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Selecting the most important parameters in geosynthetic reinforcement applications

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ABSTRACT: Geogrids have different mechanical properties, depending on the end-use. The ideal geogrid for each application will be the most suitable and economical. These properties and characteristics will be illustrated in two case studies:

1. Around South Africa the government is providing financial support for the upgrading and development of new townships, and the sewage network is an integral part of this process. Several concrete block trickling filters have been reinforced with a high-strength, high quality, PVC coated, polyester geogrid.
2. An old sand quarry was developed into a golf estate, with a driving range constructed over a wash discard tailings dam. During construction a failure occurred and a composite geotextile was used to act as a reinforcement and separation layer.

1 INTRODUCTION

Diverse ranges of non-uniform, geosynthetic reinforcement products are available in South Africa, each with different mechanical properties and therefore unique behavior. The question is: "Which product is most technically suitable, economically viable and practical to be incorporated in a range of different applications and site conditions?" The purpose of this paper is to illustrate the diversity of non-uniform geosynthetic reinforcements, and to highlight the relevant and most important mechanical properties for the various applications. The client expects value for money, therefore the engineer must provide economical and cost-effective designs that are safe, provide adequate stability and are aesthetically acceptable.

2 SPECIFICATIONS

A geogrid specification must include at least the following properties:

- Minimum ultimate tensile strength in the machine direction and cross direction
- Long-term design strength
- Maximum elongation (strain)
- Tensile strength at 2% and 5% elongation (strain)
- Minimum and maximum aperture size in both directions
- Creep data for 10 000 hours on the same product
- An indication of:
  - Ultraviolet light stability
  - Chemical stability
  - Biological stability
- Junction strength
- Base polymer
- Minimum roll width
- Minimum roll length
- Maximum roll weight

These are discussed in more detail in the following sections.

3 PROPERTIES OF GEOSYNTHETIC REINFORCEMENT

3.1 *Tensile strength*

The ultimate tensile strength of a geogrid is of little significance if specified without stating the maximum extensibility. The type of polymer and the maximum elongation are critical characteristics that need to be shown on a specification sheet. Each polymer has different elongation properties. The extrusion method and type of polymer will determine the maximum elongation property of the product. The maximum elongation of the polyester yarns available in South Africa range between 18 to 22%. Imported high tenacity polyester yarns are used in the manufacture of the reinforcing geosynthetics used in the two case studies discussed in this paper. These products have a maximum elongation of 11%.

Soil exhibits a strain at failure of between 3 and 5%. The strain of the soil will determine the maximum allowable design strength of the geosynthetic reinforcement. If higher strain values are used, failure will occur within the soil structure before the allowable design strength of the geogrids is reached.

3.2 *Aperture size*

The aperture size of geogrids determines the interlocking thereof with the soil, stone or any other geotechnical material. Larger aperture size geogrids perform best with coarse, granular backfill material and sandy materials interact better with smaller mesh structure geogrids.

Aperture size plays an integral role when the pullout resistance is determined. Pullout resistance is the ultimate tensile force required to generate outward sliding of the reinforcement in the reinforced structure. The pullout resistance is determined by two predominant factors: (1) the interface friction between the grid and the backfill material; and (2) the passive resistance from the backfill material against the transverse elements of the geogrids.

It is therefore important to carefully select the appropriate geogrid that will provide maximum pullout resistance. A guideline would be that the average particle size of the backfill material must be 3.5 times smaller than the minimum aperture size of the geogrid.

3.3 *Rigidity*

This property can be measured using ASTM D1388, a test for flexural rigidity or flex stiffness and is expressed in terms of mg-cm (Koerner, 1998). Stiff geogrids are normally extruded and manufactured from polyethylene or polypropylene. The weaving or warpknitting process is normally used to manufacture flexible geogrids from polyester, nylon or fibreglass. Transverse reinforcing elements that have some rigidity can withstand some form of shear and bending moment. The rigidity values can influence the clamping force between the geosynthetic reinforcement and facing elements.

3.4 *Creep*

Creep is defined as time dependant and permanent deformation of materials when subjected to a constant load or stress. Creep is normally an undesirable phenomenon and is often one of the limiting factors in the lifetime of an engineered fabric reinforced retaining structure. It is observed in all types of materials. Generally, in polymeric structures, the presence of a crystalline structure within an amorphous matrix will reinforce the material, potentially reducing the tendency to creep. Therefore molecular structures influence the creep characteristics of different polymers. Creep testing on geosynthetic specimens are of an absolute minimum of 10 000 hours duration to achieve meaningful results. The Stepped Isothermal Method (SIM) is a recently developed accelerated creep test that has good correlation with the 10 000 hour creep tests (Thornton and Baker, 2002).

Creep safety factors ranging between 2 and 2.5 are considered sufficient when designing polyester (PET) based geosynthetic reinforced systems. Polypropylene (PP) based geosynthetics on the other hand have a linear chain structure. The monomer units are joined together end-to-end to form long single chains. When compared to PET realignment of these chains under a constant load will continue more readily prior to break. Safety factors to compensate for a higher tendency for creep in PP should range from 4 to 5. The creep reduction factors for HDPE geogrids range between 2.5 and 5.

3.5 *Coating*

A chemical reaction (hydrolysis) occurs between Polyesters (PET) and materials with pH values greater than 9 (e.g., cement stabilised fills, ash fills). Polypropylene and polyethylene are sensitive to materials with low pH values (acids).

It is thus important to coat the geogrid with either PVC, latex or bitumen to prevent chemical degradation in the long term.

3.6 *Junction or joint strength*

The stiff extruded grids have high junction strengths. The flexible grids are woven or knitted into an open structure. The junctions are either stabilised with a leno weave for woven geogrids or by knitted loops for warpknit geogrids providing high junction strength in only the machine direction. It is critical, even if the geogrid is biaxial, that the contractor must be aware that the junction strength in the cross direction for the woven or warpknit geogrids is very low compared to the machine direction. Therefore it is advisable that these geogrids are only applied in the machine direction.

4 GEOSYNTHETIC REINFORCED CONCRETE BLOCK TRICKLING FILTERS

4.1 *General site description*

Trickling filters are wastewater treatment systems that biodegrade organic matter. Generally they consist of a large diameter solid concrete structure filled with railway-ballast size stone. Wastewater is pumped through the centre up into a rotating distributor. The wastewater then trickles under gravity through the stone bed into an outlet system at the bottom. Microorganisms in the wastewater attach themselves to the stone, which is surrounded with bacteria. The bacteria break down the microorganisms and pollutants are removed from the wastewater. High oxygen levels are required to ensure the effectiveness of the aerobic bacteria.

The conventional solid concrete perimeter retaining walls can be replaced with geosynthetic reinforced concrete blocks. Concrete blocks are stacked in an open structure allowing additional oxygen flow between the stones. Manual labour can be used to place the blocks. This creates excellent opportunities for the contractor to use local labour from the surrounding settlements.

Figure 1. Concrete block trickling filter.

The geosynthetic reinforcement is installed at predetermined levels between the concrete blocks. The height and face angle of the structure determine the tieback length and strength of the geogrid in trickling filters. Tieback lengths required range between 0.7 and 0.8 times the height of the structure. Geogrids are positioned at the required level on top of the blocks and stone bed. It is important to level the stone bed with the top of block before the reinforcing layer is laid down. Movement of the front face can occur if the reinforcing is not installed in one plane. The geogrid is placed right to the front to ensure maximum clamping between the facing unit and the reinforcing material. The geogrid is installed in the machine direction perpendicular to the wall face. The next layer of concrete blocks is installed before more stone is placed. Damage to the geogrid can occur if proper construction practices are not followed when placing the stone.

It is good practice to tension the geogrid before the stone is placed. This is to mobilise the tensile stresses in the geogrid preventing lateral movement at the front face.

Figure 2. Placing of stone.

4.2 *Geosynthetic physical properties*

The reinforcing geogrids used consist of high tenacity and high quality polyester yarn fibres with a maximum elongation at characteristic short-term tensile strength of 11%. The ultimate tensile strength of the geogrid used in this application normally ranges between 35 and 50 kN.

The manufacturing process is warpknitting providing significant tensile reinforcement capacity in one principal direction. It is important to specify and verify during construction that the machine direction is the required installation direction.

The aperture size is 25 mm in the machine direction and 30 mm in the cross direction. The open structure provides excellent stone-to-geogrid interaction. Interaction between the stone and the reinforcement determines the tensile strain required to attain equilibrium in the structure.

The geogrid is also coated with a protective polymer and has high resistance against hydrolysis after 10 000 hours of immersion in water and excellent long-term durability against chemical and biological degradation. This is evidenced by the applied partial factor for environmental effect being 1.10 for soils encountered indicating pH levels of 4–9 for design lives up to and including 120 years. A continuous flow of wastewater over the reinforcement can cause chemical degradation and ultimately a reduction in the tensile strength, therefore this geogrid was chosen. The protective polymer coating also protects the geogrid against installation damage due to the sharp-edged stones used as backfill material.

5 EAGLE CANYON DRIVING RANGE, DAM 3 STABILITY

5.1 *Site history*

The quarry was established in the early ’60s. This quarry produced the highest quality washed sand ever to be produced in South Africa. The grading analysis was consistent, and as a result the concrete manufactured with this sand had such high values and test results that consulting engineers specified this specific sand to be used in concrete mixes for high profile projects.

The quarry was upgraded with sophisticated plant in the early '70s. Eighteen separators that fed 36 discharge towers were installed. A section of the quarry was widened and deepened during the upgrade to form a catchment dam. Storm water was channeled from the surrounding areas and farms into this dam. Water was pumped to the plant to be used in the sand washing operation. The tailings generated from the washed sand were pumped into an allocated tailings dam on the site. Offices and shops developed in the area in the early '80s had to be relocated and the storm-water was re-routed. The water supply dam then became a waste deposit dam. All the over-burden and tailings were dumped into this dam. A new water supply dam was constructed on a lower part of the site. This dam was in operation until the early '90s. The quarry was then fed with municipal water, which was expensive and as a result the plant closed soon after.

Figure 3. Eagle canyon driving range.

The property has since been developed into a golf estate called Eagle Canyon Golf Estate. The site was reshaped according to the golf course design and a driving range constructed over the tailings dam.

5.2 *Failure*

Unknowingly the original dam-wall and a section of the toe were used as a source of borrow-pit material. This material was taken up-stream to cover the tailings and to reshape the required area of the driving range. Heavy earth-moving equipment continuously drove over this area during the reshaping and levelling process. The additional load from the cover material and dynamic action from the earth moving equipment generated additional earth pressure. As a result of the removal of the material from the original tailings dam-wall, the contained tailings, which were still saturated, "flowed" out filling the borrow-pit that had been created downstream of the dam-wall.

Figure 4. Tailings "flowed" over cover material.

Earth moving equipment was immediately evacuated from the borrow-pit and the driving range section as the borrow-pit rapidly filled up to the natural ground level. The depth of the borrow-pit varies between 7 m and 9 m and had an area of approximately 5 000 m^2. As the tailings flowed towards the borrow-pit the driving range capping material sheared. In some sections the tailings flowed out from beneath the capping causing settlement in the layer works. During failure these areas of subsidence were filled and covered with tailings from up-stream.

Figure 5. Cover material sheared.

5.3 *Subsoil conditions*

The soil is classified as decomposed granite residue. The in-situ moisture content was such that the contained tailings were virtually saturated (98–99%). The dried out block that was tested was only 11% saturated, corresponding to 3.3% moisture content.

From the Dynamic Pentrometer Super Heavy (DPSH) tests it was clear that the soil, which was essentially soft to very soft, clayey silt, extended down to depths in excess of 9 m in places. Beneath this was dense to very dense residual granite.

Shortly after the slip, the ground water level was recorded at approximately 3 to 4 m below the existing ground level.

5.4 *Function configuration*

A starter berm was constructed on the down-stream side of the borrow-pit to prevent the flow failure from invading an adjacent property. The starter berm was 1.5 m high with a 1:3 and 1:2 down- and up-stream slope angle respectively. Backfill material was placed in layers and compacted to 93% MOD AASHTO.

A 3 m deep, 0.8 m wide conventional subsurface drain was installed on the down-stream side of the berm, approximately 4 m from the starter berm toe. The 3 m deep trench was lined with a nonwoven, continuous filament, needlepunched, polyester geotextile. A 160 mm diameter drainage pipe was placed on top of a 150 mm thick stone-bedding layer. The remaining portion of the trench was filled with 19 mm stone and wrapped in the nonwoven geotextile.

A composite, reinforcing geotextile was placed over the filled borrow-pit. The 5.2 m wide panels were stitched together using 1 mm thick binding wire. A continuous reinforcement and separation blanket was thus formed with the composite geotextile. A 600 mm thick dump-rock layer was placed over this blanket layer. The purposes of the composite geotextile were to act as a reinforcement, separation and drainage layer. This layer prevented the dump-rock from punching through into the soft, saturated tailings, thereby controlling the dump-rock volumes used. Furthermore, it prevented tailings contaminating the dump-rock. The composite geotextile layer allows water to pass through but prevents fines entering the drainage path that the dump-rock layer provided, thereby accelerating the consolidation process. This drainage path was connected to the 3 m deep subsurface drain via solid 160 mm diameter PVC pipes at 10 m spacing. The nonwoven geotextile component provided protection to the high-tenacity, polyester, reinforcement yarns when the dump-rock was placed.

Figure 6. Placement of dump-rock.

Differential movement occurred when the dump-rock was placed and compacted. This mobilised the tensile force in the composite geotextile layer that was trapped between the two different materials. The composite geotextile and the dump-rock layer formed a stiff but flexible layer after the compaction effort was complete. A low-elongation reinforcement product was critical in this application to ensure that high tensile forces were generated during the dump-rock placement period. The dump-rock was covered with a compacted layer of suitable backfill material that was tied in with the starter berm.

Figure 7. Preparation of final levels.

5.5 *Geosynthetic physical properties*

The biaxial-oriented, 50 × 50 kN/m composite, reinforcing geotextile used comprised a combination of high tenacity polyester yarn that provides 11% maximum elongation, stitched to a 100% polypropylene, continuous filament, nonwoven, needlepunched geotextile.

This product has two main functions. Firstly, it acts as a separation layer between the very soft, in-situ material and the dump-rock layer. The required thickness of the dump-rock was therefore reduced. The nonwoven, needlepunched geotextile also has the capability to transport water within its plane, thereby dissipating any pore water pressure build-up. Secondly, the biaxial-oriented, high-tenacity, polyester yarns, by virtue of their relatively high strength at low strains, absorb the stresses induced by the dump-rock layer and earthmoving equipment, thereby reducing the loading on the in-situ material.

The nonwoven geotextile component was proven to resist damage of the polyester reinforcing yarn and retain > 90% of residual tensile strength when subjected to compaction of 300 mm of crushed stone gravel placed directly on the geotextile. Due to the very soft yielding nature of the in-situ material installation damage was not of great concern.

In terms of the specification the composite geotextile had to be UV stabilised and needed to retain at least 70% of the residual tensile strength after 30 days exposure to natural sunlight. The geotextile was exposed to sunlight for a few days until it was covered with the dump-rock blanket. The roll sizes were 5.2 m × 150 m. This width helped minimise the wastage factor.

6 CONCLUSION

The geosynthetic reinforcement used in the two case studies is manufactured from high-tenacity and high-quality polyester yarn fibres with a maximum elongation at characteristic short-term tensile strength of 11%, making them cost-effective in terms of cost per kN/m of strength.

The open-structure geogrids provide excellent soil-to-geogrid interlocking with the stone and granular backfill materials. The open structure of the geogrids also increases the pullout strength and prevents outward sliding from occurring.

The PVC-coating prevents chemical degradation of the polyester yarns by the continuous flow of aggressive liquids over the geogrid. The protective polymer coating also protects the geogrid against installation damage.

The composite reinforcing geotextile used in the Eagle Canyon Golf Estate acts as a separation layer between the in-situ material and dump-rock. The nonwoven, needlepunched geotextile also acts as a drain. The biaxial-oriented, high-tenacity polyester yarns reduced the stress on the in-situ material.

In both case studies the reinforcing geosynthetics used proved effective in fulfilling the functions for which they were designed.

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