ABSTRACT:
Geosynthetics are used in many geotechnical applications. Geogrids are in one geosynthetic group and are products which are used for reinforcement applications, especially as base course reinforcement. In applications where roads are built over soft soils the dynamics occurring from the traffic load can create a pumping effect and therefore a mixing of the soft subsoil with the base course material or severe deformation of the road which reduces the applicability of the road. Proper designed geogrids however can reduce these effects and maintain the construction of the road and increase service life. This paper will concentrate on the design of roads (reinforcement of the base course) with geogrids and introduce criteria for geogrid specifications. Guidelines for geogrid properties will be discussed and various test trials and field performance data will be presented. The test trials were carried out with numerous geogrid types and also varying field conditions so that the reader of this paper can benefit from the experience of these trials. The presentation will concentrate on technical facts of the geogrid performance in the test trials and the research and suggest geogrid properties for design.

1. WHAT ARE GEOGRIDS AND HOW ARE THEY MADE?
Geogrids are polymeric products formed by joining intersecting ribs. They have large open spaces also known as “apertures”. The directions of the ribs are referred to as machine direction (md), orientated in the direction of the manufacturing process or cross machine direction (cmd) perpendicular to the machine direction ribs (figure 1). Geogrids are mainly made from polymeric materials, typically polypropylene (PP), high density polyethylene (HDPE) and polyester (PET).

Geogrids are manufactured as either biaxial or uniaxial. Biaxial geogrids are those that exhibit the same strength in both the machine and cross machine directions while uniaxial geogrids exhibit the primary strength in the machine direction with minimal strength, enough to maintain the aperture structure, in the cross machine direction.

Presently geogrids are manufactured in different manners.
One manufacturing method consists of extruding a flat sheet of plastic, either high density polyethylene or polypropylene, punching a controlled pattern of holes (the apertures), and stretching the sheet in both directions, orienting the polymers, developing tensile strength. However, there is a little orientation in the junction.

Another method is to take high tenacity polyester or polypropylene yarns that are typically twisted together. The single yarns are then weaved or knitted forming flexible junctions. Typically these products are additionally coated, depending on the manufacturer, with polyvinyl chloride (PVC), a bituminous material or latex.

The latest method which produces a new generation of geogrids (laid and welded geogrid, figure 2) is to extrude flat polyester or polypropylene ribs (also known as straps or bars) that are passed over rollers, running at different speeds that stretch the ribs and orientate the polymers into high tenacity flat bars. These ribs are fed into the welding equipment where cross machine direction ribs are introduced and are welded together forming dimensioned apertures.

2. WHERE ARE GEOGRIDS USED?

There are several major markets for geogrids. These are base reinforcement, earth retaining wall construction including veneer stabilisation, the segmental retaining wall market, embankment reinforcement and pile cap platforms. Biaxial geogrids are primarily used in base reinforcement applications, while the uniaxial geogrids are often used in the other markets. This paper will only be concentrating on base reinforcement and biaxial geogrids.

The base reinforcement market is just what the name implies. These are applications where an engineer is trying to improve the performance of a gravel base over poor soils, trying to minimise the amount of gravel in the base course design, or increasing the life of the surface cover, concrete or asphalt. Geogrids are used under parking lots, airport runways, gravel construction roads, highways, dam levees and railroad tracks.
3. HOW DO GEOGRIDS WORK?

Geogrids work by interlocking with the granular or soil material placed over them. The apertures allow for strike-through of the cover soil material which then interlocks with the ribs (flat straps/bars) providing confinement of the overlying granular/soil material due to the stiffness and strength of the ribs (figure 3).

![Figure 3: Demonstration of the interlock effect with a car standing on a laid and welded geogrid reinforced gravel column](image)

4. WHAT ARE GEOGRID PHYSICAL PROPERTIES?

Geogrid physical properties are the characteristics of the geogrid that provide it with its strength and ability to act as soil reinforcement. The following properties are those that the majority of the geogrids can be tested for and will provide a means to compare the various geogrids against each other. The test methods to determine these properties are nearly all standardised by ISO, CEN, ASTM, Geosynthetic Research Institute (GRI) or national standards. The properties typically listed are as follows:

1. Tensile strength @ ultimate
2. Elongation @ ultimate
3. Tensile or true tensile strength @ 1%, 2% and 5% elongation (strain)
4. Elongation
5. Initial or true initial modulus
6. Aperture size or dimensions
7. Junction strength
8. Junction efficiency
9. Flexural rigidity or stiffness
10. Aperture stability
11. UV Resistance
12. Rib thickness and width
13. Resistance to installation damage
14. Resistance to long term degradation
15. Creep behaviour

A more detailed explanation of physical properties with a simple explanation of the test method is described in the specific test procedures or standards. Most of these properties will impact the level of performance of the geogrid
as a base reinforcement material. Table 1 identifies the property, the geogrid characteristic and the generally accepted belief this property has on the performance of the geogrid to reinforce the base material.

<table>
<thead>
<tr>
<th>Geogrid part</th>
<th>Effect</th>
<th>Property</th>
<th>Test method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rib</td>
<td>Stiffness</td>
<td>Stiffer is better</td>
<td>Flexural rigidity and Aperture stability test</td>
</tr>
<tr>
<td>Rib</td>
<td>Aperture shape</td>
<td>Square or rectangular is better than curved or rounded</td>
<td>No specific test method available</td>
</tr>
<tr>
<td>Size</td>
<td>Aperture size</td>
<td>Related to base aggregate size. Optimum size not determined but should be minimum 25 mm to 400 mm (1 in to 1.5 in)</td>
<td>Test trials or cyclic loading tests are applicable</td>
</tr>
<tr>
<td>Aperture</td>
<td>Rigidity</td>
<td>Stiffer is better</td>
<td>Flexural rigidity test</td>
</tr>
<tr>
<td>Junction</td>
<td>Strength</td>
<td>Need some minimum strength. However values at strains less than 2 % elongation of more importance</td>
<td>Junction strength test and pull-out test</td>
</tr>
<tr>
<td>Junction</td>
<td>Aperture stability</td>
<td>High value shows good potential for improved traffic performance</td>
<td>Junction strength test, pull-out test and field tests</td>
</tr>
<tr>
<td>Rib</td>
<td>Initial modulus</td>
<td>Higher values are better</td>
<td>Tensile strength test</td>
</tr>
</tbody>
</table>

Table 1: Geogrid properties affecting base reinforcement applications

5. IMPORTANT CRITERIA FOR GEOGRIDS

There are several features of geogrids that make it the choice to use for base stabilisation applications. Some issues to consider for the design in a base course with geogrids are:

- True biaxial geogrid with equal strengths in both the machine and cross machine direction which allow stress transfer in all directions, e.g. in road curves.

- Strength - Higher strengths @ 1%, 2% and 5% strains are important to pick up the loads (figure 4). Typically the maximum elongated allowed in a base course should be under 2 %.

- Modulus - Very high modulus which means the geogrid will pick up the stresses quickly with little or no movement in the overlying base materials.

- Junction strength and/or efficiency – Often junction strength at ultimate stress/elongation which is at approximately ± 8 % elongation are specified in tenders. When dealing with base reinforcement designs the stresses considered in any design will be ≤ 2 % as failure of any paved surface is defined as 10 mm to 25 mm deflection and 25 mm deflection is close to 2 %. Based on the failure definition, one can argue that you realistically only need to be concerned with the geogrid junction strength at strains of ≤ 2%. Here extruded as well as laid and welded geogrids will exhibit 90% ± efficiency which is more then adequate to provide the reinforcement required in base stabilization. The strongest statement against the junction strength at ultimate as performance criteria however is made by Professor KOERNER in his book "Designing with Geosynthetics"; 5th edition, 2005 on page 332. "A secondary tendency is to evaluate the in-isolation junction strength by pulling a longitudinal rib away from its transverse rib’s junctions. It is important to state in-isolation since there is no normal stress on the junction; thus the test will not represent performance conditions. A performance junction strength test must be done with the entire geogrid structure contained within soil embedment. This is a much more complicated test and will be covered in this section under anchorage strength from soil pullout". On page 333 Professor Koerner comments on the junction strength efficiency: “It is important to note that these tests have the junction in an unconfined status. Thus, it is an index type of text.”.
- **Flexural rigidity** - It is generally accepted that a stiff geogrid will perform better for base reinforcement, as the geogrid will hold its shape, maintaining a horizontal plane versus flexible geogrids when installed. As a result, there is no movement when the loading from the overlying gravel is transferred to the geogrid, whereas the flexible geogrids have to move to lie in a horizontal plane and be placed in tension. The stiffer geogrids pick up the transferred loading quicker with little or no deformation in the overlying gravel.

- **Aperture stability** - Based on the Kinney test (COLLINS et. All, 1996) method stiffer products perform better in this test. According to test trials carried out by WES and Kinney, a geogrid with high aperture stability (also referred to as torsional stability) will allow more traffic passes than products with lower aperture stability. Therefore, they have a higher Traffic Benefit Ratio (Relationship between number of truck passes over an area with geogrid compared to an area without geogrid).

- **Wide rolls** will translate into less overlaps. In a large flat area this will result in less material required and save overall costs.

- **Resistance to installation damage** - Installation damage testing is performed on geogrids to see what, if any, damage occurs to the geogrid during installation. In this test the geogrid is installed and covered with, typically, three types of cover material, exhumed and wide width tensile (wide width strength) testing is performed on the exhumed material. These test results are compared to "control" tests performed on the same material not buried and the percentage of retained strength is calculated. A reduction factor can then be calculated and taken into account by an engineer when designing with geogrids. Current installation damage results of laid and welded geogrids are listed in the table 2 and are compared to published geogrid values in the same test (e.g. SPRAGUE et al., Geosynthetics Conference 1999). The results show that laid and welded geogrids are as durable if not better than other geogrids.
Table 2: Installation damage test results

- Soil pull-out testing - For soil reinforcement with geogrids, the comparison of the stress-strain behaviour of the soil and the geogrid is very important. To determine the strength of a geogrid in a soil that will also indicate the ability of the aperture to interlock with the soil, pull-out tests are typically carried out. Recent research publications of soil pull-out test with laid and welded geogrids have shown that they are again, as good if not better than comparable geogrids (CHRISTOPHER 2007, FLOSS et al. 2000).

6. GEOGRID TEST TRIALS OVER SOFT SOILS

6.1 Geogrid base course reinforcement over loess loam

The growing amount of traffic on roads increases stress conditions to the road structure resulting in the necessity to improve the strength of the structures. The long-term stability of the pavement depends primarily on the structure of the base course. Typically the base course under roadways is made of crushed gravel that must ensure efficient load distribution of the stresses transferred from traffic. In all cases it is important that the shear strength of the subsoil is exceeded, which in general can be very low, by the base course material. Plate load tests, such as described in DIN 18134 (similar to AASHTO T 222 and ASTM D 1196) allow a means for determining the bearing capacity of the subsoil and the compacted base course which can then be correlated to a CBR (California Bearing ratio) value.

In Germany and many other parts of the world there are subsoils very similar to loess loam, requiring additional measures for base course construction if roads are built over this type of soil. Often the thickness of the base course is simply increased. This requires more excavation of subsoil and additional material in the thicker base course resulting in increased labour, equipment and material costs. An alternative and cost effective method to achieve a long term safe solution for low strength subsoils is to use polymeric geosynthetic geogrids, such as the laid and welded Secugrid® geogrid, between the subsoil and the overlaying base course. The additional benefit of this solution is the overall reduction of the base course thickness because the selected geogrid reinforces the base course allowing for uniform stress distribution across the base course.

A test trial was made on an access road to a landfill where various cross sections of base courses were constructed over a loess loam (EV2 = 27.6 MN/m², approximately CBR = 6 %). These various sections were then tested using a plate load test to determine the resulting bearing capacity of the subsoil. Control sections were also built where the thickness of the base course, without geogrid reinforcement, were 300 mm and 400 mm thick. Three (3) different geogrids were incorporated in the study and were installed in the geogrid reinforced base course sections as follows.

- F35 - A PVC coated polyester geogrid with a biaxial ultimate tensile strength of 35 kN/m (2400 lbs/ft) in both machine (md) and cross machine direction (cmd)
- T30 - A stretched polypropylene geogrid with a biaxial ultimate tensile strength of 30 kN/m (2055 lbs/ft) in both md and cmd
- SG 30/30 Q1 laid and welded geogrid - manufactured of extruded, stretched, monolithic, structured flat bars with welded junctions and a biaxial ultimate tensile strength of 30 kN/m (2055 lbs/ft) in both md and cmd

It was assumed that the bearing capacity of the unreinforced control section would exceed a value of 45 MN/m² (CBR 12.5 %).

In figure 5 the bearing capacity values are summarised by cross section and after compaction. Using only a 300 mm thick crushed gravel base course resulted in a bearing capacity improvement to the subsoil. In addition the cross sections using the three (3) geogrids all showed an additional improvement in the bearing capacity of the subsoil. However the test plot reinforced with laid and welded geogrid 30/30 Q1 achieved the highest improvement in bearing capacity values. The bearing capacity results (EV2) with this geogrid, averaged at 95.2 MN/m² (CBR: 14.5 - 19 %), ranging approximately 18.9 to 29.8 % higher than the other geogrid sections.
6.2 Soil reinforcement with a laid and welded geogrid and true biaxial strength

In the community of Neuenkoop-Koeterende, Germany several farm access roads required improvement because the roads could not withstand the stresses developed from current traffic levels. The roads were several decades old and had only very thin bearing layers (approx. 30 cm). In addition these roads were built over very soft peat with a CBR value of approximately 1 %.

The local design engineer used test results from an investigation in 2001 of the nearby wind mill Neuhuntertorfer Moor project, which had similar subsoil conditions, as the basis for re-designing the farm access roads. The new design increased the base course bearing layer and incorporated geogrids for additional strength. The designer recommended new cross sections to the existing road which included the installation, depending on the soil CBR values, either the laid and welded Secugrid® or Combigrid® (geogrid with an incorporated geotextiles for separation and filtration purposes) geogrids with tensile strengths of 30 kN/m (for higher soil strength CBR values), 40 kN/m or 60 kN/m (for the weakest soil strength CBR values). To achieve the recommended CBR value of the bearing layer, without allowing any long term rutting, the designer recommended two different bearing layer thicknesses using available recycled materials to keep the overall project costs low:

- 200 mm crushed tile material, 300 mm crushed recycling concrete
- 300 mm crushed tile material under 100 mm B2 recycling concrete

The needle-punched nonwoven geotextile, an integral part of the Combigrid geogrids, ensured adequate filter and separation performance between the bearing layer of recycled materials and the subsoil.

The load bearing tests performed after placement of the geogrid and the base course showed that the CBR results had variation, due to the very different subsoil conditions which was expected. While the newly installed base course did not achieve the expected CBR value of 50 % in all cases the results from areas not meeting 50 % were very close and determined to be adequate. Based on the performance of the new base course from construction traffic as well as a few weeks of farming traffic it was concluded that the proposed solution fulfilled the expectations of the design. The design engineer, as well as the owners, concluded that a huge improvement was achieved using geogrids in the design and expectations are that the road would perform successfully for a long time.
7. CONCLUSION

Geogrids are increasingly being used as soil reinforcement, especially as base course reinforcement over soft soils. Different geogrid types on the market have proven their efficiency against solutions without geogrids and demonstrated that geogrids allow a reduction of the base course thickness and thus achieving the required stability. However different geogrid types do perform differently, which results in different required base course thicknesses.

Due to different geogrid types manufacturers, designers and/or specifiers have developed various specifications around product types, some not reflecting to the application at all, e. g. junction strength/efficiency requirement.

The authors of this paper have focused on the important application related design issues and pointed out that the tensile strength and the modulus need to be compared under realistic site conditions which in the case of a base course reinforcement should be at strains under 2 %.

Furthermore the pullout performance, the resistance to installation damage as well as the aperture stability (torsional stability) reflect more to application related conditions and are therefore more useful to describe the requirements of the geogrid.

Finally true test trials under site specific conditions show how geogrids perform and allow a further judgement on the performance of geogrids in base courses.

Concluding from the various tests carried out with a new generation of geogrids (cross laid extruded bars and welded at the junctions) the tests and trials show that these geogrids are suitable as base course reinforcement and allow cost effective designs.

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