Ground displacements related to deep excavation in Amsterdam

Déformations du sol liées à des excavations profondes à Amsterdam

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ABSTRACT: This paper explores the ground displacements related to deep excavations for a case study from the Netherlands, the construction of the North South Metro Line in Amsterdam. The overall goal of the analysis of the displacement is to study the interaction of deep excavations with piled buildings. The response of buildings is governed by the soil displacements resulting from the excavation. These displacements, at the surface level and at deeper levels, are described in this paper. The response of the piled buildings is described in a second, related paper in this conference.

RÉSUMÉ : Les auteurs ont analysé les déformations du sol liées aux excavations profondes de la ligne nord/sud du métro à Amsterdam. L'objectif principal de cette analyse des déformations est d'étudier l'interaction des excavations profondes avec les bâtiments sur pieux. La réponse des bâtiments est régie par les déformations du sol résultant de l'excavation. Ces déformations, de sub surface et de niveaux plus profonds, sont décrites ici. La réponse des bâtiments sur pieux quant à elle est décrite dans un article connexe de cette conférence.

KEYWORDS: deep excavation, ground displacement.

1 CONSTRUCTION OF THE NORTH-SOUTH LINE

1.1 *Deep excavation and soil conditions*

The North-South Line in Amsterdam passes under the historical centre of the city in twin tunnels. Five underground stations are currently under construction. Rokin, Vijzelgracht and Ceintuurbaan Station are three of the deep stations in the historic city centre. They are built using the top down method.

The soil consists mainly of Holocene and Pleistocene, soft clay, peat and sand deposits, underlain by a stiff, lightly over consolidated clay, with OCR=2. Fill and soft Holocene deposits are present to a level of about NAP –11.0m (ground level is around NAP +1.0m (NAP is Dutch Reference Level). These are underlain by the 1st sand layer. The 2nd sand layer is found at about NAP –16m, extending to NAP –25m. Below the 2nd sand layer the stiff clay layer of around 15m thickness (the Eem clay) is found, overlaying the 3rd sand layer. Phreatic ground water is found just under NAP and the piezometric levels in the aquifers are influenced by deep pumping for the polders surrounding the city to a level of about NAP-3m.

1.2 *Rokin Station and Vijzelgracht Station*

Rokin Station is the first of the Deep Stations for the North South metro Line in Amsterdam, following the line south from Central Station. The station is 24.5 m wide. The diaphragm wall is 1.2m wide and 38m deep. At 4 cross sections, surface measurements as well as inclinometer and extensometer measurements are taken, see Figure 1. Vijzelgracht Station is 250 m long, 22 m wide and the diaphragm walls extend to a depth of NAP - 44.5 m. Both stations had reached a depth between NAP-12 and NAP-15m at the time of the measurements presented here, while the final depth (results not presented in this paper) is about NAP-30m.

⊠ inclino/extensometer point
□ surface measurement point

Figure 1 Top view of cross section west of Rokin Station

1.3 *Ceintuurbaan Station*

Ceintuurbaan Station is 220 m long, only 11 m wide and a maximum of 31 m deep. It is also built by means of a top down construction, with 1.2m thick diaphragm walls extending to a depth of NAP-45 m. A cross section of the excavation, soil profile and monitoring instruments is shown in Figure 2. The monitoring instruments include extensometers behind the wall, inclinometers in the soil and in the wall, manual levelling of the surface and the buildings and automatic monitoring of the buildings. Details about the construction and monitoring of Ceintuurbaan Station are given in De Nijs & Buykx (2010).

Over a period of about 8 years, preparations for the construction and the subsequent excavation of the deep station took place, see Table 1. The preliminary activities include raising the ground level (≈0.7m), diaphragm wall construction, jet grout strut installation, excavation to NAP-2m, construction of the roof, backfilling above the roof and a pumping test for water tightness of the D-wall in the 1st and 2nd sand layers.

Table 1 Construction activities and dates for Ceintuurbaan

Construction activity	End date
Base monitoring start 2001	2003-11-01
Preliminary activities	2007-04-01
Excavation to NAP –6.2m	2007-09-13
Excavation to NAP –15.3 m	2007-12-10
Excavation to NAP –19.4 m	2008-03-01
Excavation to NAP –24 m	2008-08-01
Excavation to NAP –25.6 m, Floor construction, pumping test	2009-06-24

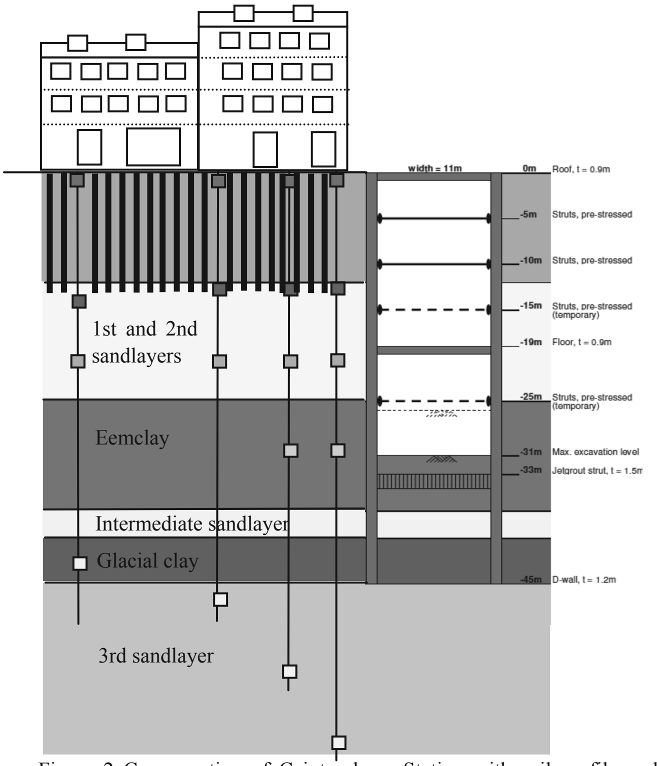


Figure 2 Cross section of Ceintuurbaan Station with soil profile and extensometer locations

2 SURFACE DISPLACEMENTS

In the Amsterdam deep excavations, the following construction effects contributed to the displacement of the ground surface:

- Installation of diaphragm wall including preliminary activities
- Excavation of the station box.

Figure 3 shows the measurements of the ground surface for all three stations, Rokin, Vijzelgracht and Ceintuurbaan, for various stages of the excavation. It should be noted that the excavations had not finished at the time these measurements were taken and so the long term consolidation settlement is not completely included. The total period of the displacement measurements was over 6 years (from 2003-2009). For each stage, the excavation depth H is mentioned in the figures. From Figure 3 it is concluded that the settlement profile found in Amsterdam falls within the limit of Zone 1, as described by Peck (1969), with the ground surface displacement falling within 1% of the excavated depth. The main displacements occur within 2 times the excavation depth as also suggested by Peck. More significant however is the effect of the excavation depth itself. In all three of the Amsterdam cases, the largest effect on the ground surface can be attributed to the preliminary activities, which took in total about 4 of the 6 year*s* presented.

For each station, the average contribution of the preliminary activities to the surface displacements has been determined. The percentage of displacement caused by preliminary activities in 2003-2007 compared to the overall displacement between 2003-2009 or 2003-2010 for Ceintuurbaan Station is 70%. For Vijzelgracht Station this is 55% and for Rokin Station 74%. The percentage at Vijzelgracht is influenced by some leakage incidents (Korff et al. 2011), showing a larger effect during the excavation period after 2007. The percentages for all the stations are somewhat higher than the actual values would be if the displacements at the end of construction (after 2012) had been taken into account, although additional displacements between 2009-2012 have been very small. Such a high percentage of the settlements caused by preliminary activities was also reported by Fernie et al. (2001) for a case study in London (Harrods). The deflection of the retaining wall in a top-down construction there caused only a small fraction of the overall ground movements. The installation of a contiguous piled wall of bentonite-cement caused up to 40% of the total movement.

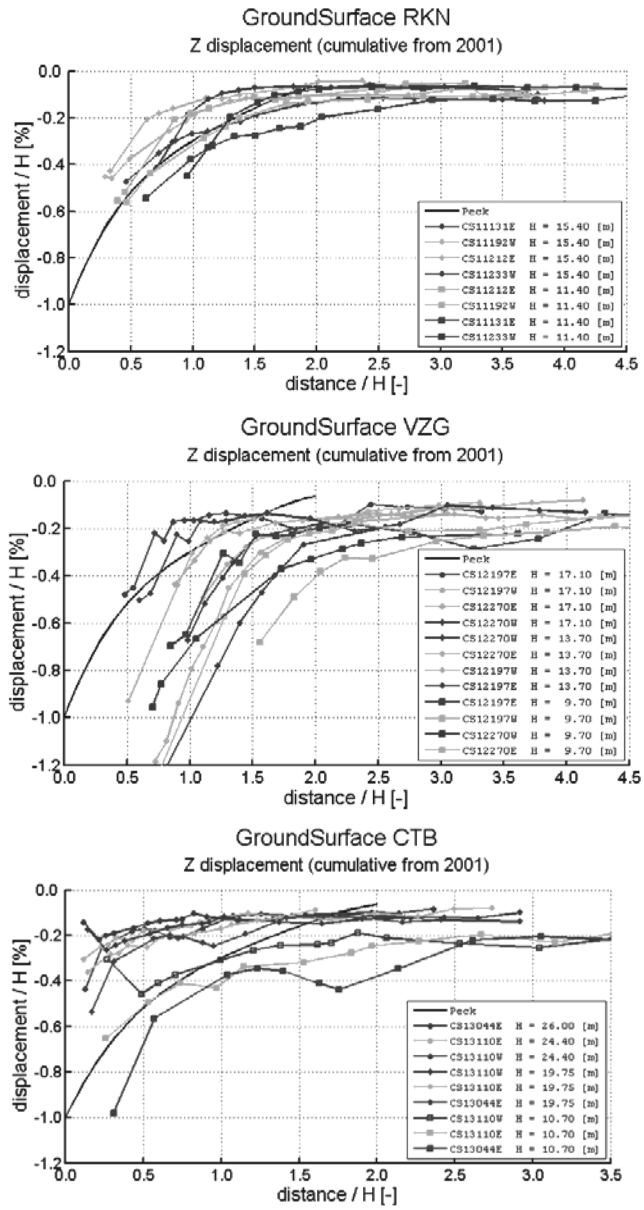


Figure 3 Settlements normalized with excavation depth H, compared with envelopes by Peck (1969)

Clough and O'Rourke (1990) evaluated the maximum displacement to be expected behind different types of retaining walls. In stiff clays, residual soils and sands the maximum ground displacement behind the wall is about 0.15% - 0.5% of the excavation depth, see Figure 4. The Amsterdam cases are plotted in a similar way in Figure 5.

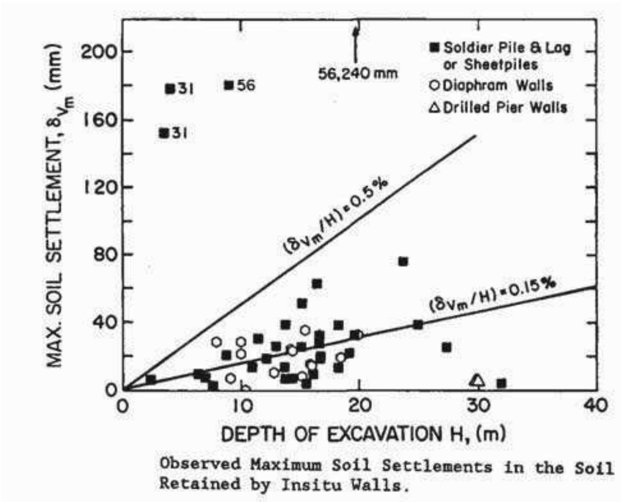


Figure 4 Observed maximum wall deflection and settlements for stiff clays, residual soils and sands (Clough and O'Rourke, 1990)

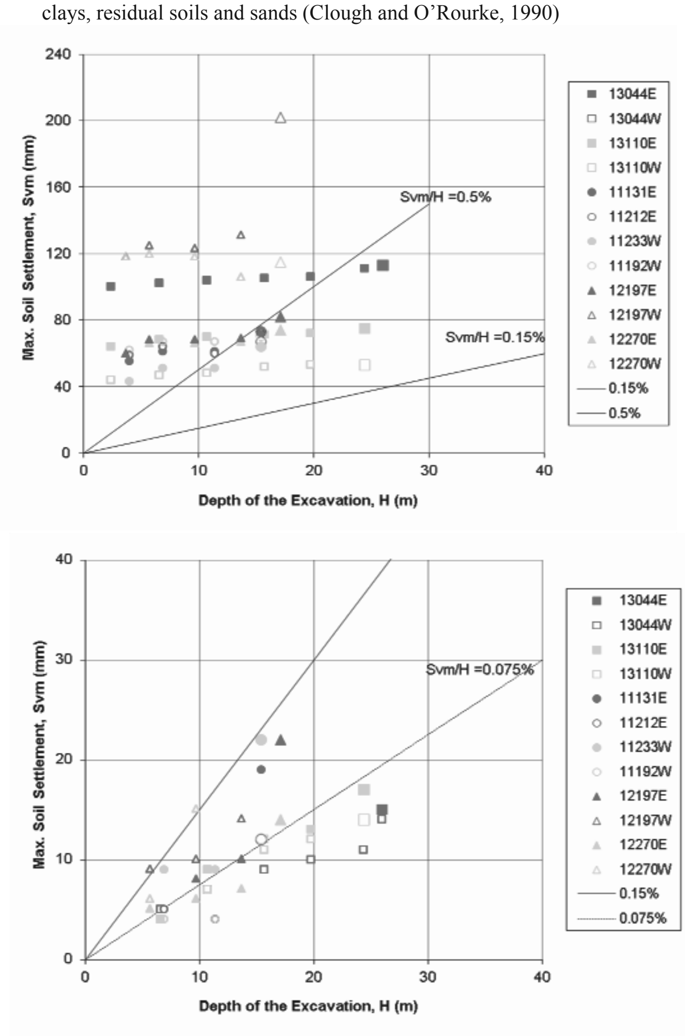


Figure 5 Observed Maximum surface settlements in Amsterdam for a) all construction effects (including preliminary activities) and b) for excavation only.

At the time of the end of the measurements presented here, Figure 5(a) shows the surface settlement to fall within the band of 0.15-0.5% times the excavation depth as determined by Clough and O'Rourke (1990), except for 2 incident locations (12197W and 12270W) as described in Korff et al. (2011). During the early stages of construction, the surface settlement is approximately 1% of the excavated depth. This can be attributed to the significant impact of the preliminary activities, mainly due to the presence of highly disturbed soil conditions. The final values (shown slightly bigger in Figure 5(a)) for the surface settlement average to 0.3 to 0.45% of the excavation depth, with 0.3% for Ceintuurbaan Station which had almost reached full depth and 0.45% for Rokin and Vijzelgracht Station, which were both excavated about halfway down. The additional displacement due to the deeper excavation steps is small compared to the preliminary activities.

If the preliminary stages are not taken into account, the values are given in Figure 5(b) look much more like the values found by Clough and O'Rourke. The surface settlement, due to excavation of the stations, is less than 0.15% of the excavated depth, with an average of 0.07%. This value was achieved through the use of the very stiff diaphragm wall in combination with a large number of struts, including the deep grout strut.

3 SHAPE OF THE SURFACE SETTLEMENT

The results of all three stations are combined in Figures 6 and 7. During the preliminary activities (Figure 6) a hogging displacement profile similar to that seen above tunnels fits the measurements reasonably well. Most of the displacement in this stage is caused by predrilling and raising of the ground level close to the edge of the excavation, both having the largest impact on the top layers, thus resulting in this curved profile.

During the excavation, shown in Figure 7, the shape of the surface displacement consists of both hogging and sagging parts. The sagging part could not always be captured, because some settlement markers close to the excavation were lost in the process of construction. The shape of the surface displacement profile suggested by Hshieh and Ou (1998) fits the curves reasonably well, although it sometimes extends further away from the wall.

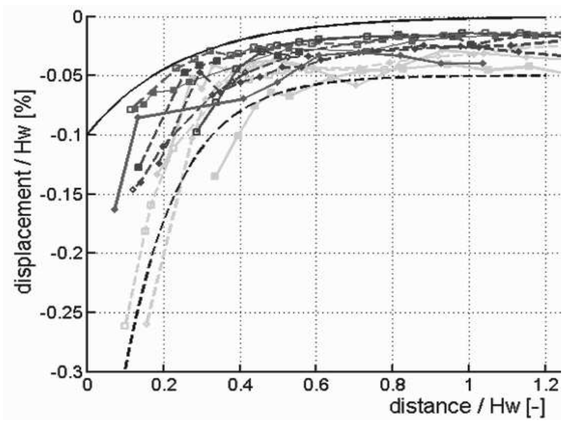


Figure 6 Measured surface displacements normalized with wall depth Hw for Amsterdam stations during preliminary activities, with upper bound (solid line) and lower bound (dashed line)

4 GROUND DISPLACEMENTS AT DEPTH

Especially for buildings with deep foundations, the displacements at deeper levels in the ground are important. Figure 8 shows the measurements of the vertical ground displacement at the surface compared to the extensometer data at two additional depths, NAP-12m and NAP-20m. At larger excavation depths the influence zone is significantly smaller than 2 times the excavation depth. The diagonal line from Aye et al. (2006) can be used as an estimate for the influence area; it is a conservative line. Also the curvature of the displacement profiles associated with it can be considered conservative. For a better fit, the maximum distance from the wall for significant surface displacements (D0) could be taken as 2 times the excavated depth, instead of 2.5 times as suggested by Aye et al. (2006).

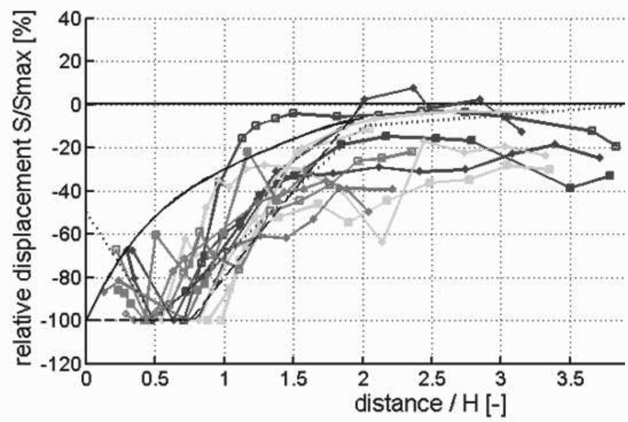
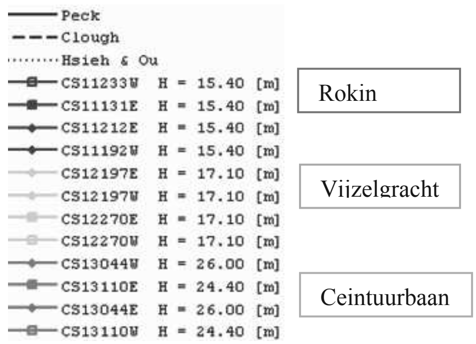


Figure 7 Measured surface displacements normalized with excavation depth H for three Amsterdam deep stations at the deepest excavation level available (2009-07-01), compared to settlement envelopes proposed by Peck (1969), Clough and O'Rourke (1990) and Hsieh and Ou (1998). With:



5 CONCLUSIONS

The settlement measurements for the Amsterdam deep excavations have been compared to several, mostly empirical, relationships to determine the green field surface displacements and displacements at depth.

It is concluded that the surface displacement behind the wall is 0.3 – 1.0% of the excavation depth, if all construction works are included. Surface displacements behind the wall can be much larger than the wall deflections and become negligible at 2-3 times the excavated depth away from the wall. The shape of the displacement fits the profile of Hshieh and Ou (1998) best.

In all three of the Amsterdam cases, the largest effect on the ground surface displacement can be attributed to the preliminary activities, which include amongst others the diaphragm wall construction, jet grout strut installation and construction of the roof and took in total about 4 years. The actual excavation stage caused only about 25-45% of the surface displacements, with 55-75% attributed to the preliminary activities. At larger excavation depths the influence zone is significantly smaller than 2 times the excavation depth.

5 ACKNOWLEDGEMENTS

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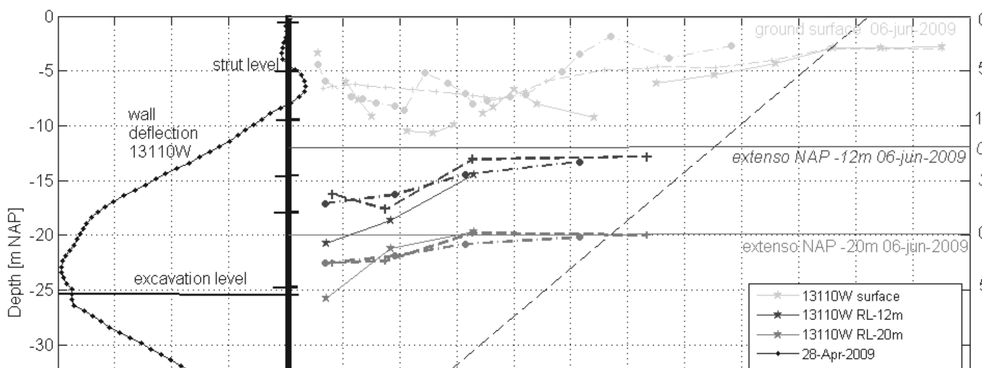

Figure 8 Measured ground displacements at Ceintuurbaan Station (13044E, 13110E and 13110W). Influence zone as described by Aye et al. (2006) but with D0=2He instead of 2.5He shown as diagonal line