The Use of Waste within Steep Walls with the Support of Geogrids and Geomembranes

L. Vollmert. BBG Bauberatung Geokunststoffe GmbH & Co. KG, Espelkamp, Germany. lvollmert@bbgeo.com
S. Westhus. NAUE GmbH & Co. KG, Espelkamp, Germany. swesthus@naue.com
A. Post. NAUE GmbH & Co. KG, Espelkamp, Germany. apost@naue.com

ABSTRACT

In the town of Lennestadt, Germany, the development of an industrial park on a previously unused area required the construction of a major road and is presented in this case history with respect of current measurements afterwards (Schmidt et al., 2014). In the course of the construction of this approx. 400 m long section spanning a height difference of 28 m, a 115 m-long, 25 m-high retaining wall with a slope-fill volume of approximately 20,000 m³ was constructed near a concrete girder bridge. Besides the height of 25 m and the slope angle of 65°, the use of road-demolition waste containing coal-tar treated with a binder as a fill material in the geosynthetic-reinforced retaining wall is a characteristic of this project. In order to fulfil the requirements of the water regulatory authorities, the fill materials were enclosed in a geomembrane "wrapping".

1. OVERVIEW

The town of Lennestadt, 100 km east of Cologne, Germany, is situated in the valley of the rivers Hundem and Lenne. The development of an industrial estate in the central district of Altenhundem required the construction of a new major road. This road enables access to a former railway area, intensively used as a railway depot in the first half of the 19th century, Fig. 1. With the decline of heavy industry in the western Ruhr Area and the electrification of the railway lines, the depot was abandoned. Thanks to the new access road, the derelict brownfield site will be developed for use by medium-sized businesses as it is typical for Germany. At the same time the new route serves as a short-cut to the narrow road for South-West transit traffic through the town centre and relieves the town of much heavy traffic.

In addition to the industrial estate, the bypass, planned by the local authority as a high-capacity access road, Fig. 2, connects a bus depot with 60 vehicles and a residential area with approximately 800 inhabitants. It thus makes a major contribution to consolidating the road network and reducing traffic on the B517 road through the town. A two-span reinforced-concrete bridge with a length of 31.8 m over the River Hundem, and a 115 m long retaining structure with a slope-fill volume of approximately 20,000 m³ and a height of 25 m were required to overcome the height difference of 28 m in the course of the 400 m-long route.

In addition to the planning and approval requirements involved with a former railway operating plant next to the town centre, fixed points related to water legislation (flood protection) had to be observed. Greve (2007) reports in detail about the fixed points requiring legal permission, and the overall planning. A retaining structure with a slope angle of 65° was chosen to maintain the discharge cross section of the River Hundem and to allow the planned wall to be vegetated. Fig. 3 shows the upper connection of the new road to the existing road network on the embankment fill to the west of the Hundem, and an elevation view of the retaining wall with gabions.

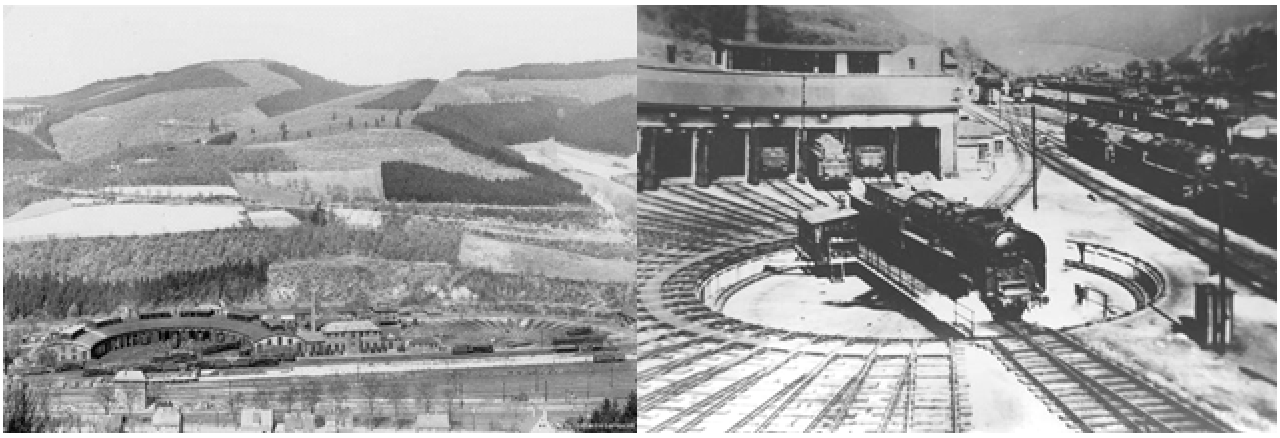


Fig. 1 Altenhundem rail depot around 1960 (photos archive Vollmert)

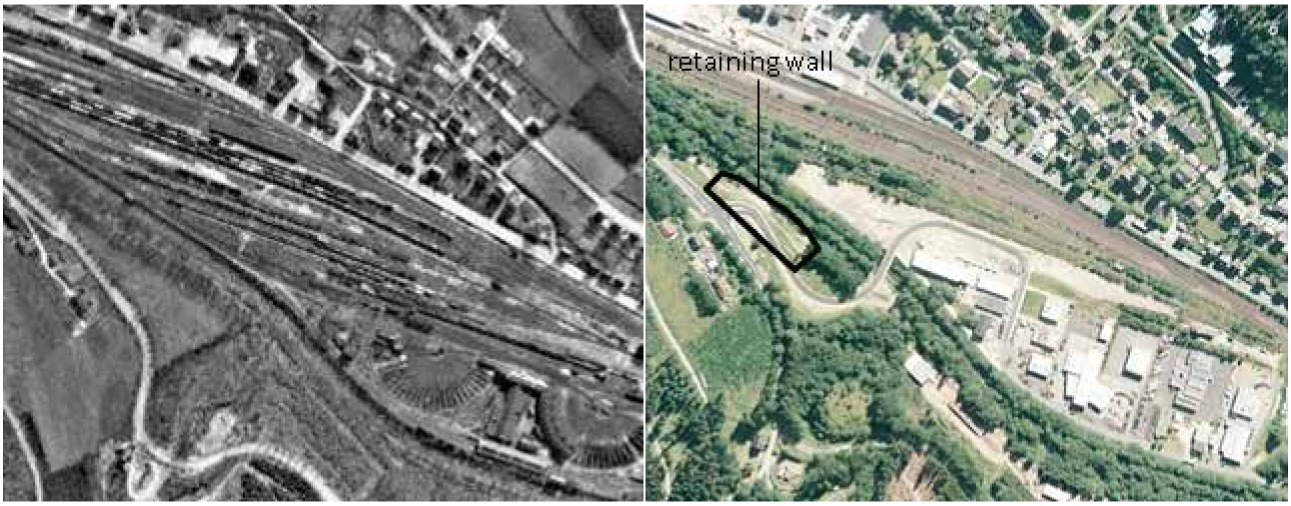


Fig. 2 Aerial photographs of the local situation in Altenhundem with rail depot around 1950 (left), and in 2012 with industrial area and new partial by-pass (right) (photos archive Vollmert)

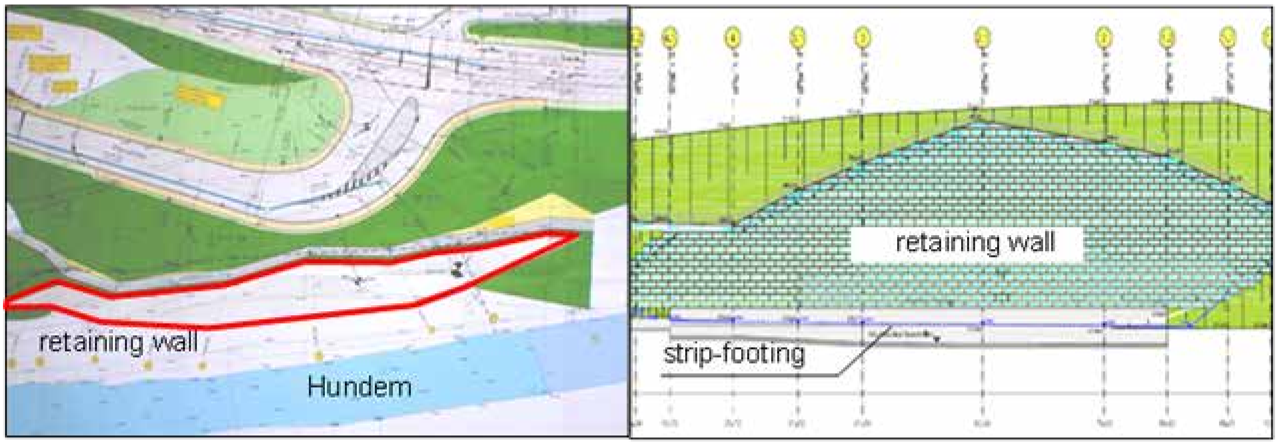


Fig. 3 Retaining structure Lennestadt (plan and elevation)

2. RETAINING STRUCTURE

As a result of the preliminary investigations, a combination of a reinforced steep slope (system "reinforced earth") and a solid strip footing was selected for the retaining structure. In the geologically and topographically difficult terrain, this construction offered significant design and construction advantages when compared with the alternatives investigated – a suspension bridge, a Krainer wall, a series of berms with gabion walls or an anchored slab wall; it was thus the most economical solution (for further information on the economics of geogrid-reinforced soil structures see also Saathoff, Vollmert & Klompmaker (2002) and Vollmert & Wessling (2004)). The choice of a vegetated elevation meant that the planned structure could be integrated into the landscape. The construction of the retaining structure was carried out by a qualified locally-based civil engineering company. The client supplied the required quantity of recycling material for use as the embankment fill.
Compared to the originally specified design of the slope surface with fully vegetated steel-mesh elements, an alternative using gabions for the embankment surface was chosen to reduce the maintenance required. The accessibility of the construction was ensured by constructing a maintenance berm with fall protection at the top of the structure. The retaining structure (Fig. 3) comprises the following features:

2.1 Foundation of the retaining structure

The retaining-wall structure at the base of the construction is founded on the load-bearing rock horizon and keyed into the rock by a spur. The retaining wall is founded above HQ 100, and the solid strip footing prevents leaching out of the support structure by the Hundem. The reinforced-concrete substructure is 4.0 m high, has a rear spur of 6,0 m and was constructed without expansion joints in two sections with a total of 1150 m³ of impermeable steel-fibre concrete C 25/30, class 1.2, to limit cracking, in combination with steel-bar reinforcement Bst 500 S as static / structural reinforcement.

2.2 Backfill / fill material

Recycled material was used for the backfill; this was readily available and consisted of road materials containing pitch/coal tar. It was treated with binders and approved for installation under the Closed Sub-stance-Recycling and Waste Management Act, and the Water Resources Act. The recycling material was used in the construction of the reinforced-earth body. For the use of the material, the provisions of RuVA-StB 01-2005 had to be met. (Guidelines for the ecological re-use of recycling materials containing tar/pitch, and for the re-use of asphalt in road construction; Edition 2001, Issue 2005).

The RuVA-StB 01-2005 defines road-construction materials containing tar or pitch as those with a PAH content > 25 mg/kg. Recycled road-construction material containing tar or pitch is considered as hazardous waste; its disposal is governed by special requirements of the Closed Substance Recycling Act (KrWG) and subordinate rules. The recycling materials underwent suitability tests to determine the amount of cement (40 to 100 kg/m³ cement/recycling material) required for their treatment. 70 kg/m³ was seen as an appropriate amount. Leachate testing in accordance with RuVA-StB 01-2005 on the recycling materials registered an effective PAH content of < 0.03 mg/l (EPA) and a phenol index of < 0.10 mg/l; samples were taken for both suitability and inspection tests.

The fill material was completely enclosed in an impermeable membrane to permanently prevent water ingress after construction. For design purposes, the friction angle of a normally compactable soil with a friction angle of φ '= 30° was used. To implement some conservatism, cohesion was not taken into account. Around 40,000 tonnes of fill material were placed and compacted, with a total transport volume of approx. 20,000 tons*km.

2.3 Geosynthetic reinforcement

To ensure adequate slope and overall failure stability, the steep slope was constructed as a monolithic reinforced-earth body. The geosynthetic reinforcement was laid horizontally over the entire surface with a layer spacing of 0.8 m. Up to a height of 12.4 m, a polyester geogrid reinforcement with 200/40 kN/m was chosen on design basis. In the upper reinforcement layers where the required tensile strength was lower, a polyester geogrid with 120/40 kN/m was used.
In addition to the installation damage, the selection and design of the geogrids had to investigate their resistance to environmental influences such as high pH values, and to take these into account in accordance with the EBGEO regulations. The monolithic structure of the geogrids means that the individual bars have a very small surface area in relation to the volume of material used. The well-known sensitivity of polyester to external hydrolysis caused by high pH values is thus much lower than for slit film wovens and geogrids made from monofilaments. According to the test certificates submitted, a reduction factor of only 15 % had to be

applied to take account of the influence of elevated pH values on the Secugrid geogrids used. The design tensile strengths of 38 kN/m and 68 kN/m required in the tender documents were observed with significant additional safety margins.

2.4 Geosynthetic Drainage

In order to prevent a build-up of seepage-water pressure behind the structure, a filter-gravel layer with a thickness d = 0.8 m was included above the foundation within the influence area of the HQ-100 water level. For the back slope of the retaining wall, an alternative solution was proposed and accepted, which consists of a compression-resistant drainage composite Secudrain XX8 with nonwoven filter layers on both sides. This was supplemented by a fan-shaped network of drainage pipes for the evacuation of seep-age, artesian and spring water from the hillside behind the structure.

2.5 Geosynthetic Encapsulation of recycling materials

In accordance with the tender, a Carbofol HDPE geomembrane with a thickness of 2.0 mm and DIBt approval was used to encapsulate the fill body (DIBt: authority of the German states for technical tasks in the field of public law; for more information compare www.dibt.de). At the front of the structure, the geomembrane was laid section by section in order to realize a connection between the slope surface (gabions) and the reinforced steep slope (see Fig. 4, gabion connection detail). Here, the top surface of the envelope was installed with a slight crossfall towards the outside face in order to prevent surface water seeping into the structure.

At the back of the structure, the alternative solution using the Secudrain XX8 geosynthetic drainage composite with the resulting nearly planar support area (see Fig. 4, geomembrane detail) meant that section-by-section placing of the geomembrane could be dispensed with. The risk of potential defects was thus significantly reduced. The upper encapsulation was also realized by the geomembrane, which was protected against accidental damage in this area by a 10 cm thick C15/20 concrete protection layer.

In order to ensure adequate friction at the layer interfaces between the geomembrane and the fill material, a structured Carbofol 406 Megafriction/Megafriction geomembrane was used.

2.6 Design of outer facing / gabions

To match the designed reinforcement-spacing of the geogrids, a height of 0.8 m was chosen for the gabions. The design calculations, using gabion baskets with a steel-wire diameter of 4.5 mm, were verified for the design loads; the gabions were filled with a coarse 60/90 mm porphyritic gravel. The connection of the gabions to the overall construction is assured by the friction bond with the geogrids. To improve the friction transfer, a layer of fine, crushed material with a particle size 5/45 mm was spread both above and below the geogrids between the gabion layers (Fig. 4). Fig. 5 shows the planned individual construction steps. The choice of stiff geogrids allowed a pre-tensioning step during the construction to be dispensed with.

The structure is then vegetated with ivy to prevent the growth of unwanted vegetation with correspondingly high maintenance costs.

2.7 Design Verifications

In addition to the overall planning and the preparation of the tender documents for the project, the Lennestadt consulting engineers Ingenieurbüro für Bauwesen Schmidt GmbH were also responsible for verifying the design of the reinforced-earth structure. This included verification of both global and slope stability, and the stability of the gabions and the reinforced-concrete strip-footing structure (Schmidt, 2007). In accordance with EBGEO 1997, specified failure planes and slip circles were both investigated. The design strengths in the verifications were determined in accordance with EBGEO 1997 and TL Geok E-StB 05, and specified based on EBGEO 1997. Taking into account the preliminary drafts for the partial-safety concept, the construction already fulfils the verification requirements later published in EBGEO 2010. The monolithic nature of the overall construction means that the combination of the reinforced-soil body and the strip-footing foundation block is self-supporting with an expected service life >> 120 years. The gabions, with an expected service life > 80 years, fulfil a cladding and surface-protection function. In principle, the uncoupled design of the reinforced-earth body and the gabion facing permits the front facing to be replaced or refurbished section by section, so that the system can be considered as being able to be repaired if required.

To check the deformation of the construction, the vertical and horizontal deformations of the wall are additionally measured geodetically at several measurement points. The plot of the values shows a significant flattening-off of the deformation curve with time (Fig. 6). Currently, the maximum vertical settlements after around 7 years are 5.2 cm. Both, these, and the shape change s / h < 1/500, are lower than expected.

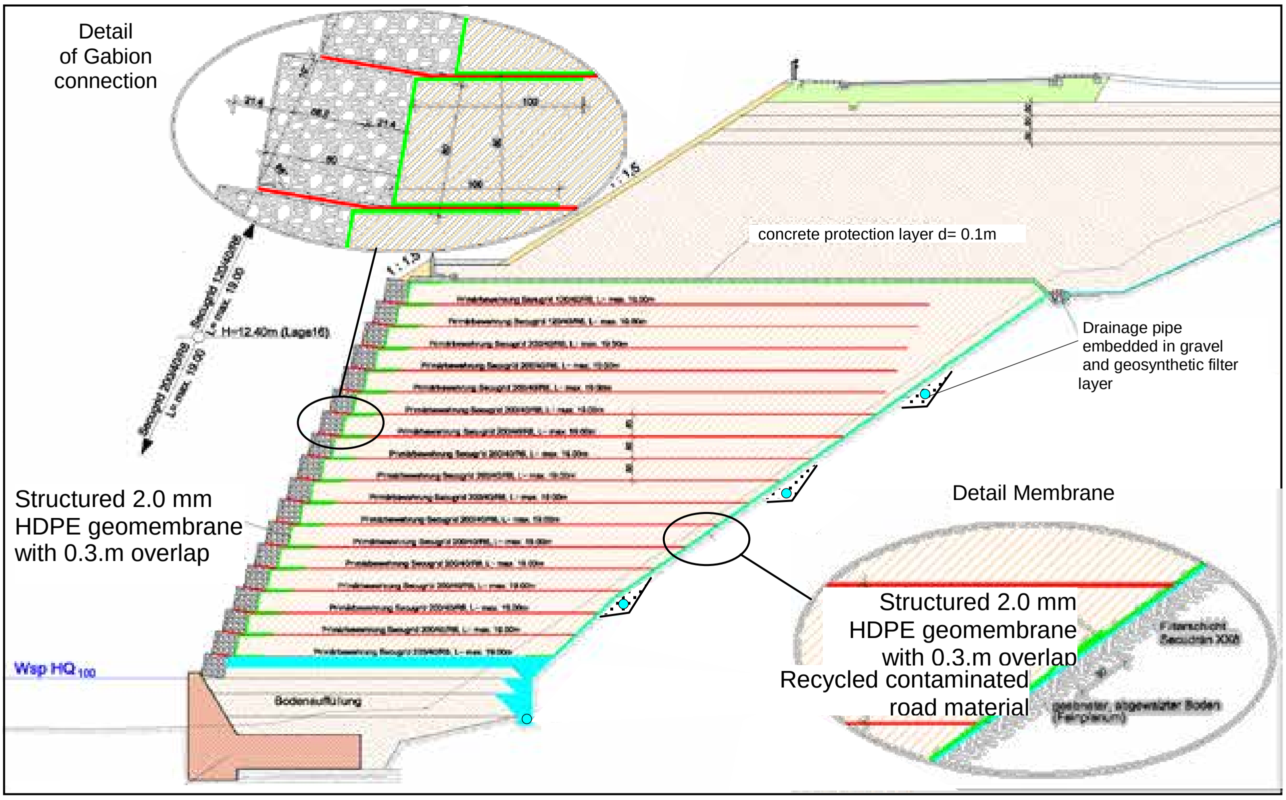


Fig. 4 Typical cross-section of the overall construction

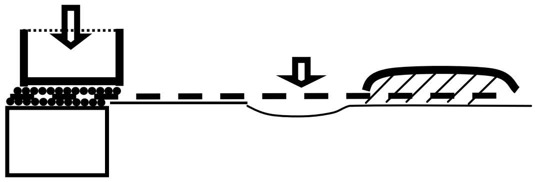
3. CONCLUSION

A sophisticated retaining structure, 115 m long and 25 m high, was built to a design comprising a reinforced-soil body, a massive reinforced-concrete substructure and an outer facing of gabions. It satisfies the requirements of both landscape architecture and urban planning and makes a valuable contribution to the development of the Altenhundem district. Thanks to a clever combination of geosynthetics, gabion baskets and locally available resources, the construction costs opposite conventional variants were able to be significantly reduced.

In accordance with the project conceived by the client, the town of Lennestadt, and supervised by its construction management, local contractor Straßen- und Tiefbau GmbH from Kirchhundem carried out the work professionally and on time (Fig. 7). The engineering and structural design, and the construction supervision of the total project, were performed by consulting engineers Ingenieurbüro für Bauwesen Schmidt GmbH, Lennestadt.

The special challenges arising from the use of locally available recycled road-building materials containing tar and contaminated with PAH were met by treating these materials with binders, encapsulating them in geomembranes, and by the careful arrangement of drainage layers. Thus, the road-demolition material was able to be recycled as a construction material, since the transport mechanisms are permanently cut off, as in a landfill.

- Placing the reinforcing geogrids 120/40 R6 and 200/40 R6 in accordance with design calculations
- Preparation of the support area for the gabions with generous spreading of angular gravel 5/45 mm for friction enhancement
- Erecting the gabions 200x80x80, d = 4.5 mm, and filling the baskets with angular gravel 60/90 mm
- Holding the reinforcement with fill material and pre-tensioning by filling over the depression



- Laying the upper layer of geomembrane HDPE 2.0 mm, Megafriction/Megafriction geomembrane
- Installation of recycling material 0/45, d = 0.80 m
- Re-laying the geomembrane previously folded back

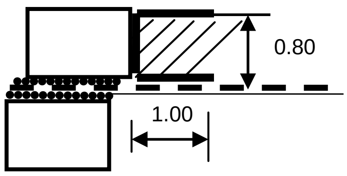


Fig. 5 Construction process in the area of the outer facing

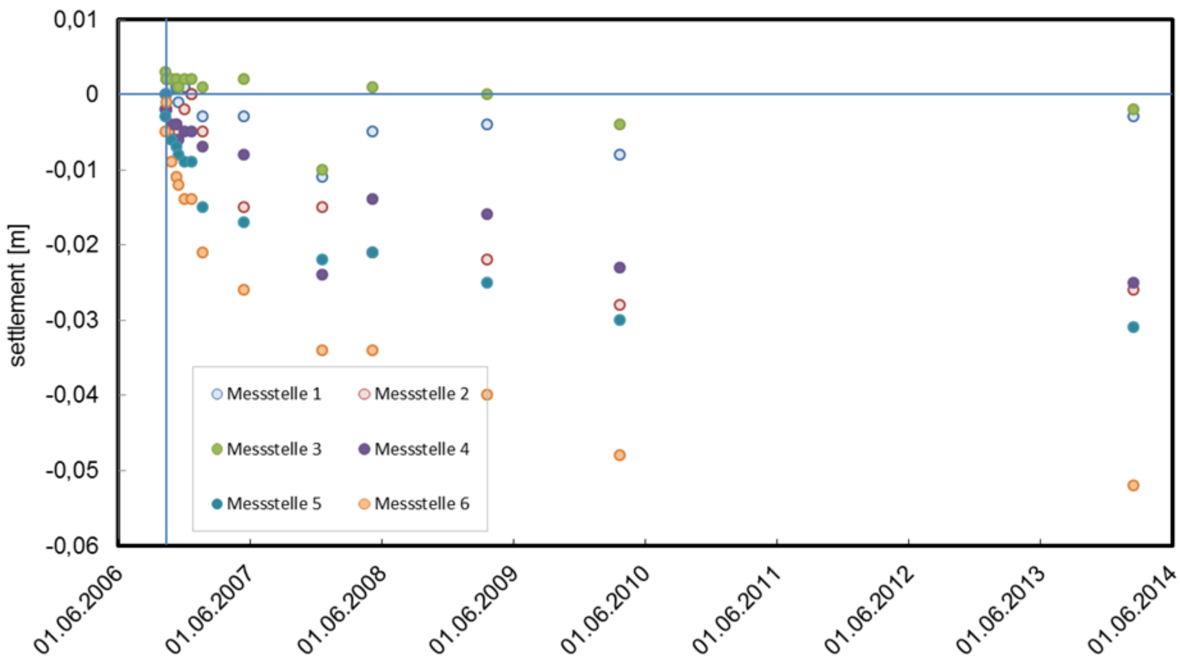


Fig. 6 Settlements of the structure facing since commencement of construction

Fig. 7 Retaining structure under construction August 2006 (left) and shortly before completion October 2006 (right)

4. REFERENCES

Allgemeine bauaufsichtliche Zulassung Carbofol® PEHD. *Deutsches Institut für Bautechnik*, aktuelle Fassung

EAG-GTD - Empfehlung zur Anwendung geosynthetischer Tondichtungsbahnen. Publ.: *Deutsche Gesellschaft für Geotechnik*. Verlag Ernst & Sohn, 2002, Berlin.

EBGEO – Empfehlungen für Bewehrungen aus Geokunststoffen. Publ.: *Deutsche Gesellschaft für Geotechnik*. Verlag Ernst & Sohn, Berlin, 1997

EBGEO (2010): Empfehlungen für den Entwurf und die Berechnung von Erdkörpern mit Bewehrungen aus Geokunststoffen -EBGEO, Publ.: *Deutsche Gesellschaft für Geotechnik (DGGT)Verlag Ernst & Sohn*, Berlin. (Recommendations for Design and Analysis of Earth Structures using Geosynthetic Reinforcements - EBGEO (English Version))

Greve, J. (2007): Wirtschaftliche Kombination von Sekundärbaustoffen und Geokunststoffen - Bewehrte Stützkonstruktion in Lennestadt. Teil 1: Entwurf und Bau. *Geokunststoffkolloquium, 25. – 26. Januar 2007*, Bad Lauterberg

Schmidt, F. (2007): Wirtschaftliche Kombination von Sekundärbaustoffen und Geokunststoffen - Bewehrte Stützkonstruktion in Lennestadt. Teil 1: Statische Nachweisführung. *Geokunststoffkolloquium, 25. – 26. Januar 2007*, Bad Lauterberg

Schmidt, Vollmert & Besser (2014): Does waste containment fit within a 25m high retaining wall with the use of geogrids and geomembranes?. *Proc. of 10th ICG*, Berlin (paper accepted)

KrWG - Ministerium für Umwelt, Naturschutz und Reaktorsicherheit: Gesetz zur Förderung der Kreislaufwirtschaft und Siche-rung der umweltverträglichen Bewirtschaftung von Abfällen (Kreislaufwirtschaftsgesetz – KrWG), aktuelle Fassung vom 24.02.2012. *www.gesetze-im-internet.de/¬bundesrecht/krwg/gesamt.pdf.*

M Geok E - Merkblatt für die Anwendung von Geokunststoffen im Erdbau des Straßenbaus. Publ.: *Forschungsgesellschaft für Straßen- und Verkehrswesen (FGSV)*, Ausgabe 2005

M TS E - Merkblatt über Bauweisen für technische Sicherungsmaßnahmen beim Einsatz von Böden und Baustoffen mit um-weltrelevanten Inhaltsstoffen im Erdbau. Publ.: *Forschungsgesellschaft für Straßen- und Verkehrswesen (FGSV)*, 2009

RuVA-StB 01-2005 - Richtlinien für die umweltverträgliche Verwertung von Ausbaustoffen mit teer-/pechtypischen Bestand-teilen sowie die Verwertung von Ausbauasphalt im Straßenbau. Publ.: *Forschungsgesellschaft für Straßen- und Verkehrswesen (FGSV)*, Ausgabe 2001, Fassung 2005

Saathoff, F., Vollmert, L. & Klompmaker, J. (2002): Geogitter bewehrte Böschung in der Altstadt von Idstein. *s+t*, Heft 10/2002

TL Geok E-StB 05 - Technische Lieferbedingungen für Geokunststoffe im Erdbau des Straßenbaus. *Publ.: Forschungsgesellschaft für Straßen- und Verkehrswesen (FGSV)*. Ausgabe 2005

Vollmert, L. & Wessling, A. (2004): Geogitter bewehrte Steilböschung spart Kosten. s+t, Heft 11/2004

WHG Wasserhaushaltsgesetz - *Ministerium für Umwelt, Naturschutz und Reaktorsicherheit*: Gesetz zur Ordnung des Wasser-haushalts (Wasserhaushaltsgesetz), aktuelle Fassung vom 31. Juli 2009 (BGBl. I S. 2585), Bonn.