# GEOGRID REINFORCED RETAINING STRUCTURE OF LAUTERECKEN LANDFILL SITE

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ABSTRACT: Between 2000 and the end of 2002, Lauterecken sanitary landfill site was sealed with an impermeable system. For technical reasons, a maximum slope of only 1:3 was permitted for the sealing at the landfill site shell. In order to avoid extensive rearrangement of the landfill site mass, a retaining structure with a maximum height of app. 16m was constructed at the eastern boundary of the landfill site, located close to a housing estate. Geogrid reinforced soil was chosen because of the following advantages: Rapid, economical and flexible construction and an attractive finish, which was important because of the close proximity of the housing. The reinforced retaining structure is approx. 140m long. It is 9.60m wide at foundation level and has a total height of 16m. The geogrid was installed in layers with spacings of 0.70m. The embankment of the supporting structure has a maximum slope of 1:0.4 (70°). During the course of the project the approval/performance design as well as the structural calculations for the retaining structure were carried out by ARCADIS Consult. ARCADIS's contract also included the construction supervision. Third party supervision was awarded to the Ingenieurgemeinschaft Prof. Meissner / Prof. Tausch. Explanations of the design details, the structural calculations as well as details of the quality control system are the subject of this paper. In addition, it also points out the experiences gained during the construction of the retaining structure and the landfill sealing.

## 1 INTRODUCTION

Lauterecken sanitary landfill site lies in an old quarry and was sealed between 2000 and the end of 2002 with surface sealing (combination seal). For technical reasons the maximum slope permitted for the seal on the body of the landfill was only 1:3. In order to avoid extensive rearrangement of the landfill site (i.e. to reduce haulage costs), a retaining structure with a maximum height of approx. 16m was constructed, which lies immediately next to tennis courts and near to a housing estate.

Earth structures reinforced with geosynthetics (composite earth system) were selected for the retaining structure. The resulting advantages over conventional methods are a more economic and flexible construction and a visually attractive design.

The stability analyses were carried out on the basis of the EBGEO. Supplementary calculations were carried out in accordance with the specifications of the product approval under the old standard and product accreditation of the selected geogrid to compare the EBGEO, which had not yet been introduced by the building authorities at the time the structural calculations were performed.

Quality management was prepared for the construction of the retaining structure. The installation of the geogrid and the backfill material were examined and tested throughout construction.

## 2 RETAINING STRUCTURE

The reinforced retaining structure is approx. 140m long, approx. 9.6m wide at foundation level and is 16m high. The maximum slope inclination of the retaining structure is 1:0.4 (approx. 70°). The finished retaining structure has a maintenance road on it. An equivalent uniformly distributed load of SLW 30 to DIN 1072 was used here.

Figure 1 Side view from the top of the retaining structure

Behind the reinforced retaining structure the surface of the waste mass was sealed with a batter of 1:3.

A gabion wall was built in the lower section of the retaining structure up to approx. 3m above ground level. The gabions are founded on an approx. 1m wide sub-concrete base structure (strip foundation). The retaining structure is embedded in the existing ground by approx. 1.4m. The gabions and the sub-concrete base structure are bonded with the retaining structure via geogrids.

In the foundation level area of the retaining structure is in-situ filled soil. This is excavated material from the old quarry. The fill consists of a mixture of stones, gravel and sand. The granular, non-cohesive soils are bonded in a cohesive soil matrix. The weathered zone of the rock horizon begins at a depth of 3 – 10m blow ground level. The rock consists of fine sandstones in alternating sequence with clay/siltstones. The groundwater level is well below the foundation level.

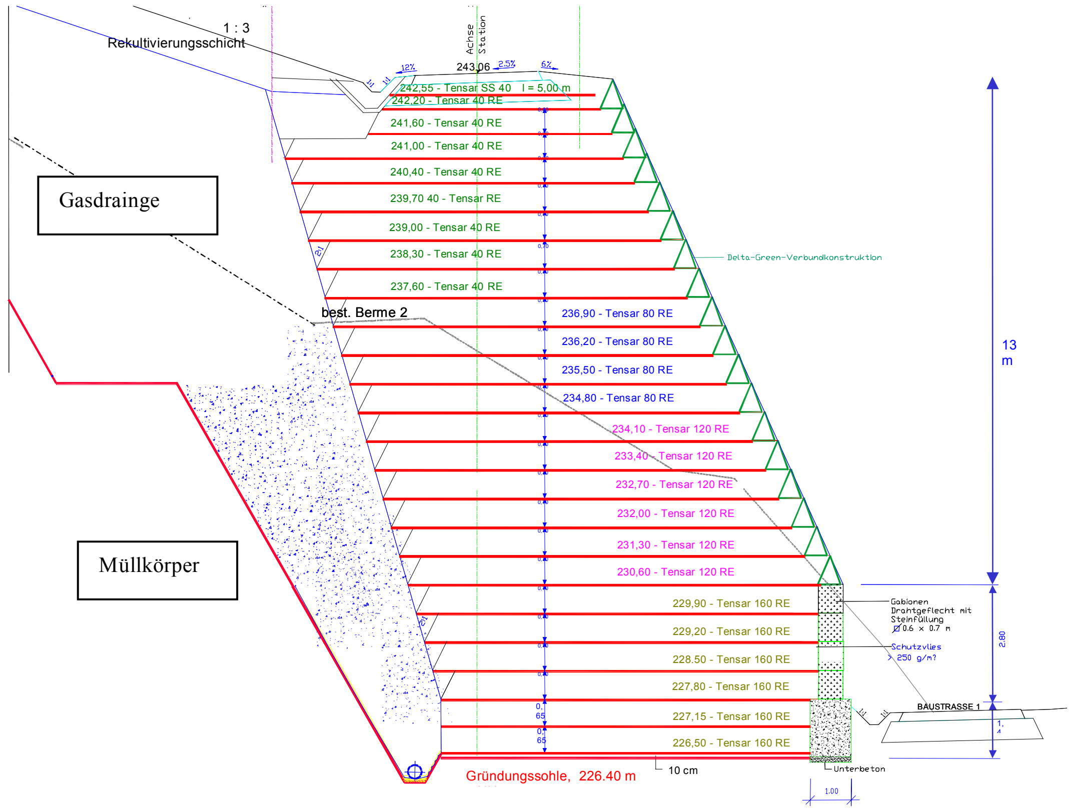


Figure 2 Cross-section of the retaining structure

Above the gabion wall the surface of the retaining structure was secured with a plantable outer skin. This is made from zinced steel mesh elements with a plantable erosion proof mat. The steel mesh elements have a triangular cross-section and can also be adapted to the required slope inclination and the geogrid layers using spacers made from zinced steel bars. The geogrid and the securing elements of the outer skin are bonded together via a full-strength push-in connection. To this end a zinced steel bar, a so-called bodkin, is threaded through the whole of the geogrid mesh and through all the eyelets (bodkin junctions) welded on to the steel mesh elements of the surface revetment layer or the gabions.

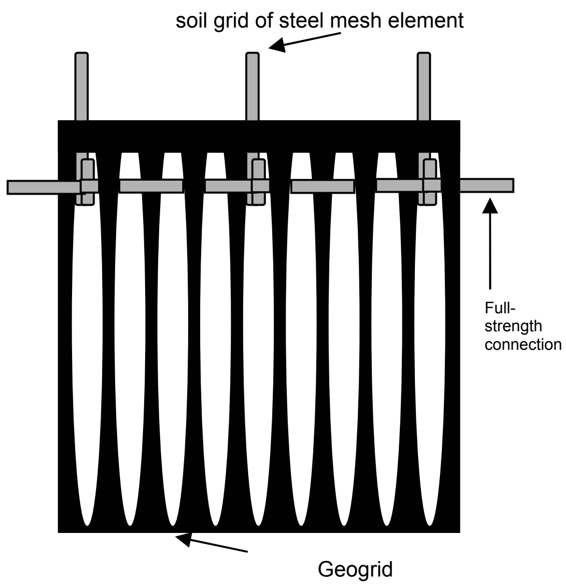


Figure 3 Connection between the geogrid/steel mesh elements

There is a gas drainage layer between the waste and the retaining structure. Only quality monitored soils with proven suitability were used for the backfill as well as for the gas drainage layer material.

The geogrid and the steel mesh elements for securing the batter surface were installed in layer spacings of 0.70m. The geosynthetics used are high strength, uniaxially loadable and stiff jointed geogrids made of high density polyethylene (HDPE material). The geogrids were installed with staggered strength properties, whereby the tensile force to be taken up by the geogrid reduces with the height of the retaining structure.

## 3 STRUCTURAL CALCULATIONS

The stability analyses for the retaining structure were carried out on the basis of the EBGEO. The following structural design calculations were carried out:

- State during construction (GZ 1C): Slope failure using the slice method
- Final condition (GZ 1B): Internal stability using the block slip method for polygonal sliding planes
- Final condition (GZ 1C): External stability based on failure of subgrade, toe slip, gaping joints; slope or embankment failure using the slice method (Bishop) and block slip method

In the aforementioned calculations, all the individual calculated steps such as the reduction factors, failure and extraction of the geogrids, transmission of force from the geogrids to the steel-mesh elements and gabions were implemented or rather entered as the input variables using the maximum permissible degrees of utilisation recommended in the EBGEO or determined in trials. Soil parameters reduced by partial safety factors were used.

Table 1 Characteristic soil mechanics parameters

| | Unit weight γ [kN/m³] | Angle of friction φ [°] | Cohesion c` [kN/m²] |
|---|---|---|---|
| Retaining structure backfill | 20 | 32.5 | 5 |
| Gas drainage | 19 | 35 | 0 |
| Waste | 14 | 25 | 25 |
| Subsoil | 20 | 32.5 | 10 |

The jump from the 70° slope to the vertical face in the area of the gabions was particularly important for the calculations. Here there is a considerable jump in the earth pressure ordinates. The active earth pressure was used in all the stability calculations.

In general, a degree of utilisation (1/f) < 1.0 was calculated for all failure modes. The gaping joint calculation showed that the earth structure would tilt in the direction of the load. However, this could not be classified as realistic when checked for plausibility. Furthermore, the serviceability calculation (GZ 2) was carried out in the form of a settlement analysis.

Supplementary calculations were carried out on the internal stability (limit state 1 B) in accordance with the specifications of the product approval. This was to compare the EBGEO, not yet introduced by the building authorities at the time the calculations were performed, with the calculations specified in the produce approval of the geogrid chosen and due to the global factor of safety of $\gamma_M$ = 1.75 for the failure strength of the geogrid given in the approval certificate. The calculations showed that the possible reduction in earth pressure in the lower third of the wall, specified by DIBt in the product approval, resulted in a decisive relief. The calculated level of safety was correspondingly higher or the degree of utilisation lower. Furthermore, the calculation method specified in the approval certificate, in which only straight fracture joints are to be examined, gives a higher level of safety than the examination with multiple fractured rupture lines according to the block slip method.

However, without the reduction in earth pressure the calculations would have been unsuccessful or rather closer geogrid spacings would have had to be chosen in the lower section.

The reasons for the permitted earth pressure reduction in the lower third are not given in the approval. It is possible that this takes into account the effects of the friction resulting from the foundation. Experience with monitored walls in the Laboratory and in Practice show that the highest deformation takes place at about 2/3 of the height of the wall. In this context, further investigations into the stress/deformation performance of geosynthetic-reinforced earth structures are desirable.

## 4 QUALITY ASSURANCE AND CONSTRUCTION

In order to achieve the high safety standards required, the retaining structure (as well as the complete surface sealing system) were permanently monitored. This monitoring ranged from testing the initial materials through to the production of the system elements and served to secure the design specifications.

As is usual for such construction projects, the work on site was accompanied by a three-stage testing. This consisted of the manufacturer's self testing, the external testing and the monitoring by the authorities.

The installation material requirements and the number of monitoring tests were specified in a QA plan and in the technical preliminary remarks to the bill of quantities and building specifications, which were enclosed with the tender documents.

### 4.1 *Backfilled earth retaining structure*

The backfill had to be free of disruptive materials (e.g. plastics, metals, timber) and fulfil the classification values Z1.2 to LAGA[1], Code of Practice 20 (Tables II 1.2-2 and – 3, soil). The suitability of the soils had to be verified using the following requirements:

- The backfill had to be dense with respect to gas permeability and adequate shear strength with respect to stability. Soils which can satisfy both requirements are mixed grained soils, e.g. soils in the groups GU and GT to DIN 18 196.
- The following additional requirements were set with respect to the particle size distribution: The proportion of settleable fines (d <0.06mm) must be > 10% and < 25% by mass, the proportion of particles d > 2.0 mm should be more than 40% by mass, the maximum grain size must not exceed $d_{max}$ = 75mm.
- The material selected by the contractor had to have at least the prescribed shear strength parameter or equivalent total shear strength.
- The permeability of the compacted backfill had to be at least 2 powers of ten smaller than that of the adjacent gas drain structure on the landfill site side. Stone free, properly compacted special samples had to have a permeability of $k_f \leq 5 \times 10^{-5}$ m/s.

The backfill had to be placed and compacted in layers maximum 30cm thick using a front tipping method. The compacted layers had to have a degree of compaction of $D_{Pr} \geq 0.97$. This degree of compaction applied for the reinforced soil mass with the exception of the some 1m wide area immediately behind the outer skin. In this area the requirement was for it to be carefully and uniformly compacted using a lightweight compactor.

The backfill material used consisted of mixed-grained soils from various soil deposits in the Rhine-Main region as well as from earthworks projects in the area of Kaiserslautern. The soil mechanics suitability of the materials was verified by carrying out appropriate tests or the test certificates provided. In addition, the chemical contamination of the backfill materials was tested by an independent testing agency according to the LAGA code of practice M20. The materials used satisfied the classification values Z 1.2.

### 4.2 *Geogrid*

The geogrid laid in the retaining structure were uniaxially drawn, stiff-jointed PEHD products. The following geogrids were used:

- Tensar 40 RE
- Tensar 80 RE
- Tensar 120 RE
- Tensar 160 RE

The geogrids are approved by the BBA (British Board of Agrément, England).

[1] LAGA = Federal states' joint working party for waste

Figure 4 Constructing the gabions

The geogrid sheets had to be laid in the direction of loading (in a transverse direction to the axis of the retaining structure), each placed on a levelof compacted tipped layer of backfill. The geogrids could only be overlapped once in the longitudinal direction. The connecting element to be used for the aforementioned geogrids was a bodkin made of PEHD 40 x 6 mm with rounded edges. Transverse to the direction of stress the geogrid sheets had to be flush jointed. Maximum spaces of 20cm were permitted due to the constructive restrictions (curvature of the retaining structure).

The laid, uncovered geogrids could not be driven on. They could only be driven on after a 15cm thick compacted soil layer had been placed.

Figure 5 Installing the geogrid

4.3 *Constructing the retaining structure*

To construct the retaining structure the eastern slopes of the landfill site had to be cut into or removed. For structural reasons, the waste slopes had been formed with two berms during the course of the waste deposit and the fresh slopes were covered with construction foils to protect against material being blown away by the wind.

In the area of the retaining structure the natural ground was activated section-wise down to the bedrock. The uneven base was evened out with fill compacted in layers thereby creating a level formation as a contact surface for the retaining structure. The compaction of the backfilled layers was tested by means of the degree of compaction, the load bearing capacity of the formation using plate bearing tests.

The retaining structure itself and the adjacent slopes were also built up in layers 20 - 25 cm thick and compacted using a sheep's foot roller. The surface of each layer was also smoothed using a flat wheel roller, on which the geogrid sheets were laid

In total, 24 geogrid layers were installed with approx. 30,000 m² geogrid and 23 layers of backfill.

Figure 6 Placing the backfill

4.4 *On-site tests*

The load bearing capacity of the retaining structure's formation was tested using plate pressure tests to DIN 18 134. In total, 15 tests were carried out on the 14.000 $m^2$ contact area. The tests were initially carried out using 60cm and 30cm circular plates, later – as no significant differences were found – only the 30cm plate diameter was used. Before the tests were carried out, areas of wettened soil had to be removed – several times in some places – and the formation reconstructed and compacted.

The plate pressure tests were carried out after a varying number of compacting passes with the sheep's foot roller. At least 6 compacting passes were usually required. Some of the areas with lower load-bearing capacities had to be recompacted with considerably more compacting passes.

The values given in the QA plan of $E_{V2}$- ≥ 45 MN/m² and von $E_{V2}/E_{V1} \leq 2.5$ were verified with respect to $E_{V2}$ in all the tests. In a few cases, despite intensive recompaction, the limit $E_{V2}/E_{V1}$ values were slightly exceeded.

The installation and compaction of the placed layers of backfill were randomly tested. Any large stones or foreign bodies in the backfill material were removed. Each layer (approx. 0.7m high) was built in 3 layers. Samples were taken from the individual layers, especially the uppermost layer, to test the degree of compaction, which had to reach $D_{Pr} \geq 0.97$.

The surface of the layers was checked to ensure it was free of stones and level. Large band imprints of the flat wheel roller were removed using a vibrating plate compactor or by hand. At times, after heavy rainfall compacted and even approved placed layers had to be removed and replaced.

When installing the geogrid, checks were carried out to ensure that the respective planned type was laid over the correct length and with an interlocked, non-positive connection with the steel-mesh elements. The latter was carried out with the help of pegs and iron bars, which were knocked into the landfill side edge of the retaining structure, and with which the geogrids were pulled straight and slightly stretched. It was also ensured that the rolled out geogrids were not driven on, but that the soil was tipped on them from the front.

Figure 7 View of the retaining structure

### 4.5 *Laboratory tests*

Special samples were taken from the installed layers of backfill and investigated in the laboratory. Here the degree of compaction, permeability and shear strength were primarily determined. Furthermore, the particle size distribution and the Proctor values were determined from the bucket samples. The number of tests was specified in the QA plan.

The most important requirements such as dry density and degree of compaction as well as the permeability were fulfilled in the samples which led to the release of the subsections. The proportions of silty particles (d ≤ 0.06mm) and Sand (d ≤ 2mm) lay within the limits given in DIN 18 196 for mixed grain soils. The angle of the overall shear strength $\varphi_s$ fulfilled the requirement set for the backfill.

### 4.6 *Measurements*

During the construction of the retaining structure the waste slope and the retaining structure itself were monitored using geodetical methods.

3 fixed points in the form of concrete blocks were installed on the top berm of the waste slopes. These were measured in at regular spacings from a fixed point within the site. During the particularly critical period of around 4 months after the start of construction, horizontal displacements of up to 42cm and settlements of up to 26 cm were measured.

The measuring marks attached to the external mesh elements of the retaining structure showed relatively uniform displacements in the order of cm during the measurement period, whereby several elements not covered by the measurements had visible bulging of up to 10cm on the air side. After a heavy rainfall period the measurement system failed completely.

Furthermore, during the construction of the retaining structure the work was recorded up to a certain level by a WebCam system, installed on a telephone mast, in 30 minute cycles and the film made available via the internet.

## 5 EXPERIENCE GAINED

Overall, the composite soil system with geogrids and external skin revetment proved to be successful.

However, the compaction of the soil immediately behind the outer skin, between the spacers, proved to be difficult or rather required extra monitoring. Here the soil of each of the 1st and 2nd layers had to be compacted manually using a hand tamper. A small vibrating plate compactor was able to be used for the 3rd layer placed. Overall, the backfill compaction here was considerably less than in the remaining part of the retaining structure.

The new steel mesh elements were placed on these less compacted areas. For optical reasons, from a certain retaining structure height the steel mesh elements were pushed in by around 10 – 20cm and at the edges the natural slope was also infilled to adapt to the natural slope.

As there was no non-woven textile beneath the soil grid elements, the elements push into the soil until they are fully interlocked, especially when certain softening occurs as a result of rainfall.

Frequent and very intensive rainfall events occurred during the construction period of the retaining wall, which had long idle intervals, due to the reshaping of the waste-fill. As a relative fine grained fill material was used, the fill should have been protected against these rainfalls. Now, the soil was washed away in areas of the grid elements or washed in behind the outer skin, which led to settlements and cracks in the surface of the punched in steps (berms) and the top filled layer. The settlements caused the grid elements of the external façade to become steeper and even bulge in places. A geotextile beneath the groundside geogrid would have reduced the imprints and thus reduced or made the slant more difficult.

Figure 8 Settlement in the area of the outer skin mesh elements

The cracks were refilled with soil and the surface compacted.

Because of installation problems, a slight problem occurred in the full strength connection between the geogrid and the steel mesh elements in the curved area. The slight concave curvature of the retaining structure caused the geogrid to become slightly distended, which led to an uneven or punctual connection and the stretching could not always be achieved uniformly. However, after the backfill has been compacted these connections will be tightened. When constructing the gabions it is necessary that they are filled with weather-resistant rock material. The rock material must be placed by hand. There must not be any voids. Tipping the rock material, e.g. using a wheel loader, is inadequate and leads to unacceptable voids and impermissible deformations in the gabion system later in the construction.

## 6 CONCLUSION

Between 2000 and the end of 2002, Lauterecken sanitary landfill site was sealed with an impermeable system. For technical reasons, a maximum slope of only 1:3 was permitted for the sealing at the landfill site shell. In order to avoid extensive rearrangement of the landfill site mass, a retaining structure with a maximum height of app. 16m was constructed at the eastern boundary of the landfill site, located close to a housing estate.

Geogrid reinforced soil was chosen because of the following advantages: Rapid, economical and flexible construction and an attractive finish, which was important because of the close proximity of the housing.

The retaining structure consists of a soil shell, which was reinforced with a geogrid (composite soil system). In the lower strata, up to approx. 3 m above ground level, the exterior layer of the retaining structure was protected with gabions. Up from 3m, a steel-mesh facing was chosen, which allowed a vegetated facing to be created. The gabions as well as the steel mesh facing were anchored using geogrids. The embankment of the retaining structure has a maximum slope of 1:0.4 (70°).

The reinforced retaining structure is approx. 140m long. It is 9.60m wide at foundation level and has a total height of 16m. The geogrid was installed in layers with spacings of 0.70m. Above the reinforced soil wall the landfill was sealed with a maximum slope of only 1:3, also constructed using geosynthetics.

A quality control system was drawn up for the construction of the retaining structure. Installation of the geogrids and the backfill materials was tested and controlled on site. This paper gives explanations of the design details, the structural calculations as well as details of the quality control system. In addition, the paper also points out the experiences gained during the construction of the retaining structure and the landfill sealing.

Figure 9 View of the finished retaining structure