# Stability analysis of the old sanitary landfill slope reinforced with HDPE geogrid after a long time of service

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ABSTRACT: The paper presents analysis of geotechnical parameters of waste material and strength parameters of HDPE geogrid reinforcing a landfill slope, after a long term of exploitation. Geogrids are used particularly where forces interact in one direction in reinforced earth structures such as road embankments and steep slopes. The main purpose of a geogrid installation on a slope is the improvement of slope stability and bearing capacity of the subsoil. The geogrid installed in a landfill is exposed to the mechanical and chemical factors (e.g. changes in a wide range of pH and high temperatures) as well as to the different weather conditions. To investigate the influence of the geogrid parameters changes in time, the analysis of slope stability were performed. For the purpose of the geogrid parameters changes in time, the samples were excavated from the landfill slope and analyzed in the laboratory. The tests characterised material properties, geometry determination and also the mechanical properties - tensile strength and strain measurements. Obtained results were compared with parameters of the brand-new geogrid samples. The shear strength parameters of the subsoil and waste material were based on geotechnical investigation and load tests on the experimental embankment. The stability analyses were computed with the use of limit equilibrium method. The calculation included verified mechanical parameters of the geogrid and waste materials.

*Keywords: landfill, HDPE geogrid, durability, stability analysis.*

## 1 INTRODUCTION

Geogrids are widely used as reinforcements in slopes, retaining walls, roads, and foundations where they are subjected to the constant stress throughout their service life (Koerner, 2005; Husan et al. 2005). Uniaxial HDPE geogrids are designed to be used in geotechnical structures where soil particles need support from a long term perspective. HDPE geogrids, due to the high strength and durability are commonly used for the construction of the steep slopes, where the geogrids of rigid nodes come to engagement and wedge up the soil in the mesh of geogrids. The grain aggregates or soil particles pass through the mesh of geogrids, partly succumbing wedged in the spaces between the ribs. The strength and stiffness of the ribs prevents displacement of soils on the sides but may then assert to mechanical damage of the material (Webster 1993; Kawalec 2010).

One of the main challenges in using geosynthetics in civil works or in ground improvement applications is their durability. However, these materials are exposed not only to mechanical impact, but also to the influence of the environment, in which they are used, and therefore also to the aging processes. The current standards do refer up to the 120 years of design life for structures, so geogrid as part of reinforcing component must fulfil also these criteria. It's a common knowledge that the properties of geosynthetics, including geogrids, generally depend on time (EBGEO 2011, BS8006, BRA 00/R122).

The decrease of the allowable tensile strength depends on the short-term effects like installation damage, which reduces the maximum tensile strength value. It also affects the long-term properties, and effects like creeping and aging caused by the oxidation and abrasion, which result in long-term strength loss (Hufenus et al. 2005). The service life of a structure where geosynthetic was applied depends mainly on the durability of the used material.

This paper focuses on the durability of geogrids used for reinforcement of a slope on the old sanitary landfill. The analysed geogrid was installed more than 20 years ago in the old sanitary landfill located near Warsaw, Poland. The geogrid was excavated in October 2013 and then tested by several methods. The geosythetic was installed in a landfill and exposed to the mechanical and chemical factors (e.g. mechanical stresses by load and trucks, changes in a wide range of pH values and high temperatures), and was also subjected to the changing weather conditions. Based on laboratory results of physical and mechanical properties of the new and aged geogrid HDPE, further computations focused on slope stability analyses were performed. The analyses allow investigating how much the factor of safety was influenced by changed parameters of the geogrid exploited for more than 20 years. The numerical computations were based on LEM. The mechanical properties of the filling material and the subsoil were measured in situ by a complex geotechnical site investigation. The geotechnical tests involved cone penetration tests (CPT), light dynamic plate tests (LDP), and weight sounding tests (WST). There were also complementary tests performed like trial loading tests and back analyses of test embankments constructed at the site, for further verification of geotechnical investigation, and for direct assessment of bearing capacity.

## 2 RADIOWO LANDFILL CASE STUDY

### 2.1 *Location and description of the study site*

Radiowo landfill covers an area of about 16 hectares, of the altitude exceeding 60 meters above the ground level. The landfill is located at the north-western border of Warsaw in Poland. In 1961 - 1991 mainly municipal waste was deposited there, and since 1992 it has become a structure receiving ballast waste from the composting plant. At high steep slopes the key issue was to improve their stability. To achieve that a number of engineering works were required: comprehensive investigation of mechanical properties of waste by using different techniques, mechanical reinforcements of slopes, changing the inclination of slopes, determining the type of waste, provision of land next to the landfill and clarifying the formal status of the landfill for further development (Koda, 1998, Koda and Osiński 2015). The central and south parts of the landfill are filled with old municipal waste (10-30 years), while the upper layers in the north part are filled with fresh non-composted material. The landfill is now planned to be closed by the end of 2017. The subsoil of the landfill consists of sands with the thickness of 2-15 m, layered by boulder clays and Tertiary clays. The first groundwater level is at the depth of 0.2-1.0 m. Before 1993 there was no protection system against the environmental pollution introduced on the surrounding area. The improvement and reinforcement measures were recommended due to the local landslides observed on the landfill (Koda, 2012).

### 2.2 *Reinforcements installation on slopes*

In 1993 reclamation works on the landfill began. They included safety improvements in terms of the geotechnical formation of the landfill body. In order to improve the conditions of the northern slope stability and to make the structure underpinning the main road entrance to the landfill, a retaining wall was constructed (in the area of the square filling waste). Further carving the slope and installation of horizontal uniaxial HDPE geogrid was also proposed (Fig. 1). The reason for such heavy modifications was that on the northern slope the space was very limited (land ownership issues).

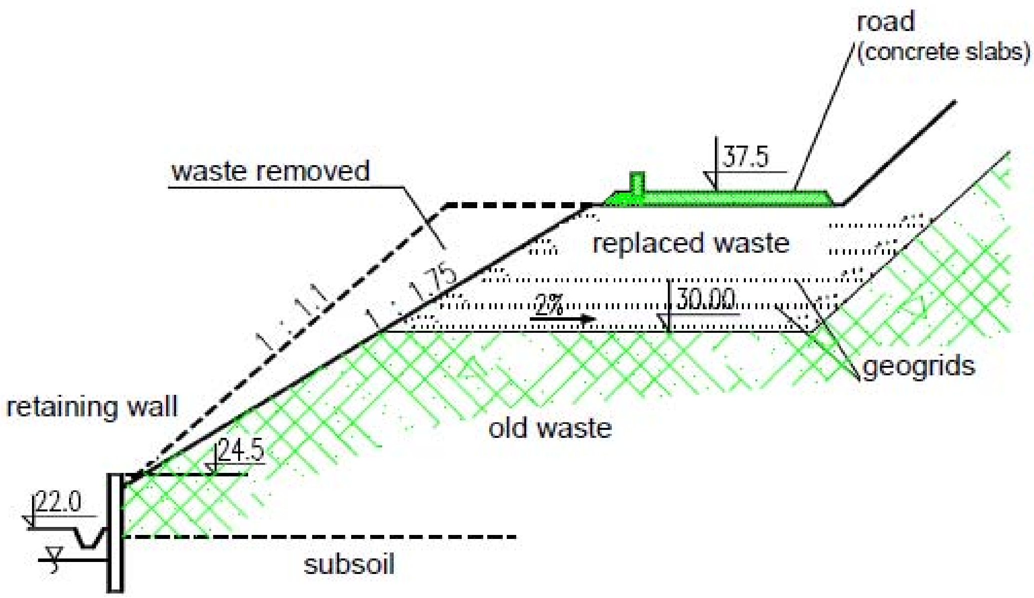


Fig. 1 The cross-section and reinforcements of the north slope of the landfill (Koda, 1998)

The main objective of the reclamation works was to allow as much as possible disposal of municipal waste on the landfill. However, due to the composition of the ballast waste, which did not meet the filling material specific requirements, a new method of compaction and slope filling was adopted. The reason for that was to basically make the material useful for a road embankment construction. Based on the waste mechanical characteristics (high compressibility) and compaction difficulties (recompression effect after compaction), the decision on mixing the waste with well graded material was made. The sub-base of the road was constructed in layers. For a single compaction, a layer of 0.6 m of ballast waste and 0.3 m layer of sand were compacted. The compaction was achieved by using 10 runs of 13 t padfoot compactor (vibrations 2200 rpm), improving the waste-sand mixing (Fig.2).

Fig. 2 The process of geogrid installation on the landfill (1993)

## 2.3 *Properties of the geogrid used for reinforcements*

The main advantage of geogrids is a high strength. This type of reinforcing solution was started to be implemented in the late 70's. The geogrid production process begins with an extruded sheet of polyethylene, which is perforated in a regular pattern. In controlled heating condition, the sheet stretches like the randomly oriented long-chain. The molecules are drawn in an ordered and aligned state. The whole process is performed to increases the tensile strength and tensile stiffness of the polymer (Tensar 1990). The main properties of the goegrid used at the landfill sit are presented in Table 1.

Table 1: Engineering properties of uniaxial geogrid

| Structure | Uniaxial geogrid |
|---|---|
| Polymer type | HDPE |
| Geometry | |
| Aperture size (mm x mm) | 16 x 140 |
| Rib thickness (mm) | 0.95 |
| CMD bar thickness (mm) | 2.5÷2.7 |
| Rib width (mm) | 6.7 |
| CMD bar width (mm) | 16 |
| Weight (g/m$^2$) | 500 |
| Mechanical properties | |
| Tensile strength at 2% strain (kN/m) | 19.0 |
| Tensile strength at 5% strain (kN/m) | 33.5 |
| Peak tensile strength (kN/m) | 55 |
| Yield point elongation (%) | 11.2 |

## 2.4 *Geogrid Sampling*

In November 2013 three samples of geogrids were collected from the landfill after 20 years of exploitation (sample size: length about 1.20 m, width approximately 1.0 m). The samples were excavated from the first layer of the structure (Fig. 1) located at the access road to the landfill (Fig. 3).

Fig. 3. The access road on Radiowo landfill in 2013

In this particular location the HDPE geogrid is exposed not only to the chemical and environmental impacts but also to the mechanical load, caused by the slope itself and loading of the incoming trucks filled with waste. The samples were extracted using mechanical diggers. They were removed from the edge of the road near the concrete slabs. Also the top layer of sand and waste was excavated in the same way. However, in this case the process was stopped when the distance of 0.3 m from the geosynthetic was reached. Then excavation was continued manually by using a shovel to avoid damaging of the geogrid. The sampling location is presented in figure 4. After the sample was excavated it was carefully raised and laid between two films of black PE and transported to a laboratory for further testing.

Fig. 4. Geogrid HDPE samples collected after 20 years of service

## 3 COLLECTED GEOGRID SAMPLES SPECIFICATIONS

The deterioration of geosynthetics properties may occur due to physical damage such as installations raptures, mechanical deformations caused by change of dimensions, and the elongation behavior. The chemical degradation (oxidative degradation) could be caused by the influence of the temperature and biological degradation such as impact of macro- and micro-organisms (Wayne et al. 1997, Greenwood et al. 2012). Physical, mechanical and resin properties compositional tests have been performed on the specimens provided by the manufacturer and also on exhumed geogrid samples. The evaluated parameters, all related tests and applicable standards are provided in the Tables 2 and 3.

The physical and mechanical test results are reported as arithmetic averages with standard deviation and they are listed in Table 2. The tests were commenced on multiple specimens: for physical properties 10 samples were used (to designate mass per unit area one sample was used). The data of aperture size were obtained from the a calliper measurement.

For the mechanical properties determination 5 samples were tested. The ultimate tensile strength falls in a range of 42.63 to 52.55 kN/m and from 5.28 to 7.41 % respectively. The average values of the ultimate tensile strength for aged samples is 48.92 kN/m. Given that the geogrid is mostly exposed to mechanical factors during installation the value is quite high. The comparison of laboratory tests of exhumed geogrid samples (Table 2), using a typical values given by the geogrid supplier (Table 1) indicates that the change in average value of tensile strength was from 55 to 48.92 kN/m and average value of elongation at maximum force was from 11.2 to 6 4 %. The physical test results (i.e. rib and CMD bar thickness, aperture size values) show no significant change in dimensional properties throughout 20 years of service.

Table 2: Physical characteristics of the geogrid

| Tests | Parameters | Specific Standard | Exhumed Samples | |
|---|---|---|---|---|
| | | | Mean Value | Standard Deviation |
| Physical | Mass per unit area (g/m$^2$) | PN-EN ISO 9864 | 532 | - |
| | Aperture Size (mm) | - | 140.24 | 1.56 |
| | Rib Thickness (mm) | PN-EN ISO 9863-1 | 0.97 | 0.0078 |
| | CMD Bar Thickness (mm) | | 2.70 | 0.0640 |
| Mechanical | Mean Tensile Strength (kN/m) | PN-EN ISO 10319 | 48.92 | 4.20 |
| | Mean Strain at Maximum Load (%) | | 6.40 | 0.89 |

The properties of the resin samples based on the tests performed on exhumed and new samples are summarized in Table 3.
The parameters like densities and flow melt index of resin geogrids after 20 years remained unchanged in comparison to the new samples. The content of exhumed carbon black samples remains above the value declared by the manufacturer.

Table 3:Resin properties

| Parameters | Specific Standard | New Samples | | Exhumed Samples | |
|---|---|---|---|---|---|
| | | Mean Value | Standard Deviation | Mean Value | Standard Deviation |
| Density (g/cm3) | PN-EN ISO 1183-3 | 0.9572 | 0.0012 | 0.9528 | 0.0012 |
| Melt Flow Index 190°C, 2,16 kg (g/10min) | PN-EN ISO 1133-1 | 0.229 | 0.0011 | 0.245 | 0.0017 |
| Carbon Black Content (%) | ASTM D 1603 | min 2* | - | 3.11 | - |

* *manufacturer information*

## 4 SLOPE STABILITY ANALYSES

### 4.1 *Geotechnical parameters of subsoil and waste layers*

One of the crucial factors when analysing the stability of a landfill slope is correct determination of geotechnical parameters of the filling material. Due to complex compositions of the material built in the slope the site investigation comprise a number of geotechnical tests for both the waste disposed on and the subsoil of the landfill body. The range of geotechnical tests involved cone penetration tests (CPT), light dynamic plate tests (LDP), and weight sounding tests (WST). For further verification of geotechnical investigation, and direct assessment of bearing capacity, there were also trial loading tests and back analyses performed on the test embankments constructed at the site. The comparison of the site investigation results allowed the final verification of mechanical parameters of materials built in the north slope of the landfill. For the initial conditions of waste material, before the compaction and sand mixing, the parameters were as follow: $\gamma$ = 14 kN/m$^3$, $\varphi$ = 20°, c= 10 kPa. For the subsoil the values were: $\gamma$ = 19.3 kN/m$^3$, $\varphi$ = 33°, c= 10 kPa. For such conditions the computed factor of safety was F= 1.06, thus the major reinforcements were required. To increase the safety of the slope several engineering solutions were proposed: replacement and compaction of access road sub-base and waste material, 5 layers of HDPE geogrid reinforcements of the road sub-base and the slope, as describe previously.

4.2 *Computations of slope stability*

For the purpose of estimating the influence of geogrid strength, changing over time on the landfill slope, the analyses of local stability were performed. There were two scenarios considered. One when the slope is reinforced with newly built in geogrid and another for conditions where geogrid was exploited on the landfill for 20 years. The analyses (Fig. 5 and 6) were performed by using LEM. For the first case (Fig. 5) the strength parameters for the geogrid were applied as recommended by the supplier: 9.61 kN/m -long term strength (Tensar. 1990). For the latter scenario the factor of safety was computed based on the actual geogrid tensile strength, determined in laboratory using samples excavated from the slope after 20 years of its exploitation (Fig. 6). The geotechnical parameters of the filling material were adjusted and increased due to compaction and sand mixing of the waste. New parameters were as follow: for technological road sub-base: $\gamma$ = 17 kN/m$^3$, $\varphi$ = 27°, c= 10 kPa, and for waste filling the slope: $\gamma$ = 14 kN/m$^3$, $\varphi$ = 23°, c= 15 kPa. The parameters of the subsoil remained unchanged. The computed factor of safety for two considered cases were F= 1.31 and F= 1.45 respectively, for the geogrid of nominal tensile strength 9.61 kN/m and for laboratory tested value of 42.63 kN/m.

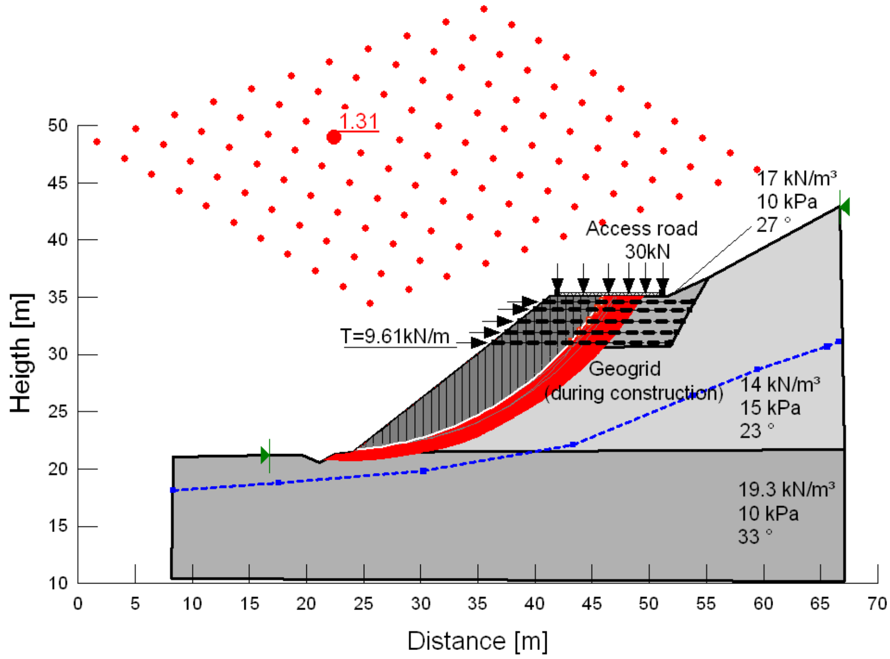


Fig. 5. Slope stability analyses for newly built geogrid, of nominal tensile strength of 9.61 kN/m

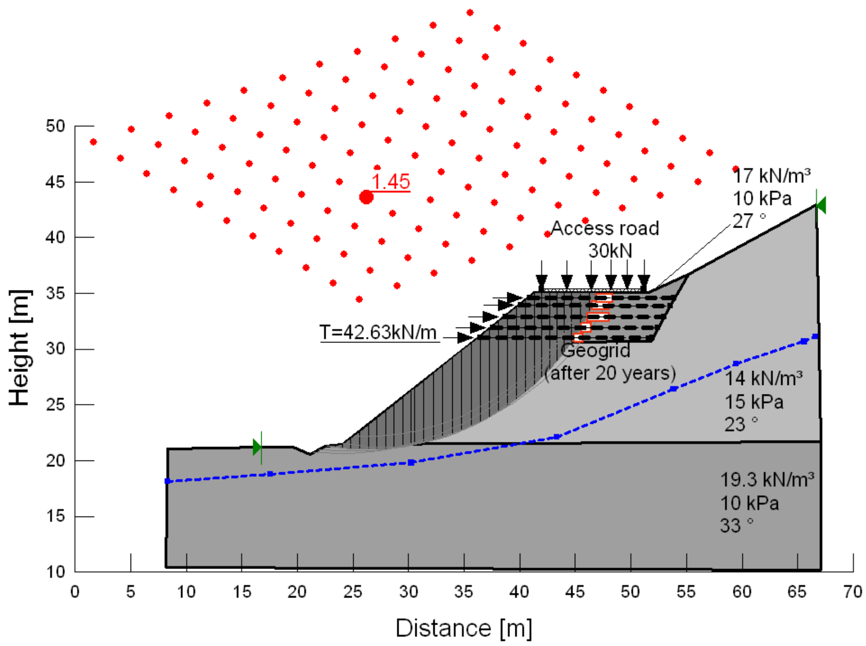

Fig. 6. Stability analyses of the slope reinforced with geogrid after 20 years of exploitation (measured tensile strength of 42.63 kN/m)

## 5 CONCLUSIONS

Based on the laboratory tests, HDPE geogrids analysed after 20 years of continuous service in the municipal waste landfill showed only a minor parameters changes comparing to the brand new material. More precisely changes in the mechanical and physicochemical properties are listed below:

- No significant deterioration of geogrid's mechanical parameters. Virgin samples showed strength mechanical damage reduced by no more then 10-20%.
- Parameters like density and the flow melt index of resin geogrids after 20 years remained unchanged in comparison to the new (virgin) samples.
- The composition of exhumed carbon black samples remains above the value declared by the manufacturer.

The paper presents also the analyses of reduction factors and determination of long term tensile strength of geogrids, according to the most recent recommendation given in EBGEO and also to nominal values provided by the material suppliers in early 90's. The mean short term strength for HDPE geogrid samples was determined in laboratory conditions. On this base the overall values of reduction factors for geogrid exploited for more than 20 years on Radiowo landfill were calculated. Moreover, the slope stability analyses for the reinforced landfill slope applying modified geogrid tensile strength and geotechnical parameters of filling material were presented. The research revealed that the factor of safety increased as much as 10 % after 20 years of landfill exploitation. Based on the laboratory tests and numerical computations the conclusion is that a careful and reasonable determination of reduction factors for reinforcing materials is crucial, especially for such hazardous environment of serviceability. The research showed that the tensile strength of material used in the study has not yet been exceed and assures safe exploitation of the technological road in the future.

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