Projects and optimized engineering with geogrids from 'non-usual' polymers

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ABSTRACT: A perfect geosynthetic reinforcement should have from the point of view of geotechnical engineers following properties: appropriate tensile module, low creep, high coefficient of interaction, low installation damage, high chemical resistance, low price. This perfect reinforcement is not available yet. Nevertheless, the use of modern polymers - additionally to the common used PP, PET and HDPE - allows for optimized solutions quite close to the "ideal case". Projects with new geogrids made from aramid and polyvinylalcohol during the last years are presented and discussed. Three of them are projects with high-strength geogrids from aramid: for overbridging sinkholes at a highway in Germany; to ensure slope stability at a waste disposal in Austria and to reinforce embankment on piles for a new high-speed train in Germany. The projects require high tensile forces at minimized strains. Further, two projects are reported with geogrids made of polyvinylalcohol: for a waste disposal and for a retaining wall in Germany. In both cases low creep had to be combined with high alkaline resistance. Typical project cross-sections, the final solutions, characteristic properties of reinforcement and photos are presented, demonstrating the broaden geotechnical engineers's options today.

FOREWORD

The geotechnical engineer's ideal geosynthetic reinforcement would possess the following features:

(1) appropriate tensile modulus (soil-compatible strain values and mobilisation of tensile force*[)])
(2) low propensity to creep (high long-term strength and minimum creep strain, say high long-term modulus)
(3) high bond coefficient with the soil in both shear- and pull-out modes (short anchorage lengths, good interaction between reinforcement and soil)
(4) very high permeability (lowest hydraulic resistance and as a result, no increasing water pressure problems)
(5) low damage during installation and soil compaction
(6) high chemical and biological resistance in all conceivable environments
(7) low costs.

[(*)] Note: a *too high* module could result in problems such as increased earth pressure in retaining structures etc!

Unfortunately, the ideal reinforcement does not (yet) exist, although high-tenacity polyester (PET), high-density polyethylene (HDPE) and polypropylene (PP) have established themselves as raw materials over the past fifteen years, becoming “common polymers”.

The polymer used largely determines the properties of a geosynthetic reinforcement. The materials used must of course be really high-quality representatives of their respective polymer families. With polyester (PET) it means high molecular weight and a low carboxyl end-group count, or with polyolefines (HDPE and PP), high-quality anti-oxidisation stabilisers etc. Geogrids (woven, knitted or extruded) are preferred mainly for the advantages (3 & 4), but also to some extent for (5 & 6).

Geogrids having adequate mesh sizes, being "open", sheet-like reinforcement structures, basically have two important advantages over, for example, woven geotextiles:

- due to high bond coefficients and soil-to-soil "through-tact", unfavourable mechanical discontinuities ("interfaces") do not occur in the reinforced body of soil;
- due to high permeability perpendicular to plane, there is no hydraulic interference (e.g. excess pore pressure) in the reinforced soil.

In recent years we have frequently witnessed the technical need for geogrids that provide mainly the advantages (1, 2 & 6) to a greater degree than the above-mentioned "common" polymers (without ignoring the cost factor). As a result, use has been made of knitted and woven geogrids involving aramid (AR) and polyvinylalcohol (PVA) as raw materials.

The present paper reports on two sets of important projects, in the first geogrids made of aramid were found appropriate and in the second polyvinylalcohol was used.

1 PROJECTS USING ARAMID GEOGRIDS

Aramid geogrids possess extremely high strength and low short-term strain (2.5% to 3.5%), almost negligible creep strain and high long-term strength. Aramid has not been mentioned as raw material in (Forschungsgesellschaft für Straßen- und Verkehrswesen 1994) for example, but has been in (DGGT 1997).

Three interesting projects involving geogrids of this type are reported below; in each a different set of requirements had to be met.

1.1 *Bridging a sinkhole on the German Federal Road B 180 at Eisleben*

This first project was developed and constructed in 1993. At that time, to our knowledge, it was the first aramid geogrid produced and used on a civil engineering project. Fortrac® R 1200/50-10 A, at 5 metres width, had a short-term tensile strength of 1200 kN/m and an ultimate strain < 3 % (for stress-strain curve see Fig. 5).

Design proceeded as described in (BSI 1995) - at that time still in draft form - and remains the same today for relatively thin, reinforced soil layers over sinkholes. Details on risk analysis, further design information etc. are to be found in (Alexiew, D. 1997). For thicker soil layers over sinkholes other analytical methods can be used, or the more recent finite-element methods, especially for cohesive or stabilised soils.

The very stringent requirements for small deformations of the Federal Road should the sinkhole reactivate could only be met by using the aramid geogrid described. (The type of problem is generally not associated with any possible increase of earth pressures, so the very high tensile stiffness of the geogrid cannot have negative effects to be regarded.) The particular problem is illustrated in Figure 1, while Figure 2 shows the cross section. The project was completed in the autumn of 1993.

A warning system with wire extensometers was also installed and if the specified strain (calibrated from the geogrid's stress-strain behaviour) is exceeded, the road would be closed. Apart from this, the extensometer data are read off once a year in order to check their reliability. Figure 3 shows the tension bar used to give the geogrid a slight pretension (really more of a straightening), because precise installation is of great importance for high-strength reinforcement.

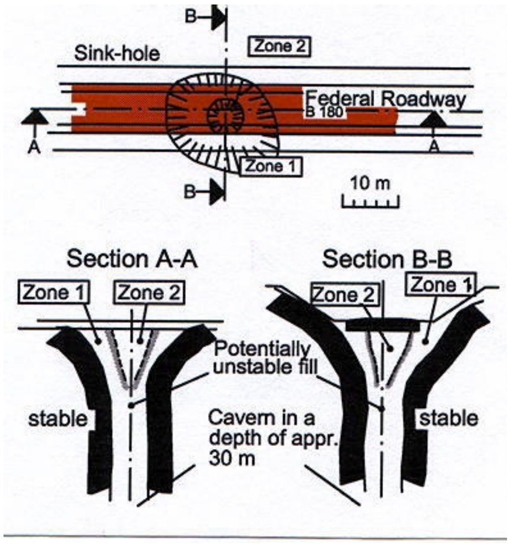


Figure 1. Bridging a sinkhole on the Federal Road B 180: overview of the problem

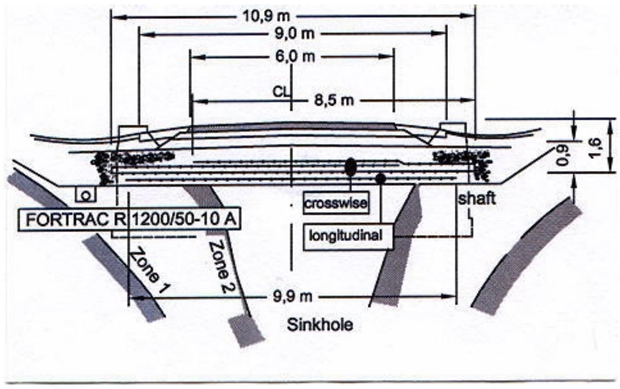


Figure 2. Cross section of the Federal Road B 180: geogrid in transverse direction with large turn-back to provide additional torsional resistance

1.2 *'Anti-sliding' reinforecement at the Böschistobel landfill site*

This is a case of a typical "anti-sliding reinforcement" on the multi-layer steep slopes of the Böschistobel landfill site in Austria, which required both high tensile strength *and* minimum displacement over time. Typical of the project are the unusually steep slopes on an inclined site and the overall tendency of the entire waste mass to slide (Fig. 4). Design was based on the method normally used to calculate safety against interface-sliding of multi-layer geosynthetic systems , i.e. assuming rigid body equilibrium mechanisms. FEM analyses were not provided. Knitted aramid geogrids were chosen due to the high tensile strengths in conjunction with low short- and long-term deformation. Fortrac® R 1200/50-10 A geogrid was used on the lower slope (smooth liner) and Fortrac® R 550/10-30 A for the higher slope segments (textured liner). Their stress-strain curves are shown in Figure 5. Creep strain is between 0.1% and 0.2% as a function of load and time.

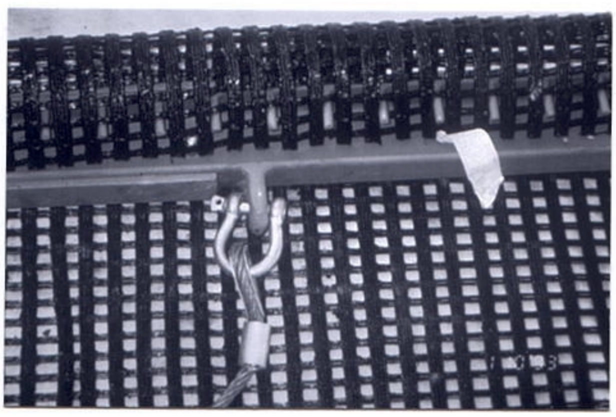


Figure 3. Tension bar used to tighten the aramid geogrid during installation

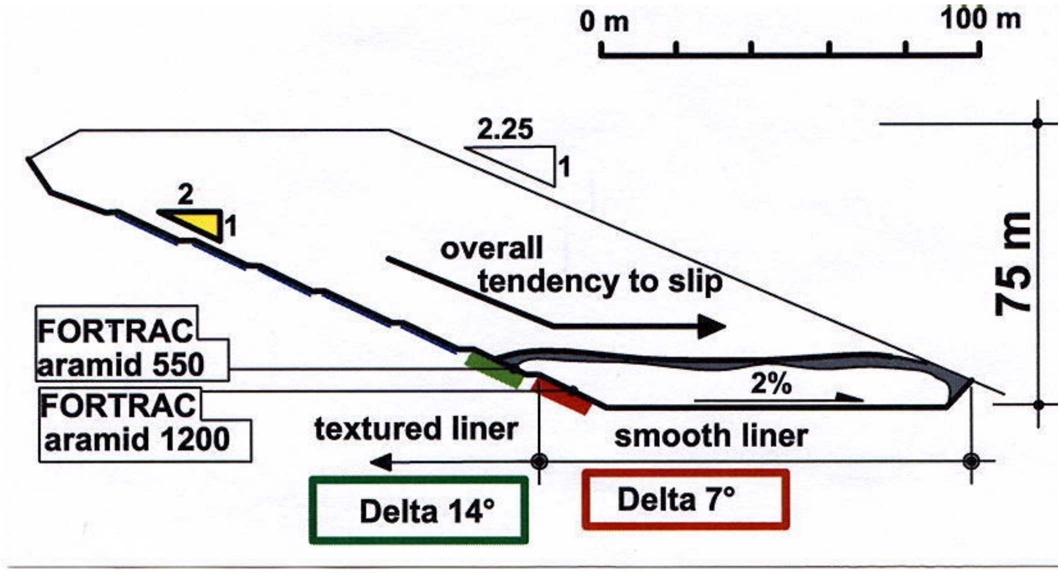


Figure 4. Illustration of the problem "anti-sliding reinforcement" of the Böschistobel landfill in Austria

Construction work was completed in stages during 1995, applying a measurement program. Typical measurement results are shown in Figure 6. Due to the delay in filling the landfill and financial reasons measurements have been interrupted after July'97, but will be continued. Please refer to (Alexiew, D. et al. 1998) for further project information and further aspects.

1.3 *Embankment with geogrid reinforcement on cemented columns on a high-speed rail-road*

The system consists of a low, geogrid-reinforced embankment on cemented columns in soft subsoil in the proximity of Rathenow Station ('Körgraben') on the new German Railways (DB) high-speed line (ICE) with up to 300 km/h between Berlin and Hanover, completed in autumn 1997 (Fig. 7 & 8).

DB had already acquired favourable experience by that time with the "geogrid-reinforced embankment on piles" system, based on the "Werder-Brandenburg" project, see e.g. (Alexiew, D., Gartung, E. 1999), involving train speeds of 160 km/h, ballast bed, and three layers of biaxial polyester geogrid Fortrac® R150/150-30 as reinforcement; also on two sections of the "Stendal Southern Bypass" project, Berlin-Hanover ICE, train speeds of 250 km/h, ballast bed, embankments reinforced with single and double layers of uniaxial polyester geogrids Fortrac® R200/30-30 and R400/200-10. On the "Rathenow / Körgraben" project it was the first time such a system was used on a concrete slab track installation, combined with very strict demands in terms of short- and long-term deformation. The design was carried out by a method described most recently in (Kempfert, H.-G. et al. 1997), using certain modifications by the present author in order to take better account of the construction phases and time factors. An aramid geogrid was used for the first time in rail-road structures (Fortrac® R800/100-20 A). Construction was completed in the autumn of 1997. Extra-heavy dynamic loads generated by special equipment were applied at different frequencies immediately after that, simulating rail traffic on a 1:1 basis; monitoring was undertaken, with positive results.

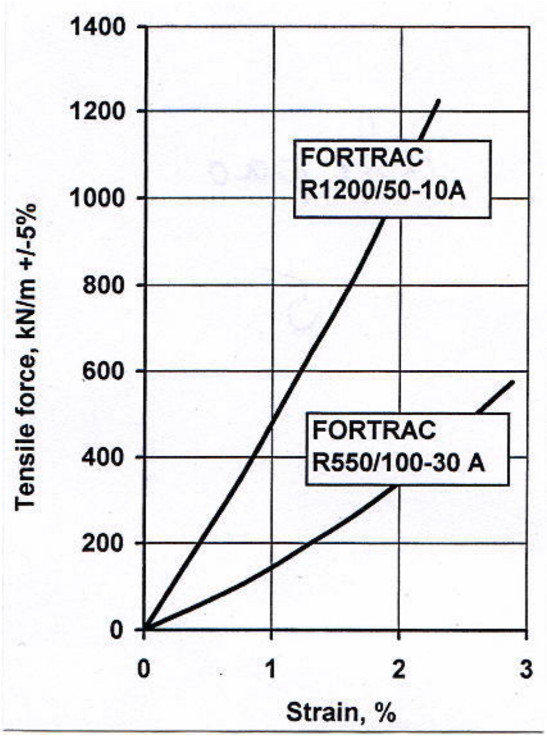


Figure 5. Stress-strain curves (short-term) of the aramid geogrids for the Böschistobel landfill

Following the high speed train test phases in the summer of 1998, again accompanied by measurements, the system has now been under ICE operation since September ’98. The structure was approved by the Federal Railways Office.

2 PROJECTS USING PVA GEOGRIDS

Geogrids made of specially modified PVA (polyvinylalcohol) can be very advantageous for engineering applications due to high short- and long-term strengths, high tension module and low creep similar to high-tenacity polyester and aramid. The typical short-term stress-strain behaviour of a family of PVA geogrids is shown (Fig. 9) in a normalised form (i.e. related to 100% of the short-term strength). The long-term strength for 120 years design life under load amounts to 60% of the short-term strength for the geogrids shown, which is a high value. Additionally, PVA geogrids are also characterised by high chemical resistance, especially in strong alkaline conditions with high pH-values, e.g. in cement- or lime-stabilised soils, concrete embedding etc (which is not the case for PET). Figure 10 shows the results of comparative tests in an extremely alkaline environment (at high temperature, which accelerates loss of strength significantly). No loss of strength was found in the PVA tested. PVA in the present (“modern”) form tested and used for geogrids has not been long available; for instance, the raw material is as yet unmentioned in the German recommendations or guidelines (DGGT 1997, Forschungsgesellschaft für Straßen- und Verkehrswesen 1994).

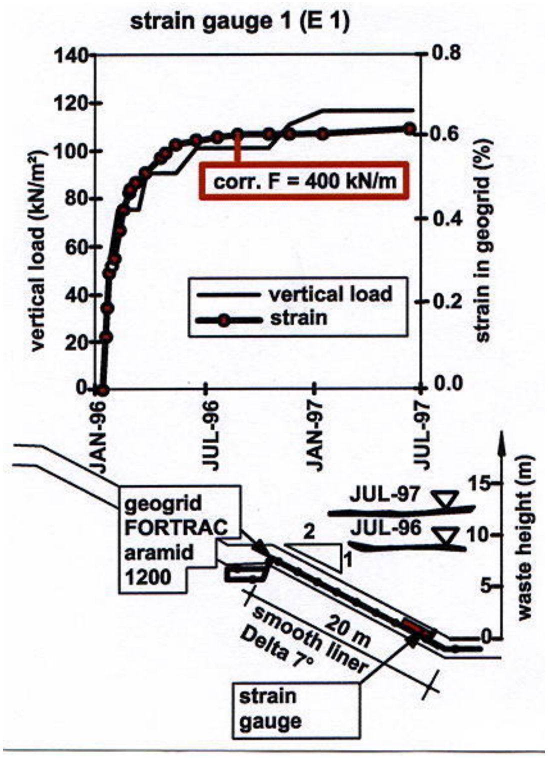


Figure 6. Typical measurement results from a cross-section at the Böschistobel landfill

Two projects are reported below, in which PVA geogrids of the type shown were used to good effect, both in 1998.

2.1 *Einöd landfill site in Stuttgart*

The Stuttgart Einöd landfill site is to be increased in height by a further 60 to 70 metres, placing an "additional" waste disposal on top of the existing landfill. To minimise deformation of the mineral layer on top of the existing fill, becoming now an intermediate sealing layer, a low-creep geogrid was required that simultaneously had to withstand pH-values > 11 due to the specific chemical environment. High tensile strengths were also required, graded according to zone and number of layers of the envisaged reinforcement. The required design strengths, considering all of the reduction factors prescribed in (DGGT 1997, Forschungsgesellschaft für Straßen und Verkehrswesen 1994), amounted to F_{design} = 40 kN/m to 200 kN/m for a virtually unlimited period under very unfavourable conditions. In this situation, the geogrid reinforcement had to approach fairly close to the "ideal" one, described in Section 1 above, including the cost factor. The choice went to PVA geogrids, which were then produced and used for the project. A simplified plan view is depicted in Figure 11.

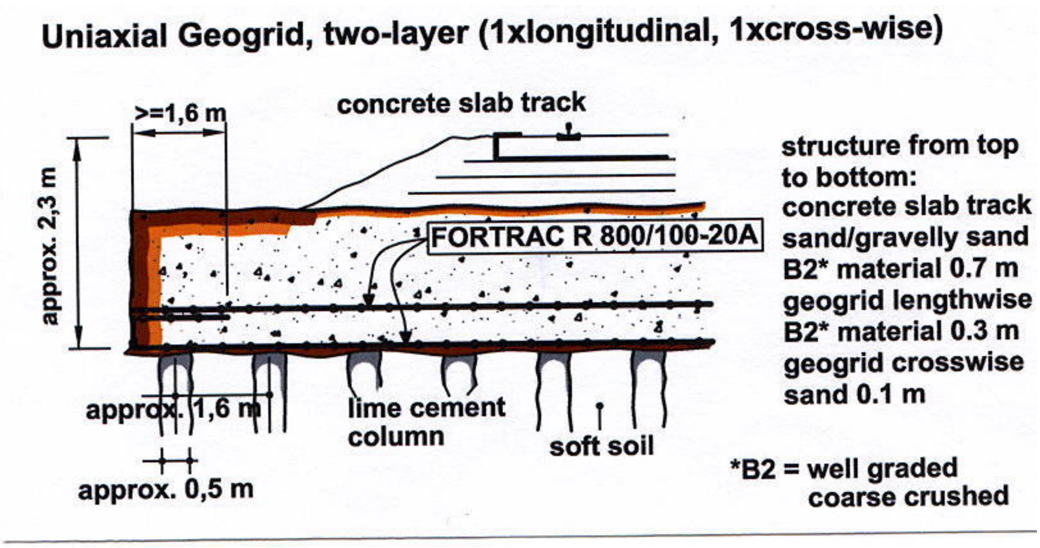
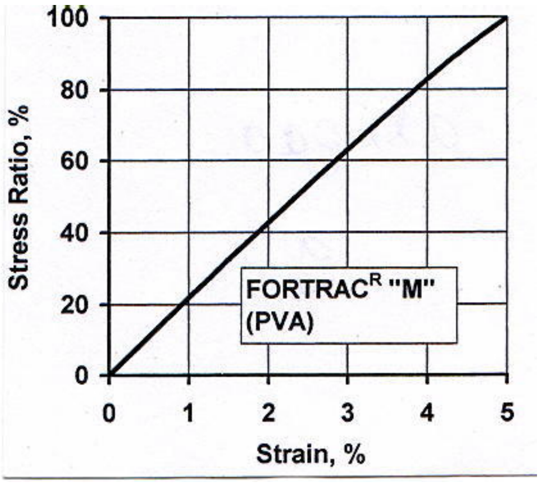


Figure 7. German Railways ICE high-speed line Hanover-Berlin, aramid geogrids on cemented stone columns at Rathenow ('Körgraben')

Basically, there are three distinct reinforcement zones: on the complete surface for general increase of bearing capacity and minimisation of differential settlement; the additionally reinforced zones as a base for the future leachate drains on the intermediate seal; and an even more strongly reinforced zone to bridge the weak point remaining after restoring the original gas dome. The uniaxial and bi-axial geogrids employed have short-term strengths of 150 kN/m to 900 kN/m with mesh sizes of 20 to 30 mm (Fig. 11).

Figure 8. Project Rathenow (‚Körgraben') : cemented stone columns before installation of aramid geogrids



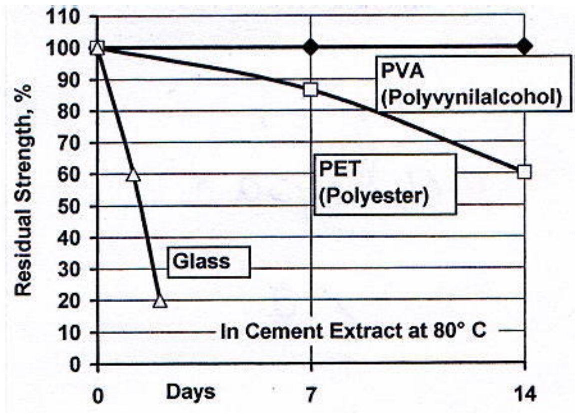


Figure 9. Typical stress-strain short-term curve for the PVA-geogrids described

Figure 10. PVA-resistance in high-alkaline media compared to other materials

The longitudinal and transverse layers of geogrid (Fig. 11) were separated by compacted soil layers to avoid possible bonding losses associated with the more easily executed installing of one geogrid directly upon the other. The construction work was completed in 1998.

2.2 *Retaining soil-geogrid structure with vegetation facing at Unterkaka, near Leipzig*

A 80°-steep, geogrid reinforced slope (retaining structure) up to 7 m in height had to be built as a permanent structure (120 years design life) at the Unterkaka Logistics Centre as a means of extending the heavily loaded distribution area.

The cohesive local soil with very unfavourable properties (low strength, high water content) was to be used after lime admixture. Due to the resulting high pH-values (> 11) and the permanent character of the structure, uniaxial woven PVA geogrids with a short-term strength of 110 kN/m were used instead of equivalent polyester geogrids. The design strength F_{design} (determined on the safe side for Germany as prescribed in (Forschungsgesellschaft für Straßen- und Verkehrswesen 1994), which is to say with an additional partial safety factor $\gamma = 1.75$) amounted to 35 kN/m. The facing was produced with "GeoGreen^R grass gabions". A cross-section is shown in Figure 11.

Because of the flexibility of the geogrid and the steel-grid structure in the contact to the gabions, a sufficiently strong and displacement-proof connection was produced between gabions and reinforcement simply by inserting the geogrid between the gabions and providing a light-duty wire tie without any other junction elements.

The construction work was completed in 1998 with occasional very unfavourable conditions (persistent rain & cohesive soil); due to pressure of time, problems arose despite the lime stabilisation.

Use of the prefabricated "GeoGreen^R" gabions (de facto separately soil and seed filled gabion-type benches) in combination with the geogrid, as described, nonetheless worked well, with stipulated cost schedules and timeframes being duly maintained. Figure 12 shows a stage of construction (not raining !…) with a typical view of the structure.

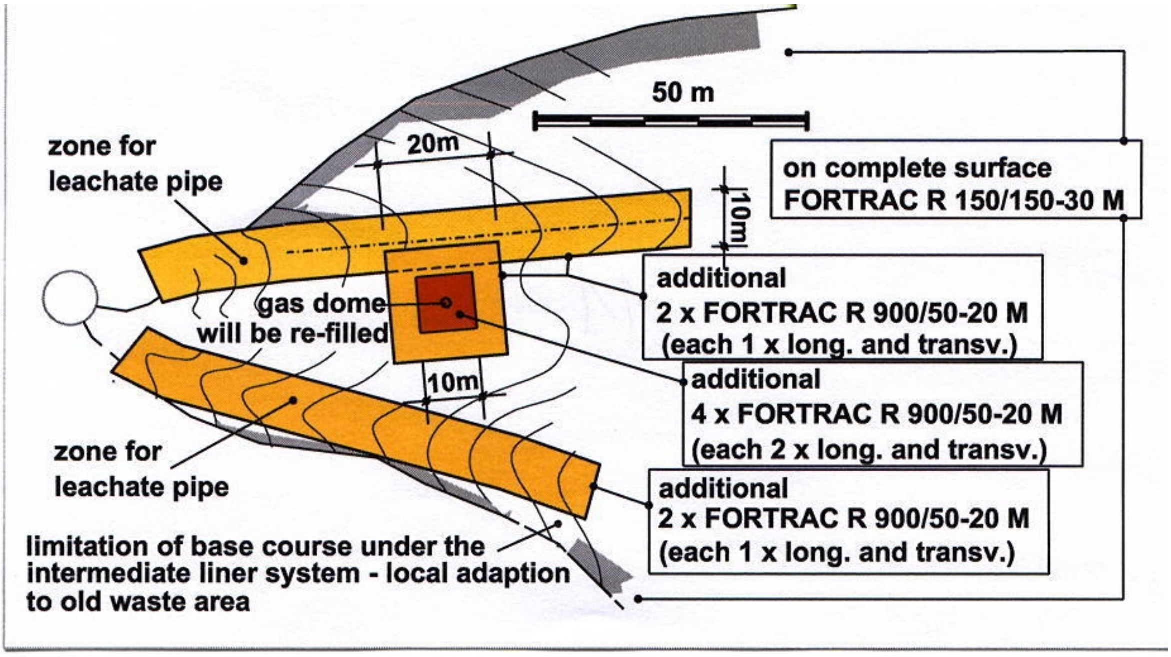


Figure 11. Einöd landfill, reinforcement of the base for the intermediate seal with PVA geogrids

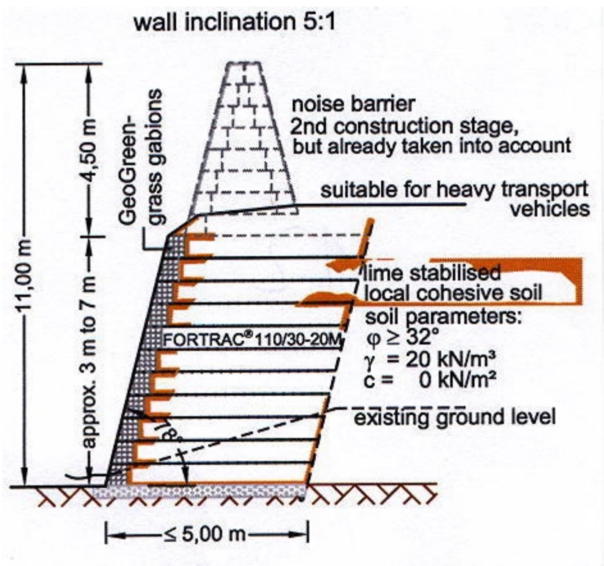


Figure 12. Cross-section of the geogrid reinforced retaining wall at Unterkaka Logistics Centre with PVA-geogrids

Figure 13. Unterkaka Logistics Centre: construction stage, PVA-geogrids, GeoGreen[R]-gabions, connections, fill soil

3 SUMMARY

The properties of the geotechnical engineer's "ideal" geosynthetic reinforcement are described, although no such product exists as yet. However, present-day "common" polymers (high-tenacity polyester: PET, polyethylene: PE and polypropylene: PP) already provide some possibility for optimal choice of reinforcement products depending on the raw material, because important properties of reinforcement are in fact largely determined by the polymer used.

The general advantages of geogrids (woven, knitted and extruded) as a reinforcement material are explained briefly.

Which is more important (being the focal point of the paper): the ongoing development of polymers and, based on that, of reinforcement, is continuously extending the geotechnical engineer's scope for project-specific optimisation.

In this connection, use of the "latest" polymers such as aramid (AR) and polyvinylalcohol (PVA) has often proved appropriate. In the context of project optimisation there is a brief discussion on properties of these novel polymer geogrids, which are relevant to the engineer, namely modulus, creep behaviour, durability, etc.

The paper includes recent, more important projects, in which geogrids in AR and PVA have provided a useful solution, sometimes the only one.

Three of these projects involve aramid geogrids in road engineering, landfill construction and railway engineering (including the first use of any kind of aramid geogrid), and two have used PVA geogrids for landfill and retaining wall construction, being the first time that PVA geogrids have been installed in Germany. Tensile strengths of geogrids in the projects presented range from 110 kN/m to 1200 kN/m and strains from about 2.5% to around 5.0%.

For reasons of space, problems posed, solutions, characteristic values, experience and design methods have been presented rather briefly, with emphasis on graphic information on project details and reinforcement behaviour.

Reference is made to the literature on the subject, in so far as it is available, given the novelty of the subject matter.

In conclusion it can be said that the above-mentioned applications of novel polymers geogrids noticeably broaden the civil engineer's options for an optimal solution on a sound base.

ACKNOWLEDGEMENTS

Our thanks at this point to everyone involved or participating in any form in the projects and developments outlined, as well as for the acceptance of new ideas.

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