

# Oosterweel connection - optical fiber monitoring of a 17-meter high reinforced fill structure

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**Abstract.** As part of the infrastructure works on the Antwerp Ring, a large number of reinforced fill structures have been constructed in recent years. These structures include reinforced fills with gentler slopes as well as those featuring vertical or near-vertical facings. Within the framework of this extensive road infrastructure project, the client Lantis has selected a reinforced fill structure approximately 17 meters high and 160 meters long, with a near-vertical facing for monitoring deformations in the geogrids ensuring its stability. This paper presents the instrumentation of the geogrids using optical fiber technology and the results of measurements conducted over the past three years at the site. The results are analyzed in accordance with design requirements and their projections.

## 1 Introduction

The Oosterweelverbinding project is one of the largest infrastructure undertakings in Belgium, aiming to complete the ring road around the city of Antwerp. Beyond just road connectivity, this project envisions a major urban transformation. It aims to improve residents' quality of life by creating accessible green spaces, reducing noise and air pollution through covered roadways, and reconnecting neighborhoods historically divided by the ring. The new developments will provide better access to neighborhoods and are expected to alleviate congestion, thus stimulating the Flemish economy. The total investment for the Oosterweelverbinding project was initially estimated at approximately 3.5 to 4 billion euros. This amount includes the construction of tunnels, new road infrastructure, green spaces, and pedestrian areas for a greener and healthier city.

Lantis is the Flemish public company responsible for carrying out the Oosterweelverbinding project, which aims to complete the ring road around Antwerp. As the project owner, Lantis oversees the planning, coordination, and execution of the work, in collaboration with various partners and contractors.

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## **2 The reinforced fill structure to be monitored**

The reinforced fill structure to be monitored is located in the zone 'Linkeroever and Zwijndrecht' of the project (see Figure 1). Built between the wastewater treatment plant of Burcht (Zwijndrecht) and the E17 highway, the reinforced fill structure to be monitored forms the connection between the E17 and E34/R1 highways for the eastbound traffic. Figures 2 and 3 show different views of the reinforced fill structure under construction before its connection to the road section supported by a reinforced concrete structure on pillars. Figure 4 shows the monitoring plan for the measurement cross-section identified by the stakeholders. The measurement section has an above-ground height of approximately 17 m. At the location of the measurement section, the construction presents a reinforced fill structure on each side of the road. The two faces are connected in the middle of the construction by geogrids installed on both sides of the structure. The reinforced fill structure is built with Maccaferri geogrids: ParaGrid 150, ParaGrid 200 (geogrids #1) and ParaLinks 300/400/500/700 (geogrids #2).

The high tenacity geogrids used in this case study are planar structures consisting of a monoaxial array of composite geosynthetic strips. These geogrids are mostly used for reinforcement purposes being their peculiar structure able to provide the necessary strength to reinforce fill material. The strips comprise of a core of high tenacity polyester tendons encased in a polyethylene sheath. In the present project, geogrids #1 present a short term tensile strength of 150 and 200 kN per meter width (machine direction) including tolerance according to EN ISO 10319. Geogrids #2 present a short term tensile strength of 300/400/500/700 kN per meter width including tolerance according to EN ISO 10319.

Both geogrids are used together with Terramesh systems preassembled units, as illustrated in Figure 5. In this system, the geogrids are clamped between two facing elements under the principle of the frictional connection: there is no physical connection between the facing element and the geogrid (such as a steel wire connecting the two materials).

The reinforcements are spaced vertically at intervals of 0.5 (for the mesh) and 0.5 to 1 meter (for the geogrids).

Figure 6 gives the results of an electrical CPT performed in the vicinity of the measurement cross-section. The subsoil beneath the reinforced fill structure mainly consists of fill sand, natural sand (Tertiary Kattendijk sand) above the Boom clay. It is likely that, in this zone, the soft soil layers were replaced or improved during the construction of the embankment of the E17 highway. Since we expected few compressible soil layers at the location of the reinforced fill structure, no ground improvement (e.g. by stone columns) was necessary.

As illustrated in Fig. 4, there is initially a different ground level on both sides of the reinforced fill structure. The initial ground surface steeply slopes under the reinforced fill structure. On the higher side, excavation is necessary to lay the geogrids.

The horizontal deformations of the reinforced fill structure that occur during construction should be mitigated during the construction process itself. This can be achieved by placing the reinforced fill structure a few centimeters back at the start of the installation. The vertical

deformations occur very gradually and will be mitigated by adjusting each layer of fill material, thus adding slightly thicker layers of sand.



**Fig. 1.** Oosterweelverbinding – Linkeroever and Zwijndrecht zone (concept view).



**Fig. 2.** Reinforced fill structure to be connected to the road supported by a reinforced concrete structure on pillars.



Fig. 3. Reinforced fill structure to be monitored under construction.

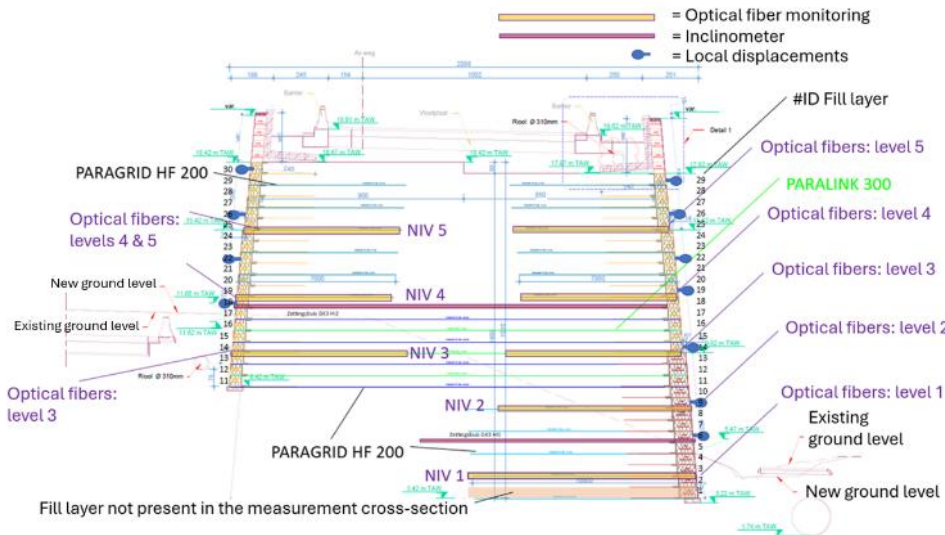
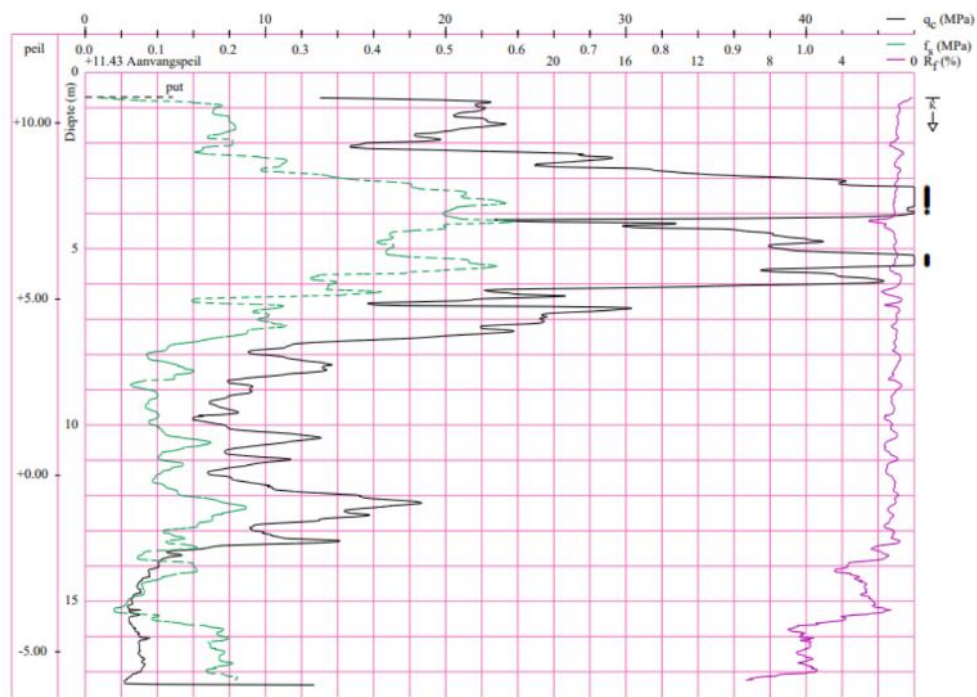


Fig. 4. Monitoring plan for the 17m-high measurement cross-section



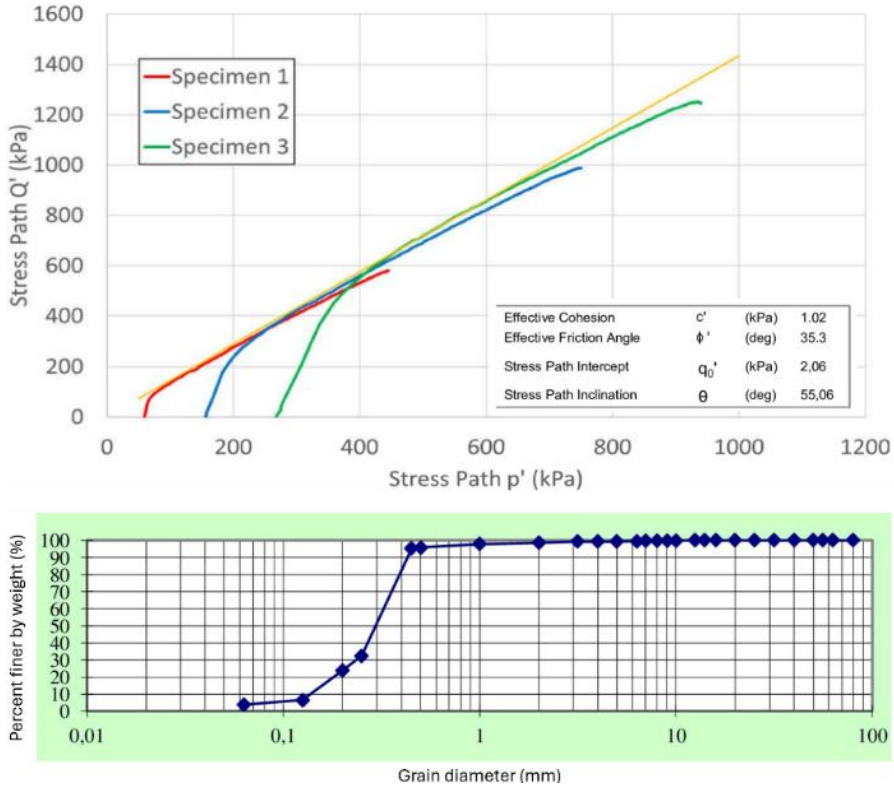
**Fig. 5.** Installation of the different geogrid and facing components on the field



**Fig. 6.** Results of an electrical CPT performed in the vicinity of the measurement cross-section

### 3 Properties of the fill material

Figure 7 shows the gradation and strength properties of the sand used as fill material. The backfill sand of the reinforced fill structure must be compacted until an effective friction angle of 32.5 degrees is achieved. During compaction of the fill layers, each layer must be controlled and achieve at least 25 MPa. Dynamic plate tests were regularly performed during the works to control the quality of the compaction.



**Fig. 7.** Grain size curve and results of consolidated undrained triaxial tests (BS 1377-8) on the sand used as fill material for the construction of the reinforced fill structure to be monitored

### 4 Some relevant design aspects of the reinforced fill structure

During the design phase, the internal, mixed, and global stability of the reinforced fill structure was verified by Arcadis Nederland, among others, using analytical methods and the Plaxis software and by the geogrid supplier using his own software. The global stability is verified with the Finite Element method using a  $\phi c$ -reduction and must have a minimum safety factor of 1.25. The design details fall outside the scope of this article. However, the authors highlight below certain points of concern that justified the establishment of a monitoring section at this location of the reinforced fill structure.

Firstly, it is the highest section of reinforced fill structure constructed as part of the Antwerp ring extension works.

Afterward, the load across the reinforced fill structure is not symmetrical, as there is a much higher structure on the wastewater treatment plant side. On that side, more settlement is expected. The soil on the E17 side has already been preloaded, and the height of the reinforced fill structure is lower there.

Finally, the geogrids have a higher stiffness in the short term, which decreases over time. This creep trend (decreasing stiffness) is included in the calculation by incorporating the time-dependent stiffness of the geogrid in the Finite Element model. For the measurement cross-section, the allowable strain due to creep after completion of the works must be limited to 1% during the service life of the structure. For this verification, forces are extracted in Plaxis from the most heavily loaded grid for the phases ( $t = 0$  and  $t = 100$  years) where only permanent loads and 50% of the variable loads are present, based on the assumption that this is the permanent loads which cause the geogrids to creep. The on-site measurements should help reassure the client about this matter.

## **5 Instrumentation of the geogrids of the reinforced fill structure**

The reinforced embankment to be monitored was constructed between June and December 2021.

Optical fiber sensors are installed along five levels of geogrids in the measurement cross-section to measure their deformations (see Figure 4). These geogrids have different lengths (10 m, 10 m, 20.2 m, 7 m, and 7 m, respectively for levels 1 to 5). Seven geogrids have been instrumented with optical fibers: three levels on the E17 side and five levels on the wastewater treatment plant side. For each instrumented geogrid, multiple samples and multiple types of optical fibers were installed (using a backup principle). Significant redundancy was also incorporated in the sensors, using both discontinuous multipoint optical fiber technology (Fibre Bragg Grating or FBG) and distributed technology (BOFDA). For more information on optical fiber sensor technology and construction-related applications, we refer to Huybrechts et al. (2017)[1].

The measurements provided in the present article were conducted using BOFDA-type optical fibers. One of the major advantages of optical fiber as a deformation sensor is that multiple sensors can be placed on the same cable. With BOFDA measurement cables, which operate using distributed sensing technology, the entire optical fiber acts as a sensor.

For this project, the optical fibers must permanently be embedded in the reinforced fill structures and protected against any possible damage during and after the construction. Figure 8 presents the instrumentation of the first level of geogrid. The optical fibers are then routed through an additional protective tube through the facing/gabions to the outside of the reinforced fill structures and subsequently connected in a monitoring box. Immediately after installing/attaching the instrumentation, the instrumented area is manually backfilled (minimum 10 to 15 cm) with sand (fraction 0-2 mm). To prevent puncture issues, a geotextile (separation type) is installed directly on the sand (fraction 0-2 mm). This geotextile does not have significant tensile strength to avoid skewing the measurements. Finally, a last layer of sand 0-2 mm (minimum 10 cm) is manually placed on the geotextile. The deformations are then measured for the first time. After the geogrids are instrumented by Buildwise, the earthworks immediately begin using the same method as for the other fill layers. There is thus no influence of the instrumentation on the working method. A new series of measurements is performed after installation of the fill material and its compaction. The same instrumentation method is followed for the instrumentation of the other geogrids to be monitored.



**Fig. 8.** Instrumentation of the first level of geogrid to be monitored

## **6 Results of the measurements – observations and conclusions**

The optical fiber measurements, carried out up to August 2024, are provided in Figure 9 for the second level of geogrids to be instrumented (see Figure 4).

The following remarks are relevant for the interpretation of these measurements.

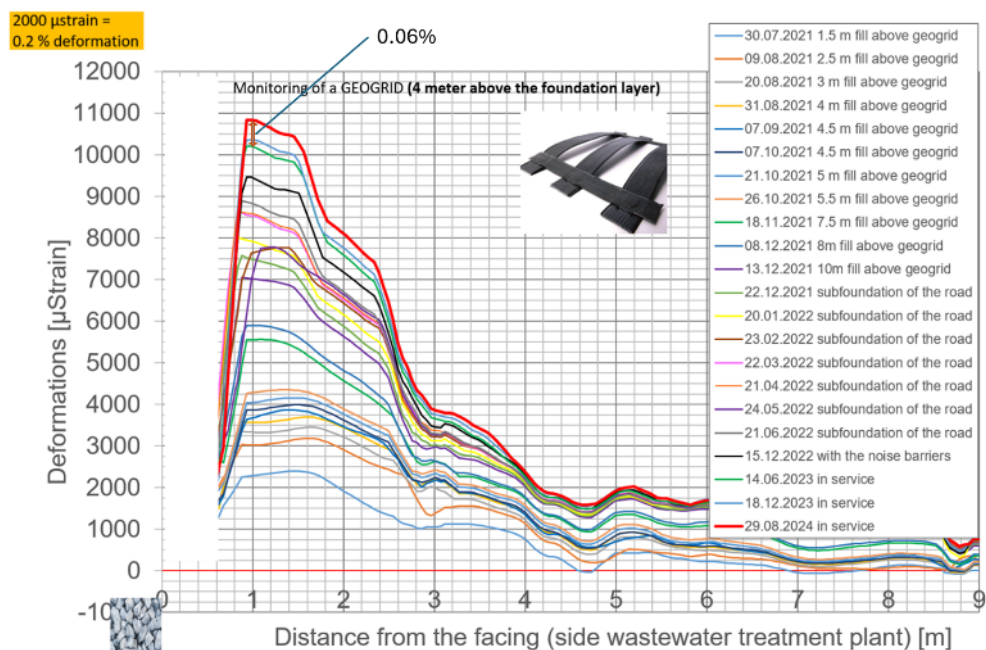
The measurement results should be interpreted taking creep behavior into account: long-term deformations are still expected.

The effect of compaction of the first layer of fill material above the instrumented geogrids has not been included in the measurements to ensure interpretable data. This effect is generally limited to 1000 to 2000  $\mu$ strain (0.1 to 0.2% deformation).

There is also a limited influence of the measurement cable (stiffness of the cable) on the readings.

The measurements provide no information about the tensile force in the geogrid in the area clamped between the two gabions.

The measurements are provided as an average value of measurements taken from two parallel reinforcement strips because the experience with the homogeneity of such measurements for multiple parallel strips is very limited.



**Fig. 9.** Measurements of the deformations in the geogrid of the second monitoring level

As illustrated in Figure 9, since the first measurements taken after its commissioning, the maximum deformation measured in the instrumented geogrid (at level 2) has evolved by about 0.06%. This value is well below the permitted 1%. Monitoring over time will ensure that no concerning evolution of this deformation occurs.

The largest deformations are actually observed at the second instrumented level. The first level benefits from the stabilizing effect provided by the installation of the roadway and the bicycle path on the side of the wastewater treatment plant. In a next stage, the deformations measured in this project could be translated in internal forces considering the isochronous curves provided by the geogrid supplier to learn more about the creep of these geogrids and to see where we stand in relation to the overall safety considered during the design with respect to the internal forces actually developing in the geogrids.

The measurement of deformations occurring during the construction of the structure and throughout its service life provides information that can be used to refine our design methods. However, the effect of the compaction of fill material layers on the development of stresses in the geogrids still remains difficult to assess.

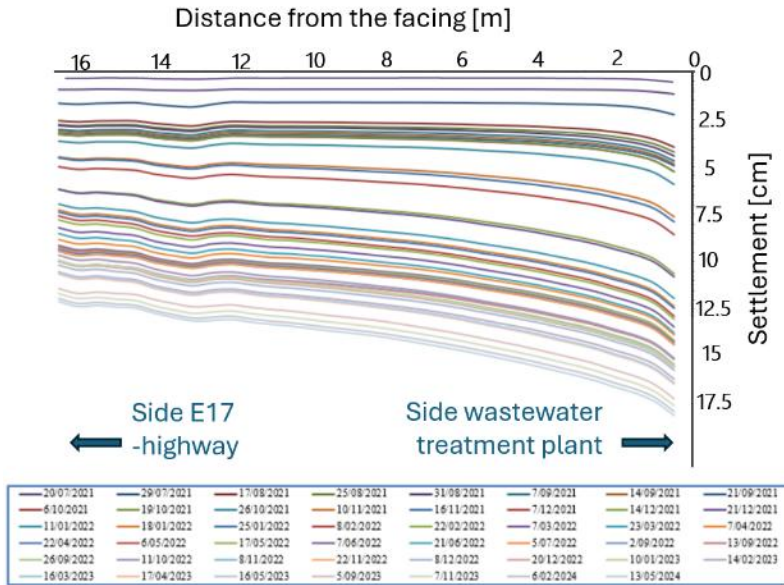
As illustrated in Figure 4, settlement measurements are also carried out using inclinometer tubes installed through the reinforced fill structure during its construction. Figure 10 illustrates the evolution of these measurements for the inferior inclinometer tube over time up to April 2024.

These measurements confirm the results of the design. As aforementioned, the load across the reinforced fill structure is not symmetrical. The soil on the E17 side has already been preloaded, and the height of the reinforced fill structure is lower there, with a higher structure on the wastewater treatment plant side. On that side, more settlement was expected. This is clearly reflected in the graph shown in Figure 10.

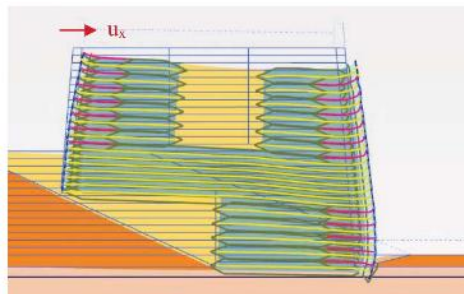
Topographic measurements were also carried out during the construction of the structure and after it was put into service. At the end of construction, the horizontal displacements of

the facing (maximum of 12 cm) on the side of the wastewater treatment plant, derived from the topographic measurements, were less than half of those expected based on finite element calculations (maximum of 25 cm).

Settlement and topographical measurements confirm the expected global behavior of the reinforced fill structure, as simulated with finite element method (cf. Figure 11). These measurements confirm this mode of deformation of the reinforced fill structure. The lateral displacement profiles of the facings were also confirmed by the topographical measurements.



**Fig. 10.** Vertical settlement measured along the length of the inferior inclinometer tube as a function of the time



**Fig. 11.** Finite element simulation results: deformations of the reinforced fill structure (amplified), the deformations of the facing on the E7 side (left) are directed towards the interior of the reinforced fill structure.

## References

1. N. Huybrechts, M. De Vos, G. Van Lysebetten, Advanced monitoring techniques for a wide range of geotechnical applications, in Proceedings of the 19th International Conference on Soil Mechanics and Geotechnical Engineering, Seoul 2017, pp. 2781-2784.