D	2-3	Clay, Sand	Ok, only wet excavation
Cuijk	2002	A	1	Sand, Gravel	Ok, no water
Amsterdam	2001	C	–	Clay, Sand	Ok
Utrecht	2003	C	1	Sand	Leakage; Secundary wall inside
Emmen	2000	A	1	Sand	Ok, no water
Hilversum	1999	C	1		Ok
Tilburg[1)]	1999	C	2	Sand, Clay	Ok
IJmuiden	1998	C	1	Sand	Ok
Middelburg	1998	C	3	Sand	Leakage; jetgrouting
Budel	1998	C	1	Sand, Loam	Ok
Nijmegen	1997	A	1	Sand, Gravel	Ok, no water
The Hague	1996	C	2	Sand	Leakage; 2nd row of piles
Groningen[2)]	1996	C	3	Clay, boulders	Leakage; injections
Budel	1995	C	1	Sand, Loam	Leakage
Heerlen	1995	A	1	Sand, Gravel	Ok, no water
The Hague	1995	C	1	Sand	Leakage, injections
Maastricht	1992	C	2	Gravel	Leakage; secundary wall inside

1) [Langhorst].
2) [Ramler&Vrieling].

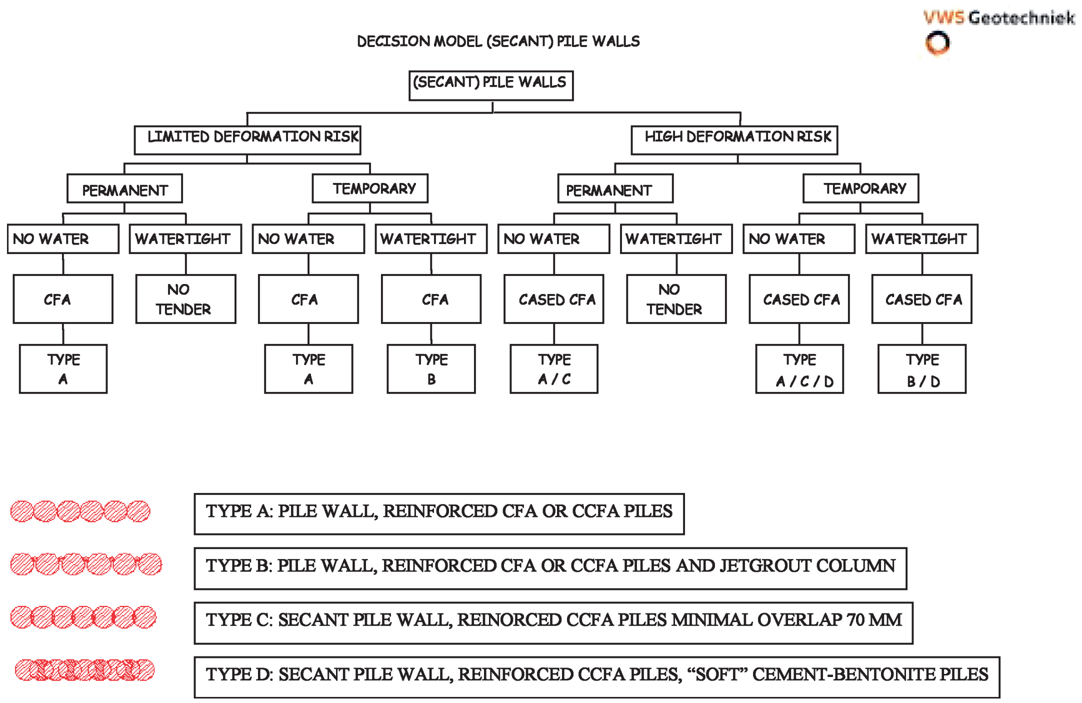

Figure 4. Decision model (secant) CFA pile walls.

secundary and the non-reinforced primary pile. Due to differences in stiffness, a shear stress will occur in the interface between the piles. Depending on the amount of overlap (length of the interface) and the quality of the concrete these stresses introduce some form of vertical crack between the piles (see Figure 3). If the amount of overlap is small, those cracks can easily connect to the groundwatertable behind the wall and form a point of leakage.

Another problem that can occur is a horizontal crack in the non-reinforced primary pile (see Figure 3 on the right) due to the bending of the wall. The bending moment in the wall is generally higher than the breaking moment of the non-reinforced pile. Since no reinforcement is available to spread the cracks over the pile as a whole, the width of the cracks is not limited. In that case a smaller overlap may cause the crack to reach the groundwatertable behind the wall.

Figure 5. Secant pile wall type C (Arnhem 2006).

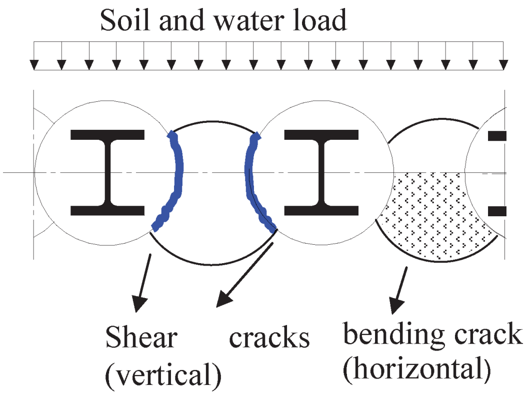

Figure 6. Cross section wall with possible crack locations.

Figure 7. Secant pile wall type D (Tilburg 2004).

9 CHECKLIST

Listed below are possible structural and geome-trical problems to account for when designing a piled wall:

- Insufficient verticality causes leakage
- Concrete of the primary piles can be either to hard before installation of secondary piles or too soft. A 'perfect' age of the primary collumns when installing the secondary ones is difficult to achieve. External influences, such as logistical problems in the delivery of fresh concrete may cause complications. Also the installation process is by definition interrupted by night- and weekend stops. If the concrete is too hard this leads to irregularities or cracks, if it is too soft this leads to deformation of the primary piles. This problem is not present with type A and B, and less in D.
- Obstacles in the soil increase the deviation of the verticality and cause diameter fluctuations and inclusions
- Low concrete pressures cause reduction of the diameter of the piles.
- Installation of the reinforcement should be performed immediately after concreting of the piles. If vibrating the steel profile (or cage) is necessary the fresh piles will be influenced.
- If the overlap of the piles is insufficient, stresses in the contact areas between the piles could be increased and possibly cause vertical cracks.
- The rough and irregular surface of the piled wall can cause inclusions of soil between the wall and the concrete floor of the building pit.
- If primary piles are placed at inward corners or in front of the secondary piles, they could be "pushed" into the building pit.

10 QUALITY CONTROL

Especially at underground constructions (not only when piled walls are used) the impact of possible imperfections must be examined. In case the expected impact is large, additional measures must be available in the form of monitoring or quality control of the installation process to determine if imperfections are present in the construction. This is already standard procedure for cast in-situ foundation piles, where all piles are tested with acoustic techniques after realization. Based on the risk assessment method, this type of control measures should be developed further and used at all types of in situ foundation works.

11 ACCOUNTING FOR VARIATIONS

Depending on the degree to which variations in construction quality/performance are foreseen, effectively happen and have been taken along in the design can in situ cast walls be very well applied as an alternative for sheet piles or diaphragm walls. A designer however should always realise that the choice for a certain wall type depends on local conditions and requirements. The designer should not expect these types of constructions to be "perfect", as seen in the examples above. This is not a realistic condition and is inconsistent with current state of experience.

Based on experience from the projects listed, wall type D (using bentonite cement columns posess a certain amount of plasticity after hardening. During installation of the important secondary (reinforced) columns) less risk for leakage and cracks occur, making it more suitable for soil and watertight Pile walls. Using wall type B The second method is to create primary reinforced collums without overcut and create watertightness afterwards bij e.g. jetgroutcollumns (wall type B). In both cases, it's necessary to establish in the design that the watertightness of the Pile wall is not permanent. A watertight cast-in place wall needs to be constructed for permanent watertightness.

It is thus recommended to perform a technical risk analysis and to take into account variations during construction as a necessary component of the design of ALL building pits and for piled walls in particular.

12 CONCLUSIONS

Design of (CFA-)pile walls should incorporate for tolerations during construction to ensure that sufficient overlap between adjacent piles is maintained over the depth of the excavation.

Countermeasures should be designed for possible leakages and loss of local strength. In some cases (mainly in conditions with sands behind the wall and high water tables) leakage can not be accepted, because it often involves loss of soil behind the wall leading to sinkholes. In those conditions the construction needs extra safety measures, such as a smaller centre to centre distance, a larger pile diameter or even another type of wall as presented in the decision model.

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