AN OVERVIEW OF GEOGRIDS

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INTRODUCTION

The origin of homogeneous punched and drawn polymer products was with Netlon Ltd. of Blackburn, England; first with geonets and then with geogrids. In this regard, the company (now Tensar International Ltd.) and its many personnel (particularly Dr. Brian Mercer), should be sincerely congratulated. This congratulatory comment extends not only for product manufacturing, but also for many new engineering applications and specific designs that were generated as well.

Two other categories of geogrids were developed in this same time period (the late 1970's and early 1980's) of very different compositions. One such category used about 200 high tenacity polyester filaments and contained them within a polypropylene or polyethylene sheath. They were then fabricated into a grid structure by melt bonding the overlapping sheaths together. This general concept was then extended to weaving and knitting PET yarns into a grid configuration and then coating the structure with bitumen, latex, or PVC. The purpose of the coating is to provide dimensional stability and some protection against installation damage to the fine denier filaments. The other geogrid category developed around this time used PET packaging straps (about 1.0 cm wide) in a grid configuration and then ultrasonically welded them together with the aid of a steel screen placed within the intersections. Subsequent development with ultrasonic and lazer welding allowed for the elimination of the steel screen within the intersections.

Figure 1 shows the current situation of the three major categories of geogrid structures that are currently available. It should be recognized that there is considerable competition among geogrid manufacturers in each of the three categories mentioned; see Table 1 for the approximate status at this point in time. There it is seen that the coated woven or knit yarn geogrids are, by far, the category with the most manufacturers.

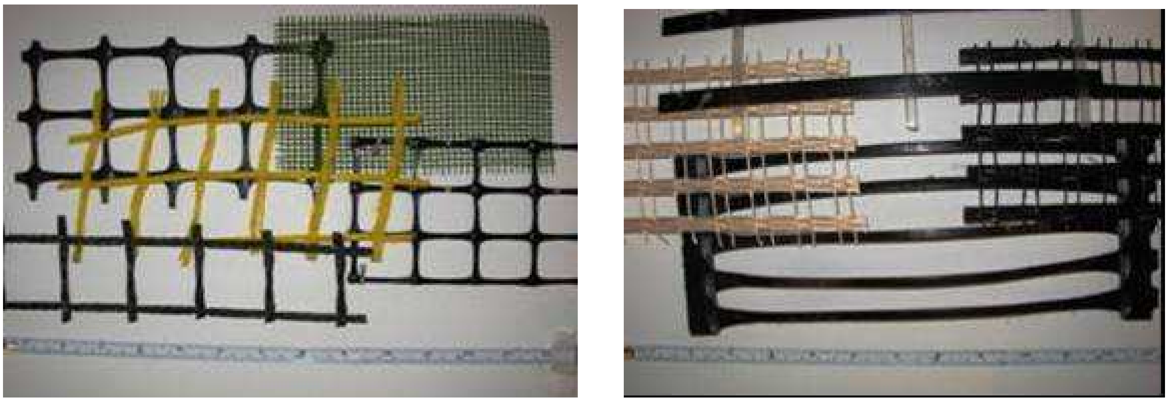
(a) Homogenous (punched & drawn) (b) Coated woven or knit yarns (c) Welded straps or bars

Figure 1. The three major categories of geogrids

Table 1. Major geogrid manufacturers by category

Homogeneous (HDPE, PP)	**Coated Woven or Knit Yarns (PET, PVA)**	**Straps or Bars (PET, PP)**
Netlon (now Tensar)	ICI (Linear Comp.)	Signode (dep.)
Tensar	Mirafi (TC Nicolon)	Colbond
Tenax	Huesker	NAUE
Permathene (Etsong)	Lückenhaus	
Checkmate	Strata	
	Synteen	
	Webtec (Hanes)	
	Checkmate	
	St.-Gobain	
	TechFab India	
	Bayex	
	Permathene	
	↓	
	7 in Korea and 9 in Taiwan	

A further classification that can be made for all three categories of geogrids can be made on the basis of application in that there are biaxial (or bidirectional) and uniaxial (or unidirectional) types available; see Fig. 2. The biaxial types are used where the major principal stress direction is not known, as with pavements and foundation applications. (A recently introduced TriAx® type of geogrid is also in this classification). The uniaxial types are used when the major principal stress is known, as in wall and slope applications.



(a) Biaxial (and triaxial) (b) Uniaxial

Figure 2. Classification of geogrids by application

A word of caution is perhaps appropriate with respect to the field usage of uniaxial geogrids in that the installer must clearly recognize the directionality of the major principal stress and orient the geogrid accordingly. Figure 3 illustrates that this was unfortunately not the case for the homogeneous punched and drawn geogrid in Fig. 3(a) and for the coated PET yarn geogrid in Fig. 3(b).

(a) Wrong geogrid orientation and very difficult to even accomplish (b) Wrong geogrid orientation even with proper product labelling

Figure 3. Improper placement of uniaxial geogrids in retaining wall applications

VARIOUS USES OF POLYMERIC GEOGRIDS

Of the myriad uses of geogrids that have been and continue to be generated, a grouping can be made on the basis of use by various industry sectors as shown in Table 2.

Table 2. Some major uses of geogrids by industry sector

Transportation	**Geoenvironmental**
• paved roads (pavement and base courses)	• landfill vertical expansions
• unpaved roads	• landfill lateral expansions
• railroads (ballast and base courses)	• landfill veneer reinforcement
• subgrade reinforcement	• 3-D foundation mattresses
Geotechnical	**Hydraulic**
• walls and large berms	• earth and earth/rock dams
• slopes and embankments	• canal side slope reinforcement
• basal foundation reinforcement	• reservoir foundation reinforcement
• encapsulation of stone columns	• erosion control mattresses
• mattresses over soft soils	• lifeline stress reduction

In order to illustrate some of the more important applications eight have been arbitrarily selected:

Aggregate base course reinforcement

While the first use of geosynthetics to provide for base course reinforcement used geotextiles on the subgrade soil's surface, geogrids were found to be competitive and particularly useful in their embedment within the base course itself. The interlocking mechanism of appropriate sized stone aggregate with the geogrids apertures was investigated by Sarsby (1985). Furthermore, a design method was also developed by Giroud, et al. (1985). In these situations, not only soft foundation soils but firm foundation soils as well have proven to be cost effective insofar as aggregate savings are concerned. Clearly, this 25-year old application exemplifies a "sustainable" situation many years before the current use of the term. Figure 4 illustrates the situation for both highway and railroad applications.

(a) Highways (b) Railroads

Figure 4. Aggregate base course reinforcement

Microgrids for soil stabilization

In the paper by Mercer, et al. (1985) in the inaugural conference on geogrids the year prior, microgrids were proposed for soil stabilization. Figure 5 shows the general situation along with an illustration of the improvement in soil shear strength, after Gregory and Chill (1998), and some aspects of mixing microgrids with the soil to be stabilized. This application is complimentary with the use of continuous and discrete fibers which are also used in soil stabilization, as well as crack retardation in bituminous pavements and concrete floor slabs.

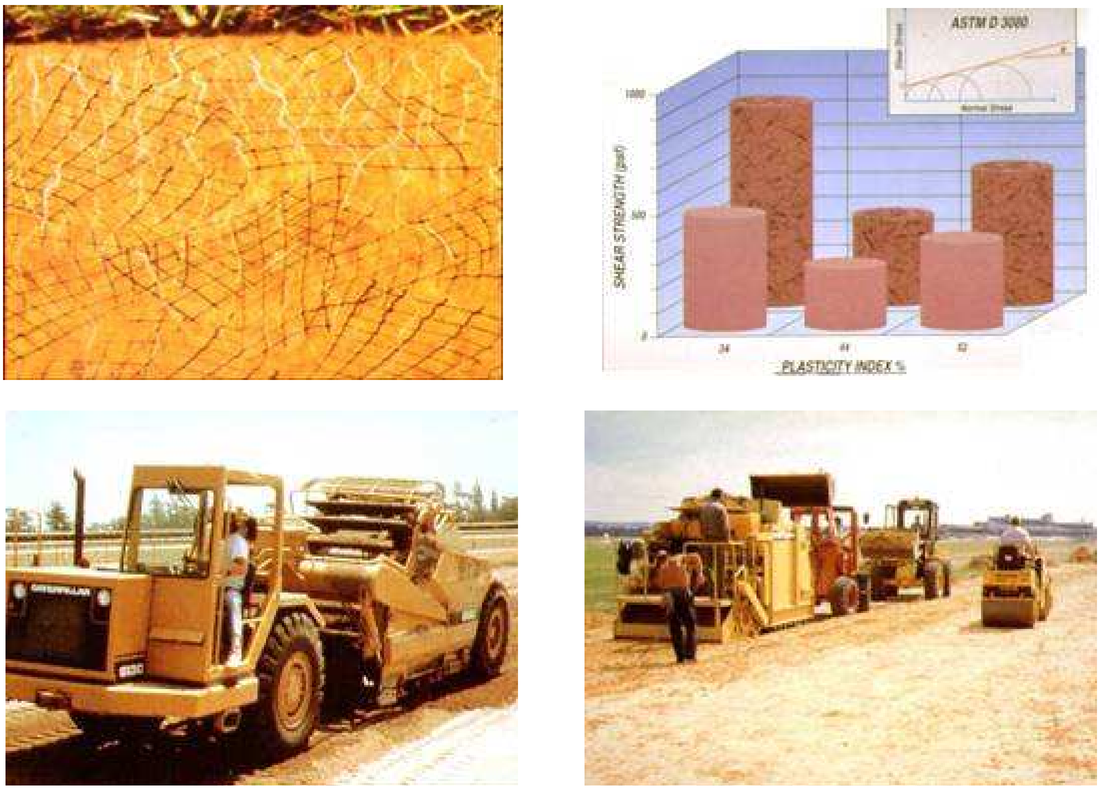
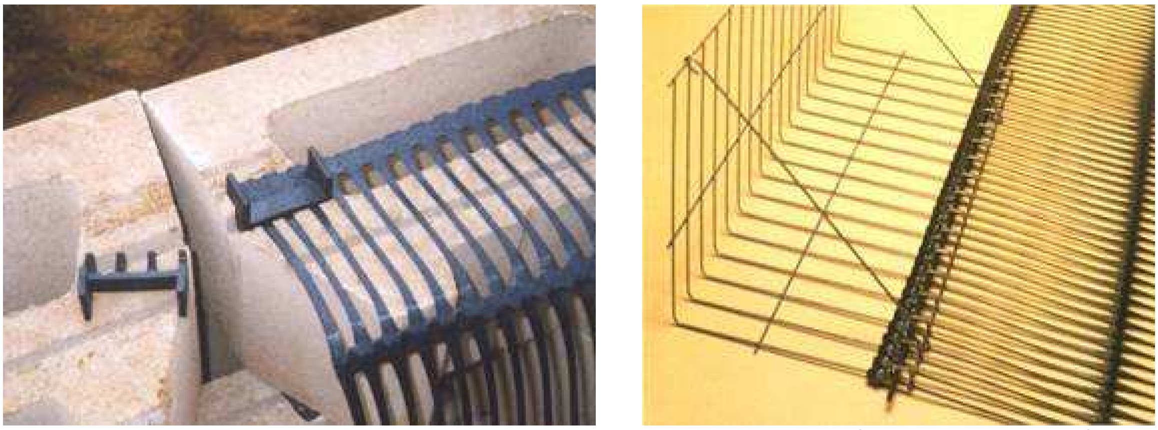


Figure 5. Microgrids used for soil reinforcement

Mechanical connections to wall facings

The issue of connecting different types of primary reinforcement geogrids to retaining wall facings has been somewhat controversial but is a moot point when it comes to a mechanical connection rather than a frictional one.

Two such connection systems are shown in Fig. 6. They use either a plastic "keeper" inserted into a masonry block groove or placed over an upset ridge in welded wire facing (for a green wall facing) and take advantage of high mechanical junction strength between the transverse and longitudinal ribs. Such mechanical connections provide fixity which eliminates potential reinforcement slippage during the service life of the wall.



(a) Mesa® wall block and connection system (b) SierraScape® for welded wire wall facing

Figure 6. Mechanical connections to wall facings

Three dimensional mattresses for foundation reinforcement

For those uniaxial geogrids with full junction strength, the possibility exists to interlace them together and then connect adjacent units to one another with a vertically inserted polymer rod or bodkin. Figure 7 shows the general configuration wherein the mattress that is formed is approximately 1.0 m high; see Edgar (1985) and Paul (1985). It is then filled with gravel and eventually forms a foundation support system used to support embankments and even landfills as illustrated, Floss (ca. 1990).

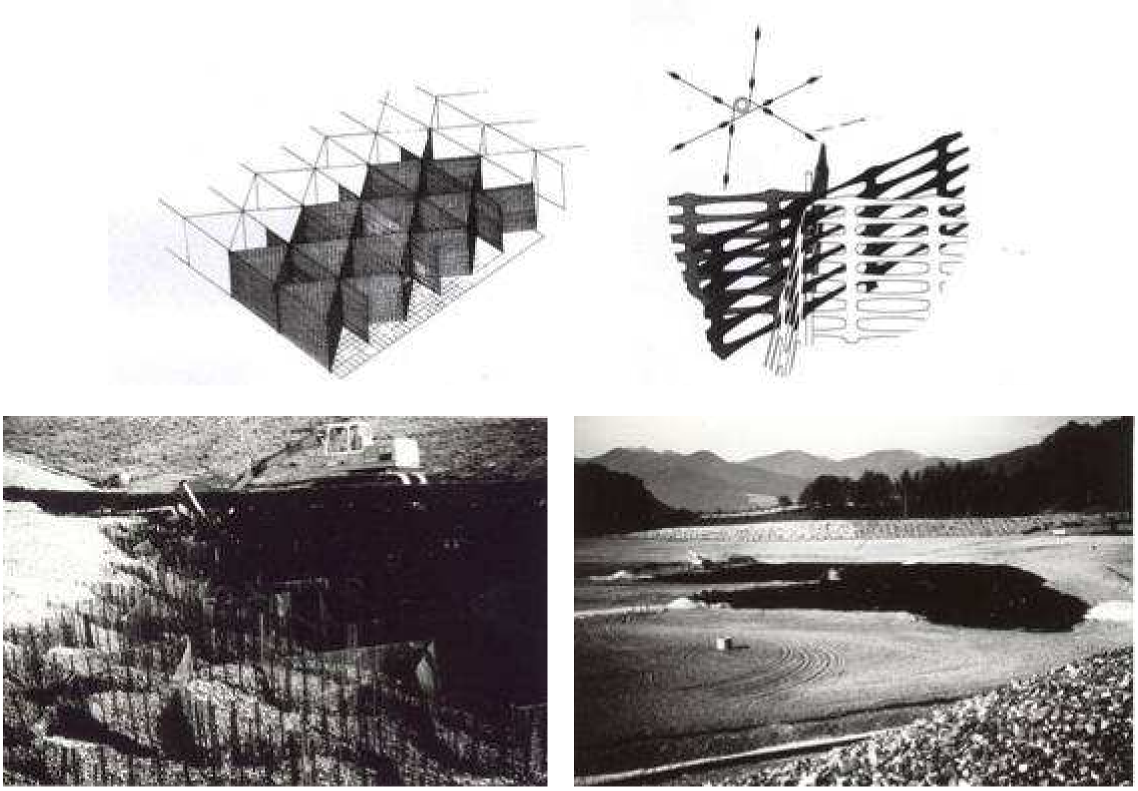


Figure 7. Three dimensional mattresses for foundation support system and used at a landfill in Hasham, Bavaria, Germany

Piggybacking of vertical landfill expansions

There are thousands of old or abandoned solid waste landfills that have no, or inadequate, base liner systems. At many of these sites there exists a need to place additional solid waste. The idea arose to place a liner system above the existing landfill as shown in Fig. 8 with the proposed waste above it. While total settlement of the existing solid waste can be accommodated by adequate curvature, differential settlement is quite another matter. Originally proposed for a site in Long Island, New York, a geogrid beneath the liner system would provide the necessary support. Design-wise, Terzaghi's 1925 arching theory for tunnel stresses in deep soil was utilized by Giroud, et al. (1988). In it the vertical stress on the geogrid reaches a constant value as the overburden becomes large. Even further, there is no longer an effect from surcharge loadings. This can be seen in the relevant equations that follow.

$$\sigma_z = 2\gamma_{ave} R\left[1 - e^{-0.5H/R}\right] + qe^{-0.5H/R} \quad (1)$$

Where σ_z is the vertical stress on the structure or reinforcement layer, γ_{ave} is the average unit weight of material above the settlement area, R is the radius of differential settlement zone, H is the total height above the settlement area, and q is the surcharge loading placed at the ground surface.

Note that for large values of *H* (typically this amounts to $H \geq 6R$) the formula reduces to the following value of constant vertical stress. This then allows for the required tensile stress in the geogrid to be calculated accordingly, Koerner (2005).

$$\sigma_z = 2\,\gamma_{ave}\,R, \text{ and} \quad (2)$$

$$T_{reqd} = \sigma_z R\,\Omega = 2\,\gamma_{ave}\,R^2\,\Omega$$

Also, $T_{allow} = T_{ult}/\Pi\ RF's$

Where T_{ult} is the as-manufactured geogrid's ultimate strength, Ω is the strain criteria, Π RF's are the site specific and product specific reduction factors and finally the factor-of-safety (FS) is calculated as follows:

$$FS = T_{allow}/T_{reqd}$$

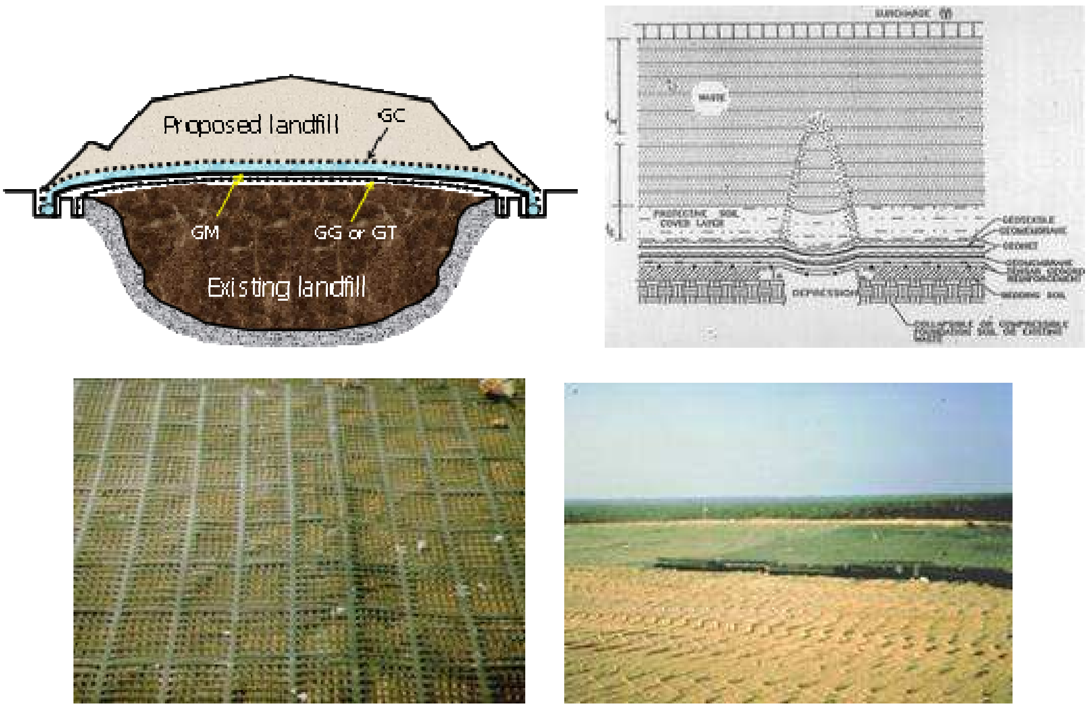


Figure 8. Piggybacking of vertical landfill expansions

Veneer reinforcement

Relatively thin layers of soil placed on slopes have a tendency to slide downward particularly if a geomembrane is located within the cross section. This is clearly the case with solid waste landfills; both for the final cover above the waste mass and the leachate collection layer below the waste until waste is placed in the facility. See Fig. 9 for both situations.

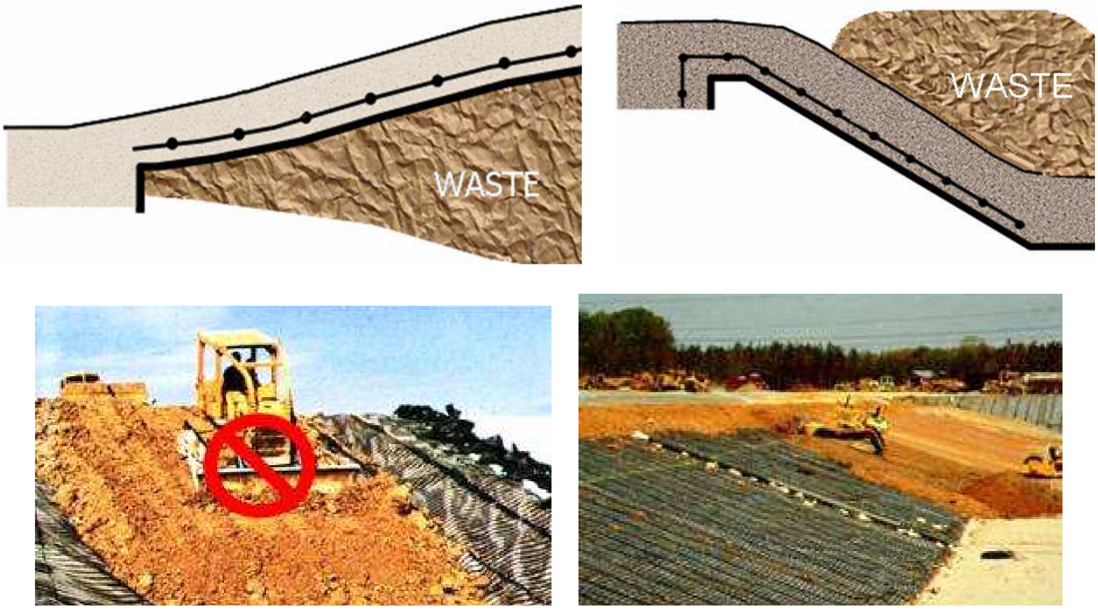


Figure 9. Landfill cover and leachate collection reinforcement scenarios (aka, veneer reinforcement) along with improper and proper placement of soil cover.

Also shown in Fig. 9 is a bulldozer pushing soil down the slope (what not to do) and one pushing soil up the slope (the correct placement orientation). The photographs illustrate a uniaxial geogrid placed on the geomembrane which will act as veneer reinforcement thereby increasing the factor-of-safety considerably. Koerner and Soong (1998) illustrate how the FS-value varies in this situation using a standard example, then variations decreasing and increasing the value. The benefit arising from inclusion of geogrid reinforcement is apparent; see Table 3.

Table 3. Summary of numeric examples given in Koerner and Soong (1998) for various slope stability scenarios

Example No.	Situation or condition	Control FS-value	Scenarios decreasing FS-values	Scenarios increasing FS-values
1	standard example*	1.25		
2a	equipment up-slope		1.24	
2b	equipment down-slope		1.03	
3	seepage forces		0.93	
4	seismic forces		0.94	
5	toe (buttress) berm			1.35-1.40
6	tapered cover soil			1.57
7	intentional veneer reinforcement (using geogrids)			1.57
8	nonintentational veneer reinforcement (using other geosynthetics)			varies; but not recommended!

*30 m long slope at a slope angle of 18.4 deg. with sandy cover soil of 18.4 kN/m^3 dry unit weight, with $\phi = 30$ deg. and thickness 300 mm placed on an underlying geomembrane with a friction angle $\delta = 22$ deg.

Large walls at landfills with exposed face

The construction of large engineered walls at landfills to provide for increase volume for solid waste placement is an existing technology for a quite new application. As seen in Figure 10, the wall facing is exposed although vegetation growth is a help insofar as the lifetime of the biaxial geogrid facing is concerned. Interestingly, wall designers completely discount the steel grid insofar as its lifetime is concerned and instead rely on the polymer geogrid in this regard. As also seen in Figure 10 is that research is ongoing insofar as lifetime prediction using laboratory weatherometers. The data indicates greater than 80% strength retained which, at an approximate correlation factor of 1000 light hours in ASTM D7238 at 70°C, is equivalent to more than 20 years in a hot, dry climate like west Texas, USA.

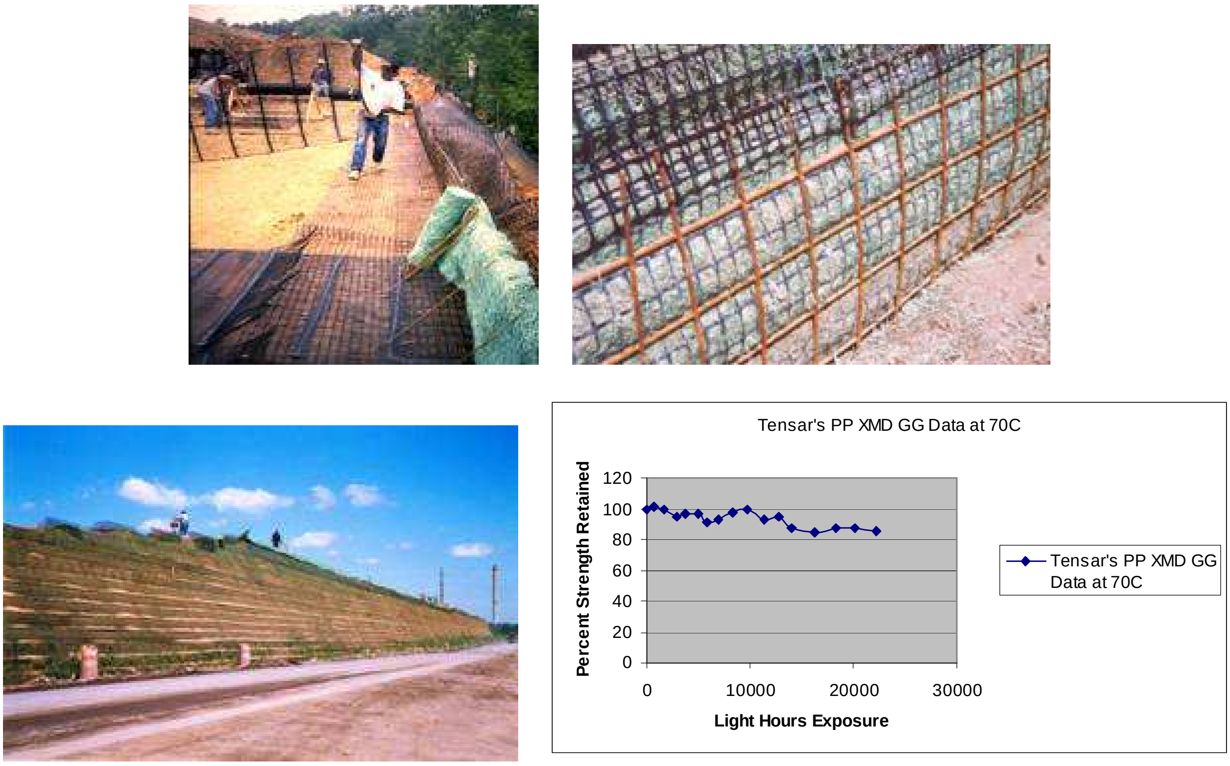


Figure 10. Large engineering berms for increased airspace at landfills

Bridge abutments with footing surcharges

The design and construction of bridge abutments and wing walls using geogrid reinforcement is certainly within the state-of-the-practice at this point in time. What is an advance, however, is to have the superstructure load being imposed on a shallow footing thereby applying a large surcharge load to the abutment wall. Figure 11 shows details of this innovative project which is presently being monitored for its performance, see Abu-Hejleh, et al. (2002).

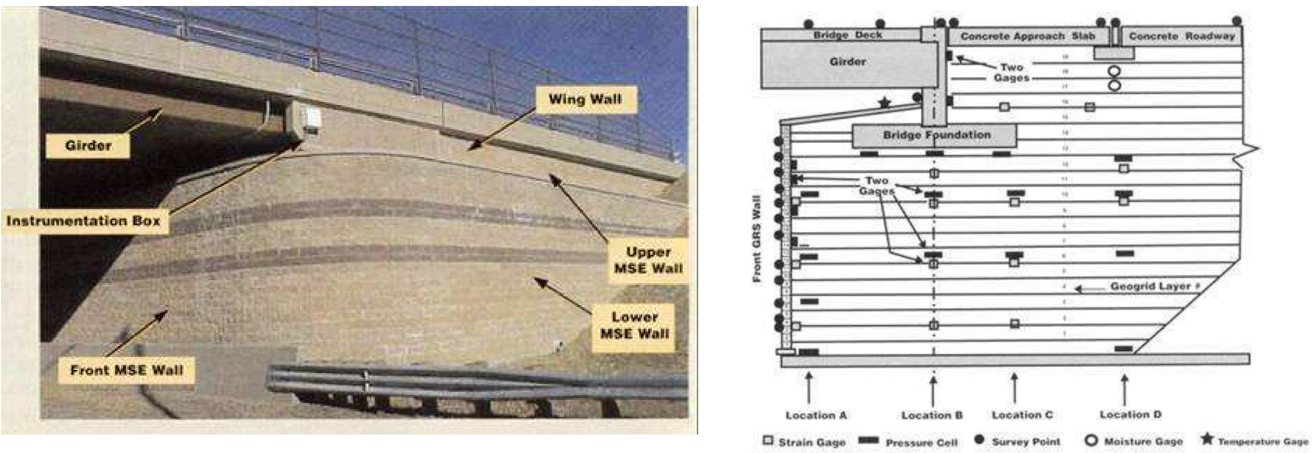


Figure 11. Bridge abutments with footing surcharge using geogrid reinforcement

QUALITY CONTROL TEST METHOD AND PROPOSED GENERIC SPECIFICATIONS

It is the Author's belief that proprietary specifications by individual companies have served the geosynthetics industry (particularly the geogrid industry) quite well in bringing us to the current situation. An approximate worldwide estimate is that geogrid usage is about 100M m^2 and at a cost of about \$2.50/m^2. This represents about \$250M per year. It is estimated to be about 6.7% of the total geosynthetics market. In order to markedly increase this activity in the next 25-years some geosynthetic materials groups have implemented generic specifications; notably geomembranes, geotextiles, geosynthetic clay liners, and geopipe. The Author believes that such generic specifications would beneficially serve the geogrid industry similarly.

To accomplish generic specifications for geogrids one must first identify the critical test properties from a manufacturing quality control (MQC) perspective. Table 4 is offered in this regard for both uniaxial and biaxial geogrids.

Table 4. Various control test methods (necessary to craft a generic specification)

Method	Biaxial	Uniaxial
1. Tensile strength	at 1, 2, 3 % elongation	at failure
2. Junction efficiency	no	yes
3. Torsional rigidity	yes	no
4. Pullout resistance	yes	yes
5. Interface shear	yes	yes
6. Aperture size	yes	no
7. Ultraviolet stability	all resins	all resins
8. Oven aging	PE & PP	PE & PP
9. Carbon black	PE & PP	PE & PP
10. Molecular weight	PET	PET
11. Carboxyl end group	PET	PET

The above listed test methods are all standardized by ASTM, ISO, or GRI and are readily accessible. Of course, the "devil is in the details" insofar as numeric values are concerned, but the Geosynthetic Institute has (unsuccessfully) attempted to craft such specifications. Table 5(a) for biaxial geogrids and Table 5(b) for uniaxial geogrids have both been through numerous iterations but with robust objections by usually more than one manufacturer. Thus, at this point in time they are offered as draft specifications but be assured that the designer community is highly desirous of such generic specifications for geogrids.

Table 5(a). Suggested standard specification for biaxial geogrids in permanent reinforcement applications (e..g, pavements and foundation bases)

Property	**Test Method (ASTM or GRI)**	**Units**	**Class 1**		**Class 2**		**Class 3**		**Test Frequency**
			MD	XMD	MD	XMD	MD	XDM	
Tensile Strength @ 1%	D6637	kN/m	4.0	5.0	3.5	4.0	2.5	4.5	MARV
Tensile Strength @ 2%	D6637	kN/m	8.0	9.0	5.0	7.5	4.0	6.5	MARV
Tensile Strength @ 5%	D6637	kN/m	17.0	19.0	10.0	16.0	8.0	13.0	MARV
Ultimate Tensile Strength	D6637	kN/m	25.0	29.0	16.0	26.0	11.0	17.0	MARV
Pullout Interaction Coef.(1)	D6706	n/a	0.8	0.8	0.8	0.8	0.8	0.8	yearly
Direct Shear Friction(1)	D5321	deg	30	30	30	30	30	30	yearly
Aperture Size	-	mm	15-75	15-75	15-75	15-75	15-75	15-75	yearly
Torsional Rigidity	GG9	mm-kg/deg	60		30		15		yearly

Durability			
Oven Aging (90 days)	D5721/GG1	PE and PP	≥ 75% retained
Carbon Black (range)	D4218	PE and PP	0.5 to 3.0%
UV Stability (500 hrs.)	D7238/GG1	all polymers	≥ 70% retained
Mol. Weight (min.)	GG7	PET	≥ 25,000 gm/mol
CEG (max.)	GG8	PET	≤ 30 m mol/kg

Notes:
MD – machine, or roll, direction
XMD – cross machine, or cross roll, direction
n/a – not applicable, i.e., dimensionless
Class 1 – most severe conditions
Class 2 – intermediate
Class 3 – least severe conditions
MARV – minimum average roll value
(1) Test conditions are using well-graded concrete sand at optimum moisture control and 95% density under 50 kPa normal pressure.

Table 5(b). Suggested standard specification for uniaxial geogrids in permanent reinforcement applications (e.g., reinforced walls and steep soil slopes)

Property	Test Method (ASTM or GRI)	Type I (Monolithic PE and PP)	Type II (a) (Coated PET Yarns)	Type II(b) (Coated PVA Yarns)	Type III (PET Rods/ Straps)	Test Frequency
Allowable Tensile Strength (min.)(1)	D6637					
(a) least strength requirements		10 kN/m	10 kN/m	10 kN/m	10 kN/m	MARV
(b) ↑		20 kN/m	20 kN/m	20 kN/m	20 kN/m	MARV
(c)		30 kN/m	30 kN/m	30 kN/m	30 kN/m	MARV
(d)		40 kN/m	40 kN/m	40 kN/m	40 kN/m	MARV
(e) ↓		50 kN/m	50 kN/m	50 kN/m	50 kN/m	MARV
(f) highest strength requirements(2)		60 kN/m	60 kN/m	60 kN/m	60 kN/m	MARV
Junction Efficiency (MD)	GG1/GG2	80%	10%	10%	30%	year
Interaction Coef. (3)	GG5	0.8	0.8	0.8	0.8	year
Direct Shear (3)	D5321	30 deg.	30 deg.	30 deg.	30 deg.	year
Default Reduction Factors(4)						
Creep (RF_{CR})	GG4	2.8	1.9	1.5	1.9	formulation
installation damage (RF_{ID})	GG4	1.3	1.3	1.3	1.3	formulation
chem/bio degradation (RF_{CBD})	GG4	1.2	1.2	1.2	1.2	formulation
Durability						
Oven Aging (90 days.)	D5721/GG1	75%	n/a	75%	n/a	year
Carbon Black (range)	D4218	0.5-3%	n/a	n/a	n/a	year
UV Stability (500 hrs.)	D7238/GG1	70%	70%	70%	70%	year
Mol. Weight (min.)	GG7	n/a	25,000 gm/mol	25,000 gm/mol	25,000 gm/mol	year
CEG (max.)	GG8	n/a	30 m mol/Kg	n/a	30 m mol/Kg	year

Notes:
(1) -To determine the comparable ultimate tensile strength per ASTM D6637 for each category, these allowable strengths should be multiplied by the product of the appropriate reduction factors as given in the table (unless less conservative values can be justified).
(2) -Still higher strength geogrids are generally available from manufacturers on a product-specific basis.
(3) -Test conditions are using well-graded concrete sand at optimum moisture control and 95% density under 50 kPa normal pressure.
(4) - These default values are to be used unless manufacturer has product-specific and/or site-specific data justifying lower values.
n/a = Not applicable

CONCLUSIONS

The growth and use of geogrids in the 25-years since the original conference has been nothing short of "spectacular". This statement applies not only to the manufacturing of the products themselves but equally as much to the innovative geogrid application areas; of which eight topics were offered in this paper. Applications, of course, require a geogrid design methodology which has been offered by geogrid manufacturers in stark contrast to other types of geosynthetics.

The next 25-years are, of course, conjecture. To continue as is, however, is often not the best company philosophy since complacency is an ever-present danger. This paper has offered a somewhat daring change in that generic specifications could open up an even more meaningful geogrid market penetration than the past spurred by engineering designers many of which feel constrained by proprietary specifications. Such a shift in strategy among geogrid manufacturers is indeed unsettling but should have the effect of growing the market considerably. In so doing, individual consultants could have their own in-house geogrid champion and not be limited by a sole-product association.

Of course, time will tell in this regard and whatever is the decision going forward, the Geosynthetic Institute is willing to participate in every way possible.

REFERENCES

Abu-Hejleh, N., Zornberg, J.G. & Wang, T. (2002). Monitored displacements of unique geosynthetic reinforced soil bridge abutments. Geosynthetics International, 9 (1), 71-95.

Edgar, S. (1985). The use of high tensile polymer grid mattress on the Musselburgh and Portobello bypass. Proceedings of Conference on Polymer Grid Reinforcement, Thomas Telford Ltd., Publisher, London, 103-111.

Floss, R. ca. 1990. personal communication.

Giroud, J.-P., Bonaparte, R., Beech, J. F. & Gross, B. A. (1988). Load carrying capacity of a soil layer supported by a geosynthetic over a void. International Geotechnical Symposium on Theory and Practice of Earth Reinforcement, Fukuoka, Balkema, Rotterdam, 185-190.

Giroud, J.-P., Ah-Line, C. & Bonparte, R. (1985). Design of unpaved roads and trafficked areas with geogirds. Proceedings of Conference on Polymer Grid Reinforcement, Thomas Telford Ltd., Publisher, London, 116-127.

Gregory, G. H. & Chill, D. S. (1998). Stabilization of earth slopes with fiber reinforcement, Proceedings 6th International Conference on Geosynthetics, Atlanta, IFAI Published, 1073-1078.

Koerner, R. M. (2005). Designing With Geosynthetics, 5th edition, Pearson Prentice Hall, Upper Saddle River, New Jersey, 796 pgs.

Koerner, R.M. & Soong, T-Y. (1998). Analysis and design of veneer cover soils. Proceedings Sixth International Conference on Geosynthetics, Atlanta, IFAI, 1-26.

Mercer, F.B., Andrawes, K. Z., McGown, A. & Hytiris, N. (1985). A new method of soil stabilization. Proceedings of Polymer Grid Reinforcement Conference, Thomas Telford, London, 244-249.

Paul, J. (1985). Economics and construction of blast embankment using tensar geogrids. Proceedings of Polymer Grid Reinforcement Conference, Thomas Telford, London, 191-197.

Sarsby, R. W. (1985). The influence of aperture size/particle size on the efficiency of grid reinforcment. Proceedings of the 2nd Canadian Symposium on Geotextiles and Geomembranes, Edmonton, Geotechnical Society of Edmonton, 7-12.

Terazhi, K. (1925). Erdbaumechanik Auf Bodenphysikalischer Grundlage, Franz Deuticke Publ., Leipzig, 399 pgs.