Observations of anomalies in diaphragm walls for deep tunnel excavations

Observations d'anomalies dans des parois moulées utilisées pour la réalisation de tunnels à grande profondeur

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ABSTRACT

By assignment of the Belgian railway company, INFRABEL n.v., diaphragm walls are used for two major tunnel projects, the Diabolo-project and the Liefkenshoek tunnel. These diaphragm walls are permanent constructions retraining a certain water pressure and having a thickness up to 1.50m. The excavation depths are between 5 and 22m and the diaphragm walls are founded at a depth of 32m. During the excavation, some major anomalies in the diaphragm walls occurred such as bentonite/sand inclusions and inadequate concrete cover. These anomalies have been investigated.

RÉSUMÉ

Pour la compagnie de chemin de fer de Belgique, INFRABELs.a., des parois moulées sont en cours de réalisation dans le cadre deux projets de tunnels majeurs : le projet Diabolo et le tunnel Liefkenshoek. Ces parois moulées sont des constructions définitives retenant une certaine hauteur d'eau et ayant une épaisseur de maximum 1,50 m. Les profondeurs d'excavation des fouilles de construction sont comprises entre 5 et 22m; dans ce dernier cas, les parois moulées sont fondées jusqu'à 32m de profondeur. Pendant l'excavation, plusieurs anomalies dans les parois moulées ont été constatées telles que des inclusions de bentonite/sol et des défauts d'enrobage d'armatures. Ces anomalies ont été investiguées.

Keywords: Diaphragm walls, deep excavation, execution details, defects, bleeding, bentonite/soil inclusions

1 INTRODUCTION

The Diabolo project, currently under construction, provides a greater access for the passengers to Brussels Airport. The largest part of the project consists of a tunnel creating a direct link between the existing underground station and a new line between Brussels and Mechelen, located at the central reservation of the motorway between these cities [1]. The subsoil at the tunnel mainly consists of Brussels sands (fine calcareous sands with horizontal sandstones and sandstone layers banks) covered with alluvial deposits of silt with a thickness of several meters.

The Liefkenshoektunnel is being built for the further development of the sea-port of Antwerp on the left bank of the Scheldt River. The railway tunnel provides a new link between the two banks of the Scheldt River for the transport of cargo from and to the left bank and the inner part of the country [2]. This tunnel is constructed primarily in tertiary sands on top of the Boom clay. The sands are covered by an alluvial deposit with a thickness of a few meters.

Even though the tunnels in both projects highly consist of drilled sections, a significant amount of diaphragm walls are being used for the construction of emergency exits, departure and arrival shafts (cut-and-cover). With the excavation of the latter, a number of anomalies were found in the diaphragm walls. Those anomalies have been investigated in a search for a causal link with the execution of the diaphragm walls.

2 DEFINED ANOMALIES

The anomalies involved in the excavation of tunnel sections can be divided into 3 groups:

- Bentonite/sand inclusions occurring in diaphragm wall panels (see figure 1)
- Bentonite/sand inclusions in joints between diaphragm wall panels (see figures 2 and 3)
- Superficial anomalies on the concrete surface.(see figures 4)

The bentoniet/sand inclusions are, in most cases, shallow with a maximum depth of penetration of 10cm.

Figure 1: Bentonite/sand-inclusion[1] in diaphragm wall panel

Figure 2: Bentonite/sand-inclusion to the surface of the joint

[1] All bentonite/sand inclusions have been washed out by cleaning the diaphram wall surface.

Figure 3: Bentonite/sand-inclusion in joints over the full thickness of the diaphragm wall panel

The bentonite/sand inclusions in the diaphragm wall panels are more or less horizontal with an observed difference in level of 20 to 30cm (see figure 1 and figure 3). Some bentonite/sand inclusions in joints between the diaphragm wall panels have been identified over the full thickness of the wall (see figure 3).

The bentonite/sand inclusions in joints can be recognised by their high and narrow shape. Most of the bentonite/sand inclusions could be linked with a long duration of concreting or a long interruption in the concreting of the panel.

Besides of the bentonite/sand inclusions, also bleeding channels as shown in figure 4, have been observed, as well as an inadequate concrete cover. The bleeding channels are superficial with a depth of a few cm. and can be recognised by their washed out delineation. Since no cores through the panels were made, no bleeding channels have been investigated deep inside the diaphragm wall, as identified in [3].

Figure 4: Bleeding channels on the concrete surface and inadequate concrete cover

3 POSSIBLE CAUSES OF ANOMALIES

3.1 Bentonite/sand inclusions occurring in diaphragm wall panels

The bentonite/sand inclusions identified in the diaphragm wall panels were created by a combination of two phenomena:

- Decreasing fluidity of the concrete during concreting
- Increase of density of the bentonite slurry just above the rising concrete surface.

As the fluidity of the concrete in the upper meters decreases, the upwards movement of the latter becomes more and more difficult during the concreting process. Once the resistance of the concrete to pass along the outer surface of the tremie pipe becomes less than the resistance to move all the concrete above the bottom of the tremie pipe upwards, a breakdown along the tremie pipe occurs [4]. This generates a fresh concrete on top of the original concrete surface in which the bentonite slurry with increased density becomes embedded and a bentonite/sand inclusion may be created.

With prolonged breaks in the concrete-process there is even an increased risk of occurrence of these bentonite/sand inclusions. Also in the top meter of the diaphragm wall panel, the up and down movement of the concreting pipe during concreting can make the occurrence of a breakdown along the concreting pipe easier.

The decrease of the fluidity of the concrete during the concreting is caused by beginning of the binding process of the concrete. Furthermore the concrete in the upper meters scrapes the bentonite cake on the walls of the excavation. In absence of the enclosing layer, a dewatering of the concrete can occur, resulting in a further decrease of the fluidity.

The scraping of the bentonite cake also increases the density of the bentonite slurry just above the top of the concrete and, depending on the bentonite type, the bentonite slurry can be affected by the cement in the concrete. This latter phenomenon causes that the slurry structure collapses as a house of cards resulting in a further increase in density. This is confirmed by measurements of bentonite slurry density at the surface at different times during concreting. Figure 5 shows the evolution of the densities as a function of time and depth of the concrete surface at the time of measurement.

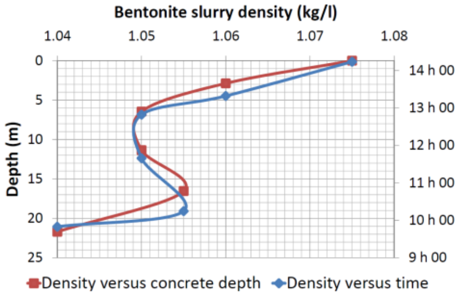

Figure 5: Evolution of the bentonite slurry densities during concreting of panel G137

The starting value of the bentonite slurry density was 1.04kg/l. This value was measured at the beginning of the concreting of the panel. As the concreting progresses a slight increase in the density of 1.05kg/l can be observed. Towards the end of concreting as the concrete surface is at 3m depth from ground level, a significant increase in the density is observed.

3.2 Bentonite/sand inclusions in joints between diaphragm wall panels

The bentonite/sand inclusions occurring in joints between the panels have a similar origin as described above. Near the joints, the flow of the concrete is further inhibited by the presence of the waterproofing strip. By placing the reinforcement cage too close against the waterproofing strip, this resistance is further increased. Due to the increased resistance on the sides of the panel, a higher gradient in the concrete surface can be observed during concreting. As a concrete breakdown along the concreting pipe occurs, the bentonite slurry with increased density is dragged with the flow of the concrete, causing a bentonite/sand inclusion in the lower parts of the concrete surface on the side of the panel.

This was confirmed by measurements. The gradient was measured at both sides and in the middle of the panel. The characteristics of the panel are listed in table 1. Table 2 shows the measured values. A maximum level difference of

0.60m was found for a panel thickness of 1m. From these measurements it may be deduced that the duration of the concreting of the panel has also an important influence on the observed level difference and that the level difference is more pronounced as the panel thickness decreases.

Table 1: The characteristics of the panels

nr.	Thickn. (m)	Length (m)	Depth (m)	Concrete volume (m^3)
G137	1	7.5	21.7	162.75
O263	1	7.5	23.43	175.725
G127	1.2	7.5	21.9	197.1
HD02	1.2	6.57	24	189.216

Table 2: Measured values during concreting

nr.	Concreting time (overall)	Max. level difference (m)	Concrete height at max. difference (m)
G137	4 h 20	0.60	13.10
O263	2 h 20	0.35	13.73
G127	3 h 30	0.18	16.70
HD02	4 h 55	0.19	20.70

3.3 Superficial anomalies on the concrete surface

Bleeding is caused when a very high pressure exits in the laitance of the concrete and this laitance is pressed through the still liquid concrete. A similar effect can also be caused by the water present in the bentonite/sand inclusions. This water being under pressure may, in an upward motion, flow through the fresh concrete and wash out laitance from the concrete. However, no link was found between the occurrence of the bleeding and present bentonite/sand inclusions.

The inadequate concrete cover on the reinforcement cage of the panel is mainly caused by the use of spacers which are not adapted to the soil in which the diaphragm wall panels are made. For the Diabolo project, the diaphragm wall panels were dug through sand with sandstone banks [5]. By digging through the sandstone banks local widening of the trench occurs. If the spacers are installed in such overwidth, they are inefficient. It is also found that asymmetrical reinforcement cages are being pushed during concreting to the side with the greatest reinforcement concentrations. On this side, the flow of concrete through the reinforcement is much more difficult, resulting in a lateral force on the cage. This movement reduces the orifice between the trench wall and the reinforcement cage which makes the flow of concrete even more difficult. This phenomenon may also lead to the occurrence of bentonite inclusions, such as visible in figure 6.

Figure 6: Inclusions caused by the lack of concrete flow

4 CONCLUSIONS

The investigation of observed anomalies in diaphragm walls, such as bentonite/sand inclusions, bleeding and inadequate concrete cover, has led to a better understanding of these phenomena.

As the investigation was carried out on a small scale, a more thorough investigation needs to confirm the conclusions made. Moreover, it is necessary to improve the monitoring of the execution of the diaphragm walls in order to improve the evaluation when new anomalies are observed.

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