

Field trial results using biobased PVD in Amsterdam

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ABSTRACT: Prefabricated vertical drains (PVDs) have become crucial in geotechnical engineering, enhancing soft soil consolidation for construction projects. Growing global awareness of sustainability has driven PVD technology to explore and adopt alternatives to the current oil-based materials used in PVDs. A field trial with innovative vertical drain materials has been conducted on a reclaimed area in Amsterdam, The Netherlands in 2024 to qualitatively compare the performance of three different PVD types and validate the use of the alternative drain types.: the conventional MD7407, an eco-friendly biodrain fabricated from Polylactic Acid (PLA), and a 100% natural PVD comprising of Jute filter integrated with coconut ropes. All types were embedded in the in-situ clay. Through a network of settlement plates and piezometers, the field behavior was monitored. The development of (excess) pore water pressure was measured using piezometers placed inside and around the installed drains, while the settlement of the fill was measured using settlement plates. Through the examination of the monitoring results, this paper clarifies the critical interplay between soil consolidation rates and drainage efficiency. The findings of this research offer insights into the operational dynamics of PVD systems and the progression of soil consolidation relative to the discharge capacities. Furthermore it validates the use of biobased materials for soil consolidation.

KEYWORDS: PVD, vertical drain, biobased, field trial.

1 INTRODUCTION

Vertical drains are frequently used for the consolidation of compressible and low permeable clay and peat deposits. The use of vertical drains offers various advantages, such as shortened construction time, better control over residual settlements, and accelerated development of the strength of the subsoil. Traditionally, vertical drains consist of an oil-based plastic core of polypropylene (PP) surrounded by a PP or polyethylene terephthalate (PET) geotextile sock.

Globally, depending on available projects, tens to hundreds of millions of meters of drainage material are permanently installed underground each year. Although still mainly focused around consumer goods, the environmental discussion has also reached the geotechnical sector driven by motivations of employees striving for a more sustainable world and made possible by the increasing availability of more sustainable materials.

After years of research, more sustainable alternatives for the traditional vertical drains with the right technical properties have now been developed. These alternatives focus on reducing the environmental footprint by both downscaling the weight of regular drainage types, and by using biobased materials such as Polylactic Acid (PLA), coconut fiber, and jute whilst assuring the required performance. The use of PLA PVD already halves the CO₂ footprint of the ex-factory material in comparison to the traditional PVD with a footprint of about 0.2kg CO₂ per meter drain. To validate these new vertical drain types, Cofra, in collaboration with the municipality of Amsterdam, has set up a test section in which the soil settlements and the progression of the water pressures as a result of the different drain types have been measured over a period of 12 months. This article describes the setup of the test, discusses its results after which conclusions will be presented and recommendations provided.

2 TRIAL SET-UP

The validation test took place on the newly constructed Buiteneiland of IJburg located in Amsterdam, The Netherlands. At this location, the contractor joint venture called “Combinatie IJburg”, formed by the consortium of Boskalis and De Vries & Van der Wiel, has constructed various containment bunds, within which soil, released from future construction pits and

excavations in the Amsterdam region, will be placed. One of the dikes of the project has been made available as a test location by the Municipality of Amsterdam and the Combinatie IJburg. Figure 1 shows the location of the trial area relative to the project area and its location within The Netherlands. In the original design, no drainage was planned for the trial area. In a total area of 50m x 40m, three different types of vertical drains were installed, in sub-sections of 25m x 20m, around an initial settlement plate that was placed as soon as the land reached a level above the water table.



Figure 1. Location of the trial area.

The following vertical drain types have been installed in a triangular grid spacing of 1.2m. Figure 2 provides a visual impression of the drain types:

- MD7407: a drain based on Polypropylene (PP). This is the most commonly used vertical drain. This vertical drain is used for the regular work on the IJburg project and many other works in the Netherlands, and serves as a reference for the trial. The CO₂ emission per meter is around 0.2 kg/m (The installation-phase emissions are identical across all drainage types);
- Biodrain: a vertical drain based on biobased Polylactic Acid (PLA) core and filter. PLA is a biobased material that only breaks down under industrial composting.

These conditions are not present in soil, and therefore a PLA drain does not degrade. Experience shows, however, that the drain becomes more brittle over time and should not be stored for too long. The main advantage of these drain types is that they are not made from petroleum products and the CO₂ emissions are around 0.11 kg per meter of drain.;

- **Green PVD:** a vertical drain based on coconut rope and a jute filter. These materials are completely natural and decompose naturally when exposed to oxygen. They are not expected to decompose in oxygen-poor peat soils below the groundwater level. Above the groundwater level, jute degrades quickly. No CO₂ data are available for this type of drainage system.



Figure 2. The trialed drain types. From left to right: MD7407, Biodrain and Green PVD.

The laboratory results show similar discharge capacities between the MD7407 and the Biodrain. The Green PVD has a much lower discharge capacity but is the only PVD made from 100% natural material that is currently available. The latter has been tested to investigate if this type of drain really performs as well as described in Purwondo & Djohan (2018), Lee (2002), Nguyen et al 2016, Nguyen (2018) and Islam (?) in comparison with the other types of drains.

Table 1 provides the properties of the applied drain types. The values are determined from samples selected from the installed drain rolls.

Table 1. Laboratory tested discharge capacities of the tested drain types

	Discharge capacity Buckled (120kPa, gradient 0.1) [ml/sec] / Amount of water Q under gradient of 0.1 [m ³ /day]		
	After 1 day	After 7 days	After 28 days
MD7407	53 / 4.6	46 / 4.0	40 / 3.5
Biodrain	75 / 6.5	54 / 4.7	42 / 3.6
Green PVD	4 / 0.4	3 / 0.3	1 / 0.1

3 DESIGN

Before the start of the trial, 6 Cone Penetration Tests (CPT) were conducted to determine the local ground profile. These CPT's showed a consistent picture of the subsoil beneath the trial section. Figure 3 presents the soil profile as determined by a representative CPT. The subsoil consists of a recently reclaimed sand layer of roughly three meters thick, overlying eight meters of compressible clay. In all test sections, the drains were installed to a depth of NAP -10.5 m in order to stay 1 meter above a sand layer to prevent connection. As per the design of the municipality of Amsterdam, the drains have all been installed at a triangular grid spacing of 1.2m. No drains were placed outside the boundaries of the trial section.

The installation of the drains took place in March 2024 from an average surface level of NAP +0.3 m. All drain types were installed without problems using regular installation equipment, see figure 4. For various reasons unrelated to the test section, the section was not raised homogeneously. Furthermore, these external factors resulted in long waiting periods between the raising steps and the final completion of the section. This had the advantage of allowing monitoring to continue longer than originally planned. However, a disadvantage was that the various sections were less comparable.

The following section presents the monitoring results and provides further explanation of the differences between the sections.

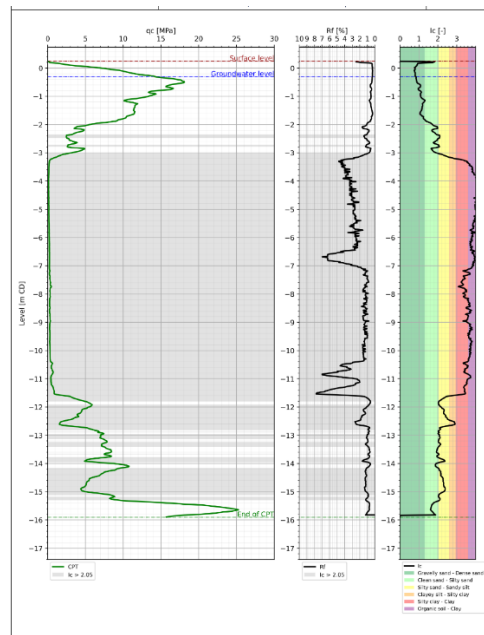


Figure 3. The soil profile at the location of the trial.

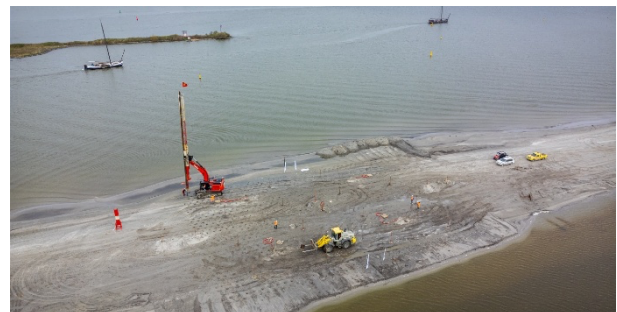


Figure 4. Installation of the MD7407 by a Cofra installation set together with the placement of settlement plates in the Green PVD area.

4 MONITORING

To evaluate and monitor the behavior of the drains, two common types of monitoring instruments were used: piezometers and settlement plates. The piezometers were installed at a depth of NAP -8.5m both within the filter in the vertical drains as well as in the center of three drains. In addition, a piezometer was placed in the overlying reclaimed sand layer at NAP -1.5m. This setup allows for the relative water levels to be followed over time. For example, if a difference occurs between the hydrostatic water pressure value calculated using the water level at the top of the drain, and the water pressure at the bottom of the drain, this may indicate a

pressure build-up within the drain. This suggests that the drain temporarily discharges a relatively large amount of water when compared to the discharge capacity. Figure 5 depicts the influence of flow resistance on the consolidation process. The graph is showing the effect of a fixed water amount flowing through two types of drains. A regular drain (green) and an inferior drain with low discharge capacity (red). The inferior drain will show a high gradient, due to flow resistance. Due to this high gradient, the water pressure in the drain will quickly increase with depth until it maximally equals the water pressure of the surrounding soil. The decrease in the water pressure difference between the drain and the surrounding soil will slow down the consolidation process, especially during these periods with higher settlement rates. An optimally designed drain will exhibit minimal, low gradients within the drain at high settlement rates, resulting in minimal pressure buildup and minimally affecting the settlement process, with a negligible gradient for the rest of the lifespan.

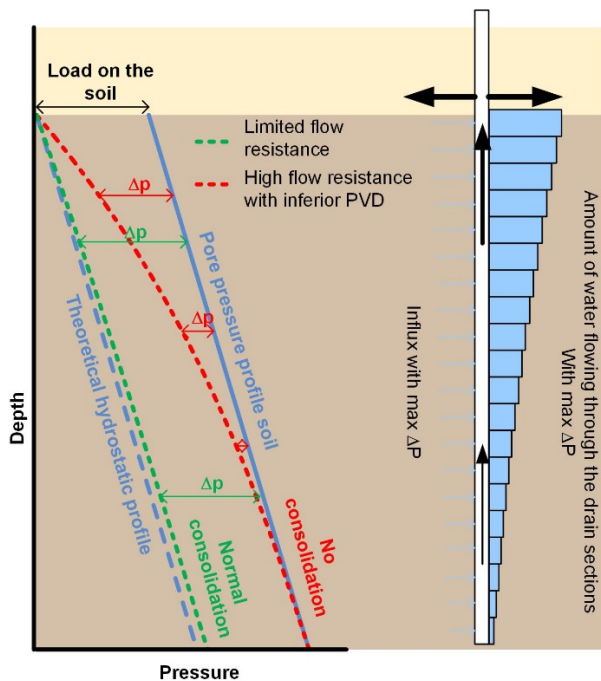


Figure 5. Graph showing the effect of flow resistance on consolidation.

The piezometers are grouped for each drain type, three piezometers are installed at the same depth, two inside the drain and one at the center between three drains. One piezometer is placed in the fill at the center of the trial area to measure a representative groundwater level for all sections. Figure 6 provides an overview of the monitoring instruments. Each section contains 5 settlement plates placed in the corners of the section and one in the center. In addition to settlement plates in the sections, settlement plates and piezometers are also placed 5 meters outside the edge of the trial area. Because the settlement markers could not be placed at the old ground level, part of the settlement was missed in the measurements. The measurements are linked to the previously installed main marker, called the official deep settlement marker ZB3 in Figure 6. However, this marker was also installed later due to the backfill in the lake.

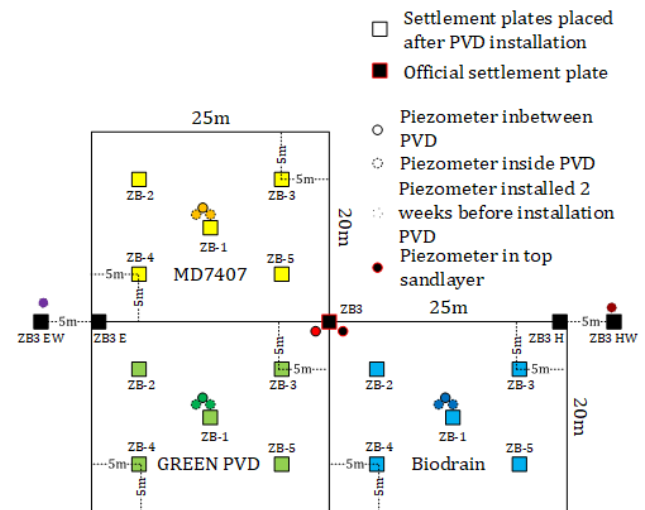


Figure 6. Location of the monitoring equipment.

5 MONITORING RESULTS: SETTLEMENT PLATES

Figure 7 shows the measured settlements. Prior to the installation of the drains, all settlement plates exhibited a similar trend: an undrained settlement rate of approximately 5 cm per month. After the installation of the drains, a clear acceleration of the settlement was observed in all test sections. A slight acceleration is also visible in the settlement plates outside the PVD installation area (Plates EW and HW, 5 meters outside the drain sections).

The largest settlement was measured at the test section with the standard drain MD7407, while the smallest settlement was observed in the section with the Green PVD. During the first three months the Biodrain showed settlements similar to the MD7407. After three months, the Biodrain showed a flattening of the settlement curve when compared to the MD7407. This difference was caused by a variation in fill height/thickness. An additional meter of sand, along with the installation of a stone shore protection, was applied midway through the test field, outside our control, creating a load difference between the MD7407 section and the sections with the Biodrain and the Green PVD. After applying this layer, filling was paused due to the observed instability of the undrained part next to the test section (right top side of figure 6).

Comparison with settlement beacon 11 (see Figure 1 for its location), positioned on a section of the dike without drainage, indicates that all tested drainage types result in increased settlement. Beacon 11 also displays a settlement pattern comparable to beacons ZB03-EW and HW, which are located approximately 5 m outside the test section. Minor variations in the recorded measurements are attributed to measurement uncertainties. According to the Municipality of Amsterdam's design specifications, the final expected settlement of the dike is 1.70 m.

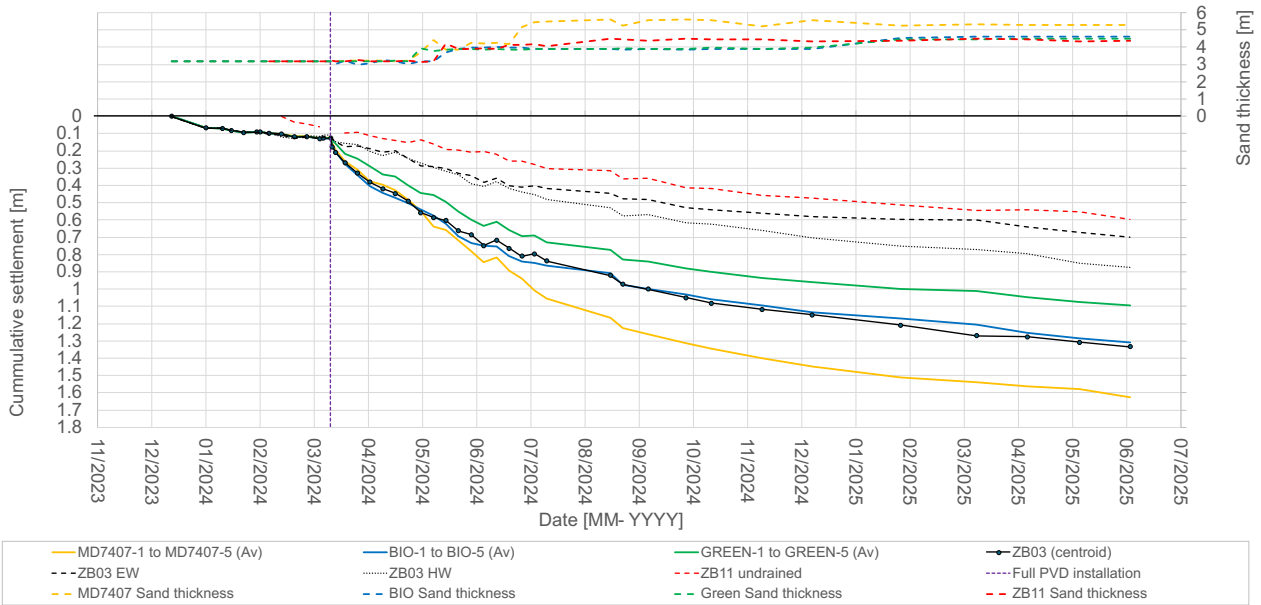


Figure 7. Visualization of the settlement beacon data. Here, the average of settlement beacons 2 to 5 for each test section is plotted, alongside the settlement beacon data of the central settlement beacon. The black plots represent the settlement beacons that are not linked to a test section. Note that the sand fill in the section with the Biodrain and the Green PVD is progressing in parallel.

6 MONITORING RESULTS: WATER PRESSURES

For the validation of the vertical drains, piezometers were placed both in the center of three drains and within the drains, as well as in the upper sand layer at NAP -1.50 m. This setup allows for the tracking of pore water pressure differences over the course of the test and the analysis of the excess pore pressure dissipation. The piezometer in the upper sand layer is corrected for the occurring settlement. The piezometer measurements at a depth of NAP -8.50 m, both in the drain and between the drains, are not settlement corrected as only surface settlement measurements were available. During the monitoring of the test section, various piezometers failed or started to "drift". The cause of this is unclear, complicating the interpretation of the data. They were removed from the data. Measurements were corrected for air pressure

6.1 Water Level in the Drains

Figure 8 shows the difference between the theoretical hydrostatic water pressure based on the groundwater level and the water pressure measured in the drain. For both the Biodrain and the MD7407, it can be seen that this pressure difference in the initial phase, with its high settlement rates, lies between 1 and 3 kPa (10cm and 30cm water column). This corresponds to a gradient of 0.01 ((pressure buildup/length = 10cm/880cm) to 0.03 (30cm/880cm), a factor of 3 to 10 lower than the laboratory test gradient of 0.1 for which the discharge capacity was determined. For the Green PVD, the difference in water level varies between 4 and 10 kPa, and consistently remains higher than the theoretical hydrostatic groundwater pressure based on the groundwater level. This is as expected since this drain has no free-flowing channels due to the swelling of the jute and

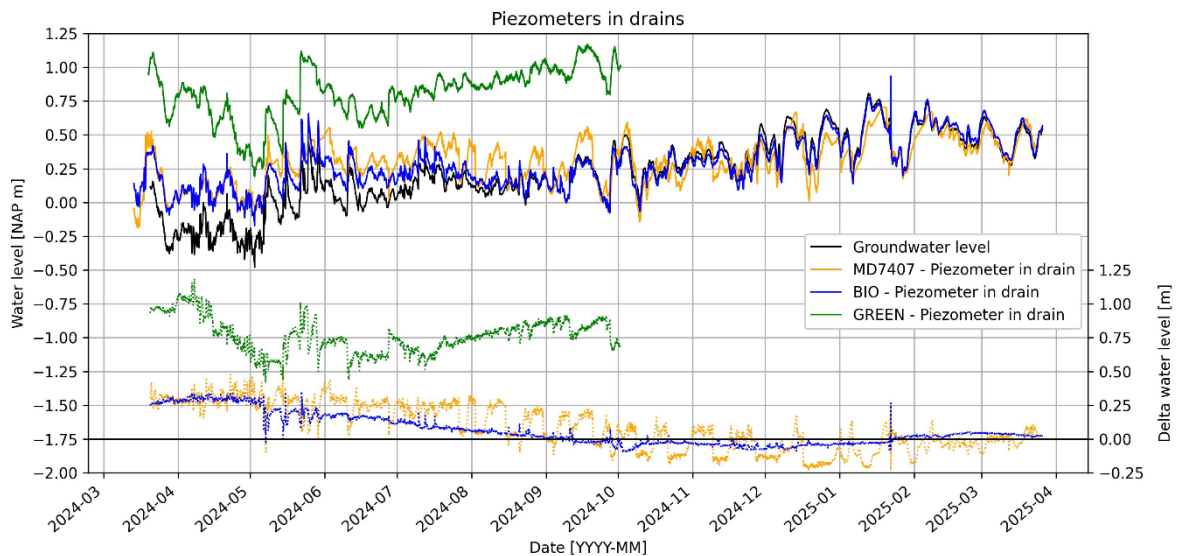


Figure 8. Water levels derived from the pressures measured inside the drain and in the top reclaimed sand layer.

coconut materials and the compression of potential flow paths. See also Table 1 for the lower discharge capacity of this type of drain and figure 4 for further explanation of the principle. The measurements are plotted till the moment the sensor no longer provides reliable values.

It is clear that as the amount of water in the soil decreases, the pressure differences between the MD7407, the Biodrain, and the groundwater level decrease as well. Small deviations are caused by a slightly varying sand thickness in the dike body. It is noted that the water level in the dike body does not follow the level of the Markermeer, but varies across the dike due to the difference in capillary rise in the sand body.

6.2 Water Level Between the Drains

Figure 9 shows that all test sections had the same initial water pressure in the subsoil at a depth of NAP -8.5 m prior to installation. Notably, a decrease in the water pressure is immediately visible in all drains after installation, regardless of the drain type. Whereas the Biodrain and MD7407 exhibit a similar outflow rate, it is clearly visible that water is draining in the Green PVD test section as well. However, the rate of decrease in excess pore pressure in the subsoil is lower for the Green PVD in respect to the Biodrain and MD7407. Consequently, during the application of the first fill layer (early May), the measured water pressure was higher in the section with the Green PVD than in the other test sections. This partially corresponds with the higher water pressure in the drains, as shown in Figure 8. After the first fill layer, all piezometers installed in the clay still show a decrease in excess pressure, even in the Green PVD area. This decrease in pore water pressure is halted after the placement of the additional fill in early July, after which the water pressure remains constant between the Green PVD drains. It is hypothesized that the top of the drain has either completely degraded or that the drain is completely compressed at the depth of the piezometer at the time of applying the fill layer.

In Figure 9, the red line in the heart of the test sections at settlement beacon 3 follows the MD7407 and the Biodrain. At some point, the water pressures even falls below the water level in the upper layer and follows the lowest water level achieved. Th

meters is fully consolidated and that there may be an influence from the lower water levels from the sand layer below the test section, see Figure 9. The Green PVD follows a similar trend to the other two drain types but continues to exhibit excess pore water pressure. However, this excess pressure is lower than the pore pressure measured in the undrained sections of the dike body.

7 CONCLUSION AND DISCUSSION

In March 2024, a test site was initiated at the Buiteneiland IJburg project to test and validate different types of drainage materials under similar field conditions. The Biodrain and the Green PVD were tested and compared to the regular MD7407. Settlement and the development of water pressure were used to gain insight into the performance of the different types of drains.

The difference in fill height over the area and the quality of the piezometers, with many providing ambiguous results after a few months made the comparison between the drain types more complicated than initially anticipated.

The test indicates that both the MD7407 and the Biodrain yield similar results in terms of in field discharge capacity. The developments in water pressure are similar. At the beginning of the project, both drain types show a gradient of 0.01 to 0.03, which are normal values for these drain types when considering the amount of water being discharged.

The absolute settlements between the Biodrain and the MD7407 PVD do show a difference, this is however caused by a difference in load on the test respective test sections.

As expected, based on the low discharge capacity, the trial results of the Green PVD shows a different pattern as opposed to the Biodrain and the M7407 PVD. High resistances are measured within the drain, and the drainage of excess pore pressure stops after the last fill layer, while settlement continues. This suggests that there may be a relationship between the pressure on the drain and the ability to discharge water, as settlement still occurs, but there is at the depth of -8.5m NAP no further drop in pore pressure is measured. Despite the extremely low discharge capacity as shown in Table 1 the Green PVD has performed exceptionally well with an

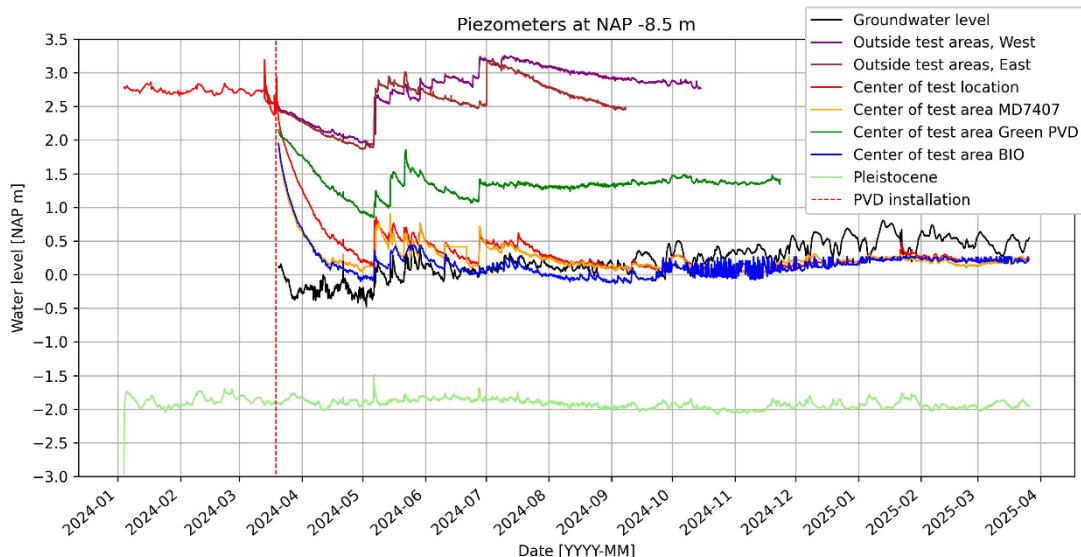


Figure 9. Water levels derived from the pressures measured in between the drains, the top reclaimed sand layer and the surrounding area.

acceleration in the settlement rates and to some extent a reduction in pore pressures.

The trial has demonstrated that the Biodrain can be an excellent replacement for the regular MD7407 and can be considered equivalent in terms of performance. Although the Green PVD does show an acceleration of settlement, this is to a lesser extent compared to the regular MD7407 and the Biodrain. This type of drain, in its current form, cannot be considered equivalent to the MD7407 given the low discharge capacity measure in the laboratory, the lower measured settlements and higher pore pressures measured in the soil. Cofra will continue to develop the Green PVD to improve this drain into a full-fledged alternative to the other two types of drains

8 ACKNOWLEDGEMENTS

We would like to thank the Municipality of Amsterdam for the opportunity to test new, more sustainable, PVD types. We would also like to thank the Combinatie IJburg for providing us with the monitoring results of the settlement plates and their patience to drive around the “forest” of settlement plates during their operations.



Figure 10. Project team and supporters of the trial.

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