Building damage examples due to leakage at a deep excavation in Amsterdam

Exemples de dommages de bâtiment dus à la fuite aux excavation profondes à Amsterdam

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ABSTRACT

The authors analysed buildings that were damaged due to leakage problems at a deep excavation in Amsterdam for the North South Line. The objective of this paper is to show that empirical relationships for damage due to excavations need to be handled carefully for extreme situations such as shown in this paper. The authors evaluated the monitoring data and building damage at the Vijzelgracht Station in the historic centre Amsterdam. The paper shows that tilt, in extreme circumstances, can cause severe problems of serviceability and stability to buildings. The monitoring results of all the construction activities around the stations will be used in a later stage of this research to identify the effect of the foundation of the building on the amount of damage experienced.

RÉSUMÉ

Les auteurs ont analysé les bâtiments qui étaient dus endommagé aux problèmes de fuite aux excavations profondes à Amsterdam pour le Ligne nord/sud. L'objectif de ce document est de prouver que des methodes empiriques pour des dommages dus aux excavations doivent être manipulés soigneusement pour des situations extrêmes telles que montré en ce document. Les auteurs ont évalué les données de surveillance et les dommages de bâtiment à la station de Vijzelgracht au centre historique Amsterdam. Les résultats de surveillance de toutes les activités de construction autour des stations seront employés dans un stade avancé de cette recherche pour identifier l'effet de la base du bâtiment à la quantité de dommages éprouvée.

Keywords : deep excavation, building damage

1 INTRODUCTION

In June and September 2008 at two different locations along the Vijzelgracht (VZG) in Amsterdam, a serious leakage occurred in the diaphragm wall of Station Vijzelgracht, which is under construction at the moment for the North South metro Line. Nearby houses settled up to 240 mm due to settlement of the foundation caused by inflow of sand into the deep excavation. This case study describes the situation, the cause of the leakage and the effect of the settlement on the houses.

1.1 Station Vijzelgracht

Vijzelgracht Station is one of the Deep Stations for the North South metro Line in Amsterdam. The station is 250 m long, 22 m wide and a maximum of 31 m deep. It is built by means of a top down construction, with 1.2m thick diaphragm walls extending to a depth of NAP (Dutch reference level) -44.5 m.

Fill and soft Holocene deposits are present to a level of about NAP –12.5m (ground level around NAP +1.5m). These are underlain by the 1st sand layer, from NAP – 12.5m to NAP – 14/ -15m, beneath which lies a 2.5m thick sandy silt stratum (the Allerod). The 2nd sand layer is found at about NAP –17/-18m, extending to NAP –25.5m. Below the 2nd sand layer a stiff clay layer of around 15m thickness (the Eem clay) is found. Details of the construction and soil profiles can be found in (Kaalberg et al. 2005).

During excavation leakage at many of the diaphragm wall panel joints has been observed, varying from damp patches to more significant water leakages. The diaphragm walls are constructed in panels of about 5.1 m length each by using traditional grabs and steel stop ends with rubber strips to provide waterproofing.

1.2 Leakage incidents on June 19 and September 10, 2008

An episode of severe water and soil leakage through a panel joint first occurred in June 2008 at panel joint 89/90 in the west wall of the station. The leakage was attributed to a steel stop end not being removed at this location and failure of the repair measures consisting of High Density Injection. The leakage of water and soil resulted in substantial settlement (140mm) of the buildings Vijzelgracht 20, 22, 24 and 26. The leakage was found directly opposite the outer wall of Vijzelgracht 26 (panel joint 89/90).

On September, 10 2008 a further episode of severe leakage of soil and water occurred, resulting in substantial settlement of some adjacent buildings (Vijzelgracht 4 to 10). This leakage was attributed to a large bentonite inclusion in the wall at the centre of Vijzelgracht 4.

The settlement in both incidents was principally associated with the ground loss into the excavation resulting from the leakage of soil and water through the wall; consolidation effects due to pore pressure reduction were minor.

1.3 Description of the buildings adjacent tot the excavation

The houses adjacent to the wall were monumental buildings from around 1670. The buildings were part of originally more than 200 houses, specifically built for weavers, wool combers and spinners.

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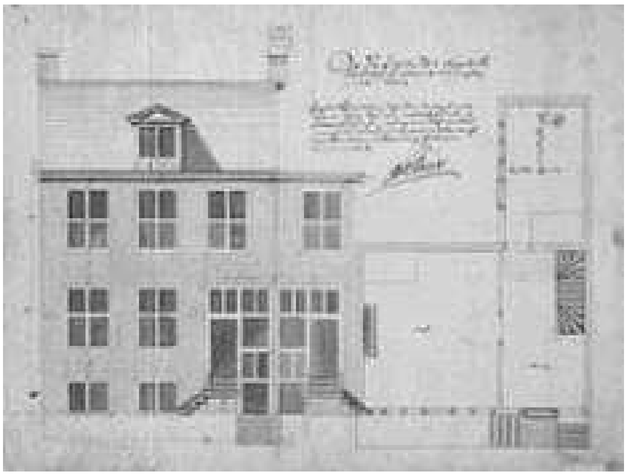

Figure 1. Original drawing of Weavers building (BMA Amsterdam)

The buildings all have a semi-basement, a raised ground floor, and a first floor with vaulted roof. The rear of the house includes a kitchen addition. Each block of houses has a continuous ridge beam. A foundation consisting of 52 timber piles per house is expected to extend to the first sand layer. Before construction of the North South Line these buildings were equipped with monitoring instruments (Figure 2).

Figure 2 Weaverbuilding Vijzelgracht 26 with prism locations (picture Projectbureau NoordZuidlijn)

2 ANALYSES OF INCIDENT AT VIJZELGRACHT 20-26

2.1 Deformations and damage

As shown in Figure 3, the block of houses Vijzelgracht 20-26 settled a maximum of 150 mm as a consequence of the incident in June 2008. The building clearly tilted towards the corner of VZG 26 and towards the excavation and the location of the leakage. Both houses 26 and 24 rotated towards the corner of the block. A slight sagging was found between VZG 26 and VZG 24 and hogging towards VZG 22. The cracks on the inside and outside of the buildings were recorded and are shown in Figures 4 and 5. The cracks reported are mainly new cracks or previous cracks that opened significantly.

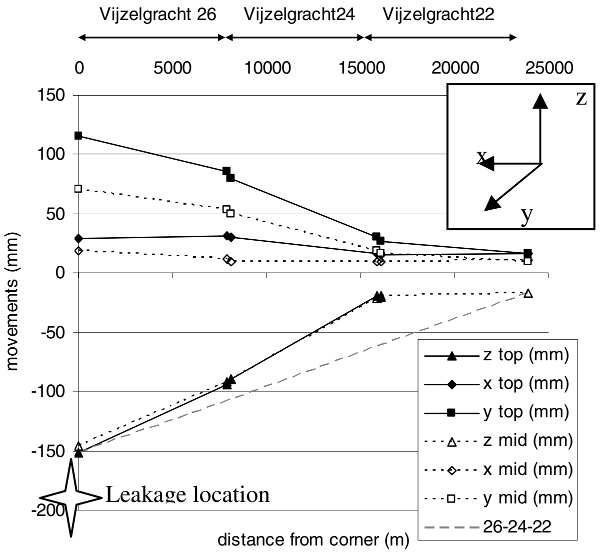

Figure 3 Deformations after incident June 2008 (measurements dated July, 31st 2008)

Figure 4 Cracks at the front façade (26 on the left side, 24 on the right)

Cracks 1 to 4 were found on the outside of number 24 and have a crack width of respectively 20 mm, 10 mm, 8mm and 8mm. Cracks 5 to 9 were found on the inside and are smaller than 5 mm. A cracked window was found at number 10. Number 11 is a crack out of plane of the drawing, separating the staircase from the house. Cracks 12 to 14 were found on the outside of number 26 and have crack widths of 2 mm, 7 mm and 2 mm. The location and direction of the cracks indicate a shear deformation with the largest crack width mainly in VZG 24, just as the differential settlements indicate. Cracks at the rear are not shown, but would indicate a twist movement of the building and horizontal extension. Since there are no deformation measurements of the rear façade, these can not be related to the crack directions.

Figure 5 Detail of crack number 1 (crack width max. 20 mm)

2.2 *Building damage indicators*

The actual damage derived from the observations for these buildings (26, 24) would be category 5, very severe (Burland et al 1977). A significant tilt of the buildings was observed, with severely sloping floors. The stability of the buildings was also in question , so the buildings have been temporarily braced by wooden supports. The front façade experienced a *maximum* tilt of 1:78 perpendicular to the façade and 1:184 parallel to the façade at the corner of Vijzelgracht 26 and between VZG 26 and VZG 24 respectively. Both relative rotation and deflection ratio have been calculated for the front façade. For the relative rotation the calculation method of Son and Cording (2005) has been used. This method calculates the slope of the building and defines the relative rotation as β = slope – tilt. The tilt is derived from the differential horizontal movements of VZG 26 and 24 and would *average* 0.27% or 1:367 parallel to the façade. Combining relative rotation and horizontal strain results in damage category 'severe to very severe' for Vijzelgracht 26/24. If one disregards the tilt and uses the slope as the relative rotation (i.e. assuming β = slope), the damage category would also be 'severe to very severe'. The method of Mair et al (1996) can also be used, combining deflection ratio for a central point load situation with the horizontal strain.

Table 1. Damage criteria Vijzelgracht 26-24 front facade

Criterium	Calculation	Damage category
Maximum slope	(89-19)/ 8 m = 0.9% or 1:111	severe to very severe
Relative rotation β (average tilt)	0.9%-0.27% = 0.62% or 1:160	severe to very severe
Relative rotation β (max. tilt)	0.9%-0.54% = 0.35% or 1:282	moderate
Deflection ratio Δ/L	43 mm / 24 m= 0.47%	severe to very severe
Horizontal strain ε_h average	10 mm/24m= 0.04%.	Included in damage category

It can be concluded that the damage to the façade is mainly caused by shear deformation and horizontal extension in the plane of the wall. The damage categories found comply well with the actual damage. Damage to the buildings as a whole is especially severe in terms of serviceability due to the overall rotation of the building perpendicular to the facades. Severe sloping and tilting of floors and walls are clearly noticeable and separation of the rear façade from both the main house and the kitchen addition is caused by horizontal extension. Although these could not be calculated because measurements were not taken at the rear, these effects are not easily described in terms of 'traditional' damage criteria.

3 ANALYSES OF INCIDENT AT VIJZELGRACHT 2-10

3.1 *Construction activities and leakage problems*

On 10 September 2008 a further episode of severe leakage of soil and water occurred, resulting in substantial settlement of a new set of adjacent buildings (Vijzelgracht numbers 2-10). At this date the general excavation level had reached NAP – 13.9m and at joint 69/70 was locally deepened to NAP –16.9m. The leakage was caused by a bentonite inclusion in the wall of at least 2m high (extending from NAP –16.9m to NAP –14.9m) and about 0.25m wide at its widest point. At first, no water leakage was observed. After about 7 hours, during repair works (putting steel plates on the wall) a serious water leakage was observed. This leakage caused considerable settlement of the adjacent houses (a maximum of 240 mm being recorded for No. 4 Vijzelgracht). Rapid action was taken to stabilise the problem, involving backfilling the excavation to above the level of the opening, together with poly-urethane injections from inside the diaphragm wall and grout injection undertaken in the ground outside the wall. The settlement substantially ceased once this action had been taken. The settlement was principally associated with the ground loss into the excavation resulting from the leakage of soil and water through the wall; consolidation effects due to pore pressure reduction were minor.

Figure 6 Vijzelgracht 8-6-4 after the incident

3.2 *Description of the buildings*

The construction of the houses was essentially the same as for the buildings described in paragraph 1.3. The foundations of numbers 4 and 8 had been renewed with steel piles before the construction activities started. Number 8 still has the original foundation. All these buildings were founded on piles bearing on the first sand layer.

3.3 *Deformations and damage*

Block Vijzelgracht 4-10 settled a maximum of 240 mm directly after the leakage incident. To some extent damage was already present before the leakage occurred, such as the distorted windows. Figures 7 and 9 focus on new cracks and cracks that re-opened.

All cracks shown in Figure 7 are on the outside, because the inside was not surveyed. Crack 1 is a separation crack of about 60mm at the top, due to tilt between VZG 10 and 8. Crack widths in the masonry facades itself are generally up to 25 mm wide.

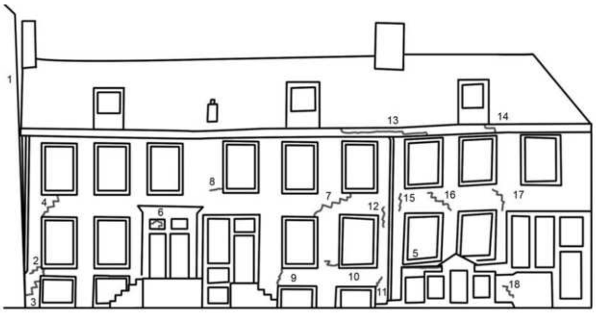

Figure 7 Cracks at the front façade VZG 8 -6 – 4

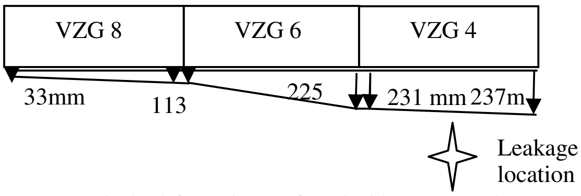

Figure 8 Vertical deformations after incident September 2008 (measurements dated 29th October 2008)

The cracks and deformations show that the houses deformed partly in hogging mode (VZG 8-6) and partly in sagging mode (VZG6-4), with the largest differential settlement found between house numbers 4 and 6. The diagonal direction of the cracks indicates a shear deformation. Both the hogging and sagging mode are consistent with the direction of the cracks.

Figure 9. Detail of crack 1 between Vijzelgracht 10 and 8

3.3.1 *Building damage indicators*

The damage clearly evident from the observations for these buildings (VZG4-8) is category 5, very severe. This is associated mainly with the sloping of the floors and walls and the separation of the different houses from each other, resulting in severe serviceability problems. The stability of the buildings was also in question, so the buildings have been temporarily braced by wooden supports.

The maximum slope of VZG4 perpendicular to the Vijzelgracht is roughly 235 mm/9m = 0.026 or 1:38. Parallel to the Vijzelgracht the maximum slope is also extremely large, being 1:70 over Vijzelgracht 6. Vijzelgracht 10 did not experience much damage, its slope not exceeding 1:550. The deflection ratio in hogging is Δ/L= 71 mm / 16 m = 0.45% and in sagging Δ/L= 187 mm / 15 m = 1.2%. The average amount of horizontal extension is 31 mm/32 m = 0.1%. Combining these according to Mair et al (1996), assuming a central point load, the principal strains become 0.6% for hogging and 0.19% for sagging, both resulting in the damage category severe to very severe.

4 CONCLUSIONS

Several authors have produced important work related to excavation induced building damage, such as Skempton and MacDonald (1956), Burland et al (1977), Boscardin and Cording (1989), Mair et al. (1996) and Son and Cording (2005). One of the main conclusions stated in all these papers is that building damage is related to the observed curvature or differential settlement of the building. The damage criteria proposed by these authors describe the observed damage to the facades reasonably well, even for these large absolute deformations.

This paper also shows that tilt, in extreme circumstances, can cause severe problems of serviceability and stability to buildings. In this case this proved more problematic than the curvature and resulting cracking of the building. Tilt usually does not receive very much attention.

In an accompanying paper by Bezuijen et al (2009) the effectiveness of the corrective grouting operations performed after the incident at Vijzelgracht 26-24 are reviewed. More monitoring results are presented as well.

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