We Will See a Significant Growth in Geosynthetic Use if …

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ABSTRACT

Geosynthetics continue to be underutilized in civil engineering projects despite the construction cost and schedule advantages, availability of a wide range of geosynthetic products, and established design methodologies. Many civil engineers remain unfamiliar with geosynthetics or geosynthetic-centric systems and their benefits. Geotextiles for use in separation, drainage, lightweight stabilization, and environmental applications (liners) have become commodity products and are widely used. However, other geosynthetic products require that geotechnical and geosynthetic engineers, product manufacturers, and suppliers spend significant effort attempting to educate civil engineers and contractors about geosynthetic benefits. When presenting geosynthetic products and solutions that could economically solve complex and expensive problems, geosynthetic specialists are often met with skepticism, and thus the potential of geosynthetics remains unrealized.

This paper presents the opinions of the four authors, each of whom was challenged to finish the sentence: "*We will see a significant growth in geosynthetic use if …*" Discussion is presented from the point of view of each author, who are geosynthetics specialists from consulting, academia, contracting, and manufacturing. The paper presents ideas that are encouraged to be adopted by the geosynthetic industry at large (i.e. university engineering programs, product manufacturers and suppliers, consulting engineers, contractors, and owners) to increase geosynthetic use in civil engineering projects.

1 INTRODUCTION

It has been more than a half century since geosynthetics were introduced; more than 4 decades since geosynthetics were widely adopted in separation, stabilization, drainage, wastewater, and landfill applications (cushions and liners); and approximately 30 years since the creation of the International Geosynthetics Society (IGS) on 20 November 1983 (Zornberg 2013) and the publication of the first edition of *Designing with Geosynthetics* (Koerner, 1986). A variety of geosynthetic products are available from dozens of manufacturers, as exemplified in the annual *Geosynthetics Specifier's Guide* (Industrial Fabrics Association International, 2013). Nonetheless, although geosynthetics continue to be considered by many in the civil engineering industry as new products, civil engineers remain unfamiliar with geosynthetics or geosynthetic-centric systems and their benefits, and geosynthetics continue to be underutilized.

This situation occurs despite the construction cost and schedule advantages offered by geosynthetics, the availability of a wide range of products, and the growing number of established design methodologies. Geosynthetic market penetration is less than what it should be, despite the long history; the development of quality assurance test procedures and ASTM International and other standards; availability of design manuals and training courses; and evidence provided by thousands of successful and varied geosynthetic-inclusive projects.

Why? And how should the geosynthetics industry proceed to increase awareness of the benefits and cost savings that could be realized by increasing geosynthetic use? The geosynthetics industry includes manufacturers, suppliers, contractors, designers, researchers, and academics. We are all in this together.

The answer to this question is addressed in this paper by authors from diverse segments of the geosynthetics industry: from engineering consulting to academia to contracting to manufacturing. Overall, the authors' consensus is that we will see a significant growth in geosynthetic use if:

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- We significantly increase geosynthetic undergraduate education and exposure for all civil engineers.
- We provide *integrated solutions* that include geosynthetics, instead of continuing the industry focus on selling individual geosynthetic products or product lines.
- We create complete design methods for a broader range of applications than are currently available; take a systems approach with integrated and complete solutions for various applications; and create, organize and promote the necessary associated design methods.

On the other hand, there was no clear consensus on whether we will see a significant growth in geosynthetic use if:

- We provide geosynthetic systems that are less proprietary, are included in national specifications and standards, and change from proprietary products/systems to more commoditized products/systems.

or instead:

- We prioritize and continue to strive for ingenuity in the development of new geosynthetic products, applications and systems, resulting in highly engineered products that distinguish themselves from commoditized products.

2 THRUST ON GEOSYNTHETICS EDUCATION

2.1 The Concept

We will see a significant growth in geosynthetic use if we manage to significantly increase the geosynthetic education and exposure for prospective and practicing civil engineers (all of them! … from structural to environmental to hydraulic to geotechnical engineers). In the words of the Boyer Commission on Educating Undergraduates in the Research University: *"Technology is never neutral. It is the role of universities to make technology positive"* (Boyer Commission 1998). The Geosynthetics community should fully endorse bringing geosynthetics technology not only into professional circles and graduate educational programs but, also, into every civil engineering undergraduate program.

2.2 University Programs

There is growing consensus within the geosynthetics community that education focus should be on offering basic information on geosynthetics, even if just a single one hour-class within a 4 year-program, to *all undergraduate* civil engineering students. In this way, all future geotechnical, structural, environmental, transportation, construction, and hydraulic engineers will have at the very least heard the term "geosynthetics" before they graduate. Providing a basic exposure to geosynthetics to all civil engineering undergraduate students is a particularly challenging task. This is because, facing ever increasing technical challenges and a vastly expanded technical base, civil engineering programs are confronted with the dilemma posed by the need of limiting the range of material that can be covered while, at the same time, meeting the needs of young engineers. Young engineers should be able to integrate an often fragmented accumulation of analytical tools before confronting real projects as practicing engineers.

The dilemmas posed by tight undergraduate curricula do not mean that new materials cannot be incorporated into the curriculum. On the contrary, new materials can and often must be included to make the courses more relevant and effective. Consequently, the topic of geosynthetics has as good as a chance as most other *new* topics to be included. Presentation of volumes of material in short periods of time requires creativity. For example, recent advances in digital image technology can bring invaluable new resources to instructional activities. Needless to say, use of visual aids has traditionally been a significant component of engineering instruction. This is particularly relevant in upper level undergraduate design courses and graduate courses, which strive to synthesize in minutes of classroom instruction the years of effort involved in the conceptualization, analysis, design, construction, and performance monitoring of engineering projects. New approaches such as digital image technology can bring powerful learning experiences to our classrooms. For example, presentation of failure of a geosynthetic-reinforced structure can be illustrated using minutes-long digital video clips.

Recent initiatives are being implemented to fulfill this educational objective under the leadership of the International Geosynthetics Society, the Geosynthetics Materials Association, and the Geosynthetic Institute. The overall goal is to "Educate the Educator" on how to introduce geosynthetics into undergraduate curricula, as they constitute a comparatively new, promising technology within civil engineering. Figure 1 shows the program of a recent "Educate the Educator" program, recently conducted in Cieszyn, Poland to offer professors in civil engineering the educational material they need in order to, in turn, offer the basics of geosynthetics education to undergraduate students (Kawalec 2014). This experience built on an earlier successful "Educate the Educator" experience conducted in Cordoba, Argentina (Montoro 2013). Inspection of the program provided in Figure 1 reveals that the main objective of the entire program was to facilitate the incorporation of ONE class (at least) on geosynthetics. This one class was the focus of the entire first quarter of the 2 day-programs offered in Poland and Argentina. The remainder three quarters of the program was indeed aimed to provide additional geosynthetics background and motivation to engineering professors, many of whom were exposed for the first time to a formal training on geosynthetics technology.

	Monday, June 23th			Tuesday, June 24th		
	Time	**Topic**	**Speaker**	**Time**	**Topic**	**Speaker**
Morning	**8:00 8:15**	Opening -	Dr Jacek Kawalec	**8:00 9:00**	1. Basic class about the application of geosynthetics materials in landfill liners and covers and in containment facilities.	Dr Jorge Gabriel Zornberg
	8:15 8:30	1. Teaching geosynthetics at undergrad classes. Objectives and Philosophy of the "Educating the Educators" program	Dr Jorge Gabriel Zornberg	**9:00 9:30**	2. Polymers properties for containment applications.	Dr Jorge Gabriel Zornberg
	8:30 9:45	2. Basic class on types and functions of geosynthetic materials	Dr Jorge Gabriel Zornberg	**9:30 9:45**	IGS Corporate Member presentation Polish milestones geosynthetics projects - sections of A1 and A2 motorways.	Dr Janusz Sobolewski
	9:45 10:00	3. Discussion of the basic class and how to incorporate it in the current civil engineering curricula – SK+CZ+PL experience	Dr Jacek Kawalec	**9:45 10:15**	Coffee Break	
	10:00 10:15	IGS Corporate Member presentation: "Comparision of designing methods commonly being used in Poland (EBGEO, BS8006)"	Dr Janusz Sobolewski	**10:15 11:15**	3. Quality Control/Quality Assurance during installation of geosynthetic materials.	Dr Madalena Barroso
	10:15 10:45	Coffee Break		**11:15 12:15**	4. Drainage systems in geoenvironmental applications.	Dr Jorge Gabriel Zornberg
	10:45 11:45	4. Seminar on recognizing different geosynthetic materials	Dr Madalena Barroso	**12:15 12:45**	5. Application of geosynthetic in Hydraulic structures and for erosion control problems.	Dr Madalena Barroso
	11:45 12:45	5. Basic properties and related tests on geosynthetic materials.	Dr Madalena Barroso	**12:45 13:00**	Discussion	
	12:45 14:30	Lunch break		**13:00 14:30**	Lunch break	
Afternoon	**14:30 15:45**	6. Basic class on geosynthetic reinforced walls	Dr Erol Guler	**14:30 15:30**	6. Geosynthetics in railway infrastructure.	Dr Erol Guler
	15:45 16:45	7. Embankments on soft soils	Dr Erol Guler	**15:30 16:15**	7. Geosynthetic in roads infrastructure.	Dr Erol Guler
	16:15 16:30	IGS Corporate Member presentation: Case study of practical use of the geosynthetics in roads.	Mr Konrad Rola-Wawrzecki	**16:15 16:45**	8. Geosynthetic reinforced pavements.	Dr Jorge Gabriel Zornberg
	16:30 17:00	Coffee Break		**16:45 17:00**	IGS Corporate Member presentation: "Non-reinforcing geogrids for stabilisation of unbound granular layers by way of interlock with aggregate	Dr Jacek Kawalec
	17:00 17:45	8. Advanced topics on geosynthetic reinforced walls and slopes	Dr Erol Guler	**17:00 17:30**	Coffee Break	
	17:45 18:45	9. Case history of geosynthetics. (National IGS Chapters case presentations, 20 min. each)	PSG-IGS 20min IGS-CZ 20min IG-SK 20min	**17:30 18:30**	9. Case history of geosynthetics. (National IGS Chapters case presentations, 20 min. each)	PSG-IGS 20min IGS-CZ 20min IG-SK 20min
	18:45 19:00	10. Discussion about the implementation of the discussed topics in the current civil engineering curricula		**18:30 19:30**	10. Final discussion on the strategies to incorporate geosynthetic topics in the actual civil engineering curricula.	
	20:30	Gala Dinner		**19:30 19:45**	11. Closing ceremony	

Figure 1: Example of a program to "Educate the Educators," geared towards introducing geosynthetics in undergraduate civil engineering programs.

2.3 Conclusion

Facing ever increasing technical challenges and a vastly expanded technical base, civil engineering programs are confronted with the dilemma posed by the need of limiting the range of material that can be covered while, at the same time, meeting the needs of young engineers who should be able to integrate an often fragmented accumulation of analytical tools before confronting real projects as practicing engineers. This dilemma does not mean that new course materials cannot be incorporated into the curriculum. On the contrary, new materials can and often must be included to make the courses more relevant and effective. Geosynthetics constitute a comparatively new technology within civil engineering. Geosynthetics must be introduced at the undergraduate level, and geosynthetic education made broadly available to practicing civil engineers.

3 STANDARDIZATION AND COMMODITIZATION

3.1 The Concept

We will see a significant growth in the geosynthetics industry as geosynthetics and systems that incorporate geosynthetics are recognized as being less proprietary, facilitating in this way their inclusion in national specifications and standards, and ultimately becoming more commoditized.

In the initial phases of marketing new products, significant and expensive effort is expended by manufacturers to encourage adoption of their new and innovative products. The marketing by manufacturers often include design guidance and proprietary specification, which is exclusive to the products being marketed. Development of industry or academically sponsored design procedures often replaces the initially proposed procedures and often incorporates generic geosynthetic properties. As the design procedures become more broadly adopted and the performance benefits are better understood, regulatory and national code bodies develop generic specifications. The generic specifications typically minimize non-critical product properties often used to specify proprietary products thus opening the market to more sources for the products. The adoption of generic, non-proprietary, nationally recognized, specifications typically leads to maturing of the market and commoditizing of the products. As this process of market maturing develops, additional manufacturers enter the market, availability increases, geosynthetic prices and margins fall and the products become main-stream, every-day items which are incorporated in the normal course of construction without strong marketing efforts by manufactures.

3.2 The Detriment of Proprietary Geosynthetic Specifications

Increased use of geosynthetics and utilizing system approaches to designing with geosynthetics is a true goal of our industry. The use of generic, near-commodity geosynthetic products that are incorporated into engineering systems is good and will enhance the growth of geosynthetic use. Unfortunately, geosynthetics used in systems often are initiated by manufacturers proposing the use of their unique products. Typically, the products are specified with proprietary characteristics which minimize and slow the growth of geosynthetics due to increased product/system cost and dis-incentive for potentially competing manufactures to invest in development of similar or “equivalent” products.

Manufacturers of proprietary products like the system approach because they can lock in products by specifying properties of the geosynthetic components that may be unique to their systems but may not have proven or accepted merit in how it performs in the system. Once the products are “locked in” via the specification, the ability to command a higher price and enhanced margins for the product are nearly assured. The end result is a system having an artificially high price. Typically, only the manufacturers that enjoy the benefits of having the proprietary position will promote the application or system and hence growth of the system and proprietary products used in the system are slow to develop.

The design engineer likes to have proprietary products incorporated into systems they design because they have gained a high level of confidence that the product proposed in the system will be supplied with the same properties and function as intended. Specifying a proprietary product minimizes the potential that an alternative product considered by some to be “similar” or “equivalent” will be supplied, which may not incorporate the “critical” properties relied on by the designer to ensure proper performance of the system – or possibly even be detrimental to the performance of the system. By specifying proprietary products, the design engineers’ exposure to liability by having “substitute” products that are not suitable for the proposed application is minimized and the confidence that the system installed will contain the products and properties that were intended and incorporated in the design is nearly assured. Again, the proprietary specification increases the cost of the geosynthetic system and limits the growth for the application and products used in the system.

Contractors and owners often hold opinions that differ from those held by design engineers and manufacturers relative to the use of proprietary products in specifications. Owners and contractors typically dislike proprietary specifications as they recognize that their ability to shop for the best product at the most reasonable price is limited and hence adversely affects their budgetary needs. Hence, owners and contractors typically avoid systems that incorporate proprietary products in their systems thus limiting the growth of geosynthetics used in the systems.

3.3 Geosynthetics Sales Cycle

3.3.1 Lightweight non-wovens

The product development and life cycle of geosynthetics as construction materials are in varying stages of maturity. Lightweight non-wovens were among the first geosynthetics to be marketed into construction applications including filtration, drainage, stabilization and separation. During their development cycle, the manufacturers expended huge efforts to establish their particular products superior characteristics and touted the benefits of manufacturing type, opening size, thickness, strength, burst, elongation, permeability, permittivity, and any other property that would provide a specification or perceived use advantage over competitors products. During this period, each manufacturer touted the benefits of their products and promoted specifications highlighting their product strengths. During this development time period, manufacturing volumes were relatively low, efforts expended to market the products were high and the costs of the products to the end users were high. Due to the efforts of the manufacturers and marketers, several design standards and academic studies were sponsored by manufacturers to speed their acceptance and enable their incorporation into systems for drainage, cushions, filtration and separation aids. The efforts and cost required to market a particular manufacturers' product into specific applications and systems was justified by near-proprietary specifications and the high probability that a sale with respectable margins would follow. However, as the products became more widely accepted, specifications became more generic and differentiation amongst products manufacturer by competitors decreased, the commodity nature of the product category grew, thus leaving the supply/fulfillment task to the low-cost producer with the best distribution coverage.

After significant use, acceptance of performance credibility by the engineering community, establishment of testing standards for index properties as well as demonstration projects that showed the useful nature of these products, national standards such as Task Force 25 (TF-25) were developed. These standards adopted primarily generic specification criteria for products to be used in specific applications. The adoption by TF-25, a national standard perceived to have been developed by a technically oriented, unbiased group, nearly instantly enabled the national DOT network to adopt their use and implement specifications and standards that could be easily and efficiently put into service for public works projects. Since that time, the standards have been refined, quality control manufacturing programs have been implemented by the suppliers, and a national testing program (NTPEP) has been developed to qualify and recognize products that meet the minimum standards set forth by certain national standards.

Such market maturity dis-incentivizes the manufacturers to invest resources to differentiate their products from those of competitors' but rather to manufacture product conforming to the national standards. Manufacturers' efforts shift to reducing manufacturing costs, expanding distribution outlets and producing quality materials that meet the required properties. During this time is when the use of geosynthetics for a particular application matures and products approach near-commodity status.

Lightweight non-woven and woven fabrics used to separation and drainage are examples of geosynthetics that have become commodity products. Products meeting the specification requirements of national standards and listed by NTPEP, are used on nearly every construction site, and are typically considered to be "interchangeable" amongst competitive suppliers. This process has taken nearly 30 years.

3.3.2 MSE Walls

On the other end of the spectrum, but progressing toward commodity status, are geogrids used for MSE wall construction. Being at an earlier stage of maturity within the geosynthetics community and having a higher perceived "liability", product-specific, system design is more common, but it is gradually slipping towards a material property, non-product-specific, system solution. Utilization of SRW/MSE design incorporating product specific connection/shear results have better ensured that systems designed with product-specific geosynthetics (geogrids in most cases) will be constructed with the products incorporated in the design rather than being substituted for a similar product from an alternative manufacturer. In this scenario, being the low-cost producer and having the best local distribution is second to having reasonable pricing and good relationships with the specifying community. At the current time, MSE systems constructed using SRW blocks is still a true proprietary geosynthetic system solution approach.

A recent development that may change the system design approach and move geosynthetics used in SRW systems to commodity status is the GRS (geosynthetic reinforced soil) system currently proposed by the FHWA Every Day Counts Initiative. In this system, the FHWA has taken the concept of SRW's designed as a unique combination of geosynthetic-facing system approach to a more generic facing-geosynthetic analysis.

The current tie back wedge design methodology complete with product specific geosynthetic/block facing connection criteria, soil-geosynthetic interaction criteria, and detailed geosynthetic time-dependent load strain documentation is being replaced with a more frequent distribution of reinforcement having simple polymer composition and ultimate strength criteria requirements of the geosynthetics used in the "design" process. Without commenting on the merits of the GRS design philosophy, it has substantially weakened the marriage between product-specific selection in the retaining wall design process in favor of more generic, simple block and geosynthetic properties. The basic properties of the block simply include compressive strengths and a few durability criteria. On the geosynthetic side, the primary specification criteria include only polymeric composition and ultimate strength. While it can be argued that this is still a system approach to a wall design (in this case it's a bridge abutment), it loosens the bond between unique product characteristics of the construction materials used in the design in favor of simplicity and more closely spaced geosynthetics. From a manufacturing and marketing perspective, the GRS philosophy moves the marketing efforts away from product-specific, innovation in product improvements to a commodity, low-cost production process that provides a product that "meets the spec".

3.3.3 Base Reinforcement/Subgrade Stabilization

Somewhere in between the above two scenarios is the base reinforcement/subgrade stabilization applications. It has been long recognized that most geotextiles will provide the functions of separation and subgrade stabilization but it has been hotly debated how much stabilization is provided and what polymeric composition and structural form of geosynthetic is best (i.e. woven or non-woven fabrics or geogrids). As a result of excellent marketing, strong patents, laboratory and field evaluations and empirical evaluations, hotly debated solutions for pavement thickness reductions, enhanced service lives and superior performance have been the fodder of many debates between those promoting the various product variants used in this large market sector.

In the case of patent-protected product variants, the manufactures often were able to reap the benefit of their excellent marketing and dollars expended to promote the use of the protected products in systems that were designed and specified with unique products that would complete the specified system.

In the case of the nonpatent-protected products, the efforts expended to get a "pseudo commodity" product specified in a reinforcement system, typically resulted in the sale going to the low-cost producer and most active supplier in the particular market – hardly a motivation for product development and promoting a system solution for their non-unique product.

3.4 Conclusion

Geosynthetics incorporate a broad range of products used for many applications and systems. The growth and acceptance of geosynthetics are influence by the natural progression of product market life cycles. The growth of the geosynthetics community will follow the market maturing process common to all products. As the use of geosynthetics and geosynthetic-inclusive systems increase, greater understanding of required specification properties and design standards are developed and extraneous, proprietary specifications are eliminated. For geosynthetics used as a component in larger *systems*, increased acceptance and use comes as: (1) design procedures incorporate specification criteria that are generic and exclusive of proprietary aspects, (2) regulatory/governmental agencies adopt standards for their use, and (3) testing/certification standards are developed to qualify the products. Growth of geosynthetics to commodity status will eventually occur as it follows the normal market product life cycle that starts with manufacturer innovation.

4 INTEGRATED SYSTEMS AND SOLUTIONS

4.1 The Concept

We will see a significant growth in geosynthetic use if we provide *integrated solutions* that include geosynthetics, instead of continuing the industry focus on selling individual geosynthetic products or product lines. We will see a significant growth in geosynthetic use if we convey to owners, designers, and contractors the overall *system* benefits, cost savings, schedule improvement, and risk reduction provided by using geosynthetic products in a project. Here, an *integrated solution* is defined as a solution in which the geosynthetic and other project components are complementary, with the overall system designed to take advantage of the features of each component and *system* is defined as a set of individual components which interact to form an integrated whole, i.e., the complete constructed project.

Few project owners set out with the goal of installing a geocomposite drainage system, building an MSE retaining wall, installing a geosynthetic reinforced pavement, or using the latest in geo-tube technology. Instead, the owners may want a building (that happens to require drainage), need a road (that happens to require a retaining wall or embankment on soft ground), desire a parking lot on a lower quality soil site, or wish to reduce shore erosion. The geosynthetics are not the focus of the project, but provide construction, cost, or schedule benefits, or reduce project risks. The geosynthetics are part of a *system* or *integrated solution* to achieve the desired end goal.

Primary motivators for adopting any technology are cost, which includes constructability and schedule (because time is money), and risk reduction. Engineering for a project should consciously identify and, to the extent possible, quantify the cost and risks of alternative approaches and technologies. If the geosynthetics industry is to broadly increase penetration into market segments, then the manufacturers, suppliers, engineers, and contractors must collectively present quantitative cost, schedule, and risk information about geosynthetic-inclusive solutions to those less familiar with the products and potential applications. The benefits that geosynthetics bring to the projects must be clearly demonstrated. Decision matrices that present and allow ready comparison of factors related to alternative designs may be key to this process.

While it may occasionally be the case, simply including geosynthetics in a project is unlikely to be sufficient to, in and of itself, result in efficient design or construction. Extra value can be realized by considering all the benefits geosynthetics can provide, e.g., (1) taking advantage of the tensile capacity of reinforcement geosynthetics to reduce lateral loads on structures, and thereby reducing structure costs; (2) reducing fill weight on buried structures by using drainage geocomposites and lightweight fill, and thereby reducing construction traffic and structure costs; and (3) incorporating reinforcement geosynthetics in pavement sections, thereby reducing excavation and fill volumes and pavement cost, and improving pavement life-cycle performance.

4.2 Examples of Integrated Solutions

4.2.1 Drainage geocomposite

Geosynthetic drainage geocomposites are thin, about 9 to 25-mm thick, yet transport more water under similar head conditions than multi-inch or multi-feet thick layers of drainage aggregates. Where drainage is to be provided below a structure foundation slab, for example, using a geosynthetic drainage geocomposite instead of an aggregate drainage layer may reduce the excavation depth, volume of excavated material to dispose of, volume of imported drainage aggregate, and damage to roads associated with hauling of excavated material and drainage aggregate from and to the site, respectively. Reducing the excavation depth may decrease shoring costs around the excavation perimeter. Thus, it is not appropriate to only compare the cost of using the drainage geocomposite with the cost of the drain aggregate that it would replace. All of the costs associated with installing either the drainage geocomposite or drainage aggregate layer must be considered.

As an example, for a 30 m-wide by 90 m-long buried structure that requires excavation perimeter shoring, using a $4.50 per square meter drainage geocomposite below the slab instead of a 0.3 m-thick drainage aggregate layer can provide significant savings. The drainage geocomposite would cost about $16,000 to purchase and install. Using drainage aggregate would cost the project about $70,000 ($5,000 for excavation and disposal of soil, $25,000 to import and install drainage aggregate, and $40,000 associated with the 0.3 m greater shoring depth around the excavation perimeter). Using the drainage geocomposite would reduce overall project costs by about $54,000. Schedule savings of 3 to 5 days, possibly more, could result from reduced time for shoring construction, excavation, and importing drainage gravel. The cost and schedule savings can increase significantly where large areas are involved, for example, when drainage geocomposites are installed below pond liners instead of sand drainage layers.

4.2.2 Reinforced Embankments

Geosynthetic reinforcement of embankments constructed on weak and compressible soils, or soils subject to strength reduction during seismic shaking, can reduce project costs, increase speed of construction, decrease risk associated with potential undrained shear failure of foundation soils, and allow steeper embankment slopes (thereby decreasing embankment volume and land requirements). Geosynthetic reinforcement can increase embankment stability and performance during seismic events, potentially eliminating or reducing the magnitude of ground improvement measures. Realizing the full benefits of including geosynthetic reinforcement in embankments requires an understanding of reinforcement geosynthetic and soil behavior, and the construction process. Convincing owners, designers, and contractors to include geosynthetic reinforcement requires demonstrating the financial, schedule, risk, and other benefits of doing so.

As an example, consider the case of a tidally influenced, 2400 m-long, 3-m high setback levee with 3 horizontal to 1 vertical (3H:1V) side slopes to be constructed in a seismic zone on an estuarine deposit of inter-bedded compressible silt and loose sand. The project is part of a wetlands mitigation effort and every acre of wetland created has significant value ($100,000 per hectacre). An annual construction season of only a few months drives a desire to complete the work as quickly as possible. For these conditions, incorporating geosynthetic reinforcement below the embankment and in embankment slopes could:

(1) Allow faster embankment construction by reducing or eliminating the need for staged embankment construction, with waiting periods for foundation soil strength gain, while simultaneously reducing the risks of construction-phase foundation failure associated with variable subsurface soil conditions.
(2) Reduce embankment base width and steepen embankment slopes, thus making more area available for the wetland, decreasing embankment volume, and decreasing land area purchased on the land side of the levee.
(3) Decrease the magnitude of seismic-event induced lateral spreading of the embankment, thereby decreasing the magnitude of levee crest settlement and the cost of repairs, while also reducing the risk of a catastrophic embankment failure, which could lead to flooding on the next tide cycle.
(4) Improve construction access and initial fill layer placement because the geosynthetic base reinforcement helps support equipment across the soft foundation soil during initial fill placement.

A high strength geosynthetic base reinforcement for this example project with may cost on the order of $7 to $10 per square meter, installed, for a total approximate cost of $500,000 to $750,000. Steepening the landside of the levee from 3 horizontal to 1 vertical (3H:1V) to 2H:1V, by including geosynthetic slope reinforcement would reduce levee footprint by about 0.9 hectacres ($550,000), embankment volume by about 21,000 cubic meters ($600,000 to $850,000), and geosynthetic base reinforcement by about 14 percent ($70,000 to $105,000). The cost for 12-foot-wide geosynthetic reinforcement strips, placed at 1 m vertical spacing along the 2H:1V slope face (assuming $2.50 per square meter) would be about $80,000. Just considering these factors, geosynthetic base and slope reinforcement would realize from $400,000 to $900,000 net benefit to the project. Additional cost savings would be realized through reduced construction management and contractor overhead associated with a reduced construction schedule. Decreased risk of embankment foundation failure during construction and during seismic events provide further benefit. Thus, when considered as part of the overall project *system* or *integrated solution*, the value geosynthetics can bring to a project can be quantitatively demonstrated.

4.2.3 Roadway and Pavement Reinforcement

Installing geosynthetic reinforcement in pavement base layers and pavement sections, for some soil conditions and sites, has been demonstrated to reduce construction cost and improve performance. For example, Cuelho and Perkins (2009) provide research results for unpaved roads. However, adoption of geosynthetic-reinforced pavement design has been slow and is not ubiquitous in the pavement design industry. Potential reasons for this slow adoption include: (1) lack of industry consensus as to quantifiable benefits of subgrade reinforcement in some pavement sections (Lenz, 2011), (2) continued production of pavement design manuals without sections that include geosynthetic reinforced pavement design procedures (AASHTO, 1998; NCHRP, 2014), and (3) the absence of ready and convincing direct cost comparisons for pavements designed without and with geosynthetic reinforcement. A simple slide rule and software for making a cost comparison for pavement with geosynthetic reinforced subgrade versus unreinforced subgrade is available from at least one manufacturer (Tensar Earth Technologies, 2003). However, cost-benefit comparisons are not frequently presented in geosynthetic manufacturer and supplier product advertisements and brochures. Instead, it is frequently left to the reader of the product-specific brochures to make the connection between the sketches showing typical and geosynthetic-allowed reduced excavation and aggregate requirements and cost savings (without being provided product cost data).

Incorporating geosynthetic reinforcement and separation below construction access roads on soft soil sites and in wet environments would seem to be an obvious cost-savings application. However, many contractors are still not aware of the savings in initial construction cost and access road maintenance that accompany the use of geosynthetics for this application. The geosynthetics message must be presented to contractors in terms of quantifiable cost and schedule (because time is money) savings to get their attention.

Geosynthetic reinforcement may reduce initial pavement construction costs and improve the pavement lifecycle performance. Savings realized by installing geosynthetics as pavement subgrade reinforcement may be greater for pavement rehabilitation than for new pavement. This greater savings results primarily from decreased excavation depth and decreased aggregate import volume. A six inch-reduction in excavation depth ($5 to $10 per cubic meter) and pavement section thickness ($20 to $30 per cubic meter of base course) through installation of geosynthetic reinforcement in the pavement section ($2.00 to $3.00 per square meter), could save on the order of $45,000 to $70,000 per 3 m-wide lane-mile of pavement. This is an application where pavement design methods and software can quantify potential cost savings. Where pavement replacement and rehabilitation projects run for thousands of feet or miles, cost, and schedule savings can really add up.

4.3 Alternatives Comparison

Holtz et al. (1997) encourage performing cost, risk, and benefit comparisons when evaluating alternative designs, so that appropriate decision are made regarding whether a geosynthetic-inclusive solution is appropriate. Holtz et al. (1997), and many other engineers (the authors included), take it for granted that these comparisons will be systematically performed. However, stakeholders are generally unfamiliar with the range of benefits that geosynthetic use could provide, with geosynthetic design procedures, and with geosynthetic and construction cost data, so they are not in a position to readily make initial assessments. Ultimately, they may be unprepared or reluctant to invest time or effort into developing the necessary understanding or advance a geosynthetic-inclusive design alternative sufficiently to properly assess the potential benefits, cost and schedule savings, and mitigated risks associated with geosynthetic alternatives. Without this capability, and in the absence of guidance to help stakeholders recognize situations where the potential for geosynthetics to provide substantial benefits exist, it will continue to be difficult for the geosynthetics industry to expand product use. The geosynthetics industry's goal should be to get designers, owners, and contractors thinking in terms of *systems* and geosynthetic-inclusive *integrated solutions*, and to not think of geosynthetics as *new* products.

Papers that present or evaluate design methods and case histories would be more valuable if they include decision matrices and cost and risk data to help readers understand the benefits that geosynthetics provide, and to compare the geosynthetics-inclusive solution against alternative solutions. Assisting stakeholders to obtain an understanding of the cost, and cost savings, associated with geosynthetic-inclusive solutions, will increase their appreciation of conditions and situations in which geosynthetics might benefit a project. We encourage authors to include cost comparison data in their papers.

4.4 Conclusion

We will see a significant growth in geosynthetic use if we can implement a *systems*, a.k.a., *integrated solution* approach to project design and construction. A systems approach was readily achieved in the days of Master Builders, who were in charge of entire projects or major elements of them. This is no longer the case. The number of sub-specialties engaged to design and construct a project can be staggering. Adopting a *systems* approach for a project requires collaboration of people in these sub-specialties, many of whom may not be familiar with geosynthetic products. A systems approach to design requires engaging the various disciplines and identifying and quantifying the benefits, cost, schedule implications, and risks associated with including geosynthetics. Geosynthetic use will increase when geosynthetics are considered part of a *system* or *integrated solution*, and not considered a new product or substitution for an older or better known method.

5 EMPHASIS ON SYSTEM DESIGN METHODS

5.1 The Concept

We will see significant growth in the use of geosynthetics if we, as an industry, develop thorough design methods for a broader range of applications than are currently available. To grow and promote the use of geosynthetics, we must take a systems approach; develop integrated and complete solutions for various applications; and more thoroughly create, organize and promote the necessary associated design methods.

The use of geosynthetics covers a broad range of civil and environmental engineering applications. Some of these applications have associated design methods backed and endorsed by either governmental agencies or industry organizations. But, there are many applications for which there is limited design guidance or none what so ever. The availability of a widely accepted design method for a geosynthetic application helps increase the understanding and usage of the solution by the engineering community. If the design and consulting engineering community were to be given researched and accepted protocols for new geosynthetic systems, their use and acceptance would increase dramatically. This is especially true in applications where the cost and/or time of current solutions greatly exceed the geosynthetic solution. As an industry, we need to create a wider array of application system design methods, which will in turn help grow our business and push our engineering and manufacturing technologies into new frontiers.

5.2 A Systems Approach Backed Up by Design Methods

To understand how a systems approach backed up by accepted design methods can help increase geosynthetic usage and market growth, we should discuss what a “system” entails. Here the term *system* is defined as a set of individual components that interact to form an integrated whole. For our purposes, these individual components will most likely be comprised of geotechnical and geosynthetic materials. But, not always. The incorporation of steel, concrete or other structural materials could conceivably be used in these systems also. As the industry moves forward, new and innovative system solutions will be developed along with the demand for innovative products to fulfill these needs more efficiently.

The use of a system design based market approach is far from unique in our industry. Commonly used design methods have helped spawning a deeper understanding of geosynthetics and their possible use. The industry must move forward as a collective unit to develop and promote methods that are proven but not widely accepted. Only then will the design and consulting community gain confidence in the methods. These individuals need a confident and trusted body or organization to “hang their hat on” before incurring the possible liabilities associated with advanced technologies and design methods they are unfamiliar with. This is where we, as an industry, should work together to create new unified design approaches to unique system solutions.

The main hurdle will of course be the use of generic properties in these design solutions. But, as we have seen with some proprietary products, these properties often do not have merit in application performance and mostly lead to conflict within the industry as well as confusion with our intended audience (i.e. designers and consultants). But, if the design approach involve properties applicable to performance and focus on material improvement and refinement, then manufacturers and distributors will have the ability to create a more efficient design along with improved margin based on new material research, development and manufacturing techniques. These properties should be based on actual performance data and should not necessarily be limited to current technologies.

A good example of this approach of expanding geosynthetic use through widening acceptance of a design method is the course of action taken by the SRW (segmental retaining wall) community. Before geosynthetic-reinforced SRW systems were fully understood and trusted by design and consulting engineers, an accepted design approach had to be developed. Collectively as a group within NCMA (National Concrete Masonry Association), the segmental wall community created a unified design method, a computer design program, and gathered regularly to discuss and integrate continued improvements to their message and recommendations. This work resulted in the *Design Manual for Segmental Retaining Walls*, currently in its 3rd Edition (NCMA, 2010). Though this effort, the use and acceptance of SRW’s increased dramatically. Indeed, this could be argued as being the largest leap forward for the reinforcement geosynthetic community in the US. The design approach used by NCMA contains material properties that are important to system performance while they do not limit product advancements. As a *system* solution, improvements to both the facing units and geosynthetic reinforcement have been ongoing and will continue to improve over time as long as the community continues to look into new and more innovative solutions possible with their current or newly developed systems.

5.3 Current Design-oriented System Solutions

5.3.1 Design Standards

To expand on what we as an industry could provide in terms of design-oriented system solutions, it would help to understand what is currently available. Within the European community’s, design standards exist for design-oriented system solutions not commonly utilized in North America. This includes the British Standard (2011) and the standards by the German Geotechnical Society (2011). These solutions cover a wide range of civil and environmental applications and provide economic benefits based on comparison with other commonly used solutions. The European community approach does suffer, much like those in the United States, with differing solutions for the same application depending on local experience. But, as with common applications in the United States and the differences in design methodologies (whether for federal, state, or commercial applications), the general theories behind the European methodologies tend to be similar. Their primary differences are in material evaluation and the required factors of safety.

Two of the frameworks to start with are the British Standard BS8006 (British Standards, 2011) and the German Geotechnical Society (2011) EBGEO Design Standards. Both of these currently available standards could provide valuable templates to consider for development of design procedures such as those that could be developed by the GMA (Geosynthetics Materials Association). We can then utilize these design methods to increase geosynthetic adoption through unique application usage and education, and establish the forum for new solutions and continued improvements. Some of these design methods could include embankments on soft soils, foundation pads, veneer stability, geosynthetic encased columns, and others.

5.3.2 Design Methodologies for Void Bridging

The use of geosynthetics for void bridging applications is still relatively uncommon, but examples of successful projects and research are available (Blivet, 2000; Alexiew, 2008). The application of void bridging, or spanning areas of possible subsidence, involves the creation of a high tensile strength membrane capable of holding the expected overburden loads while remaining within design specification with regards to deformation and time (Baillie, 2014). Within the environmental community, this technique is used for geomembrane liner support over areas of possible subsidence. High tensile strength geosynthetics are used to carry the overburden loads while keeping membrane deformations within designed limits, Figure 2. However, geosynthetics are not as commonly used as they should for this application. Not because there are a lack of projects, but because of the lack of a unified, widely accepted design method. Where potential for subsidence exists, the more common approach would be to over excavate the site and create a stable, deep seated foundation, or bypass the site all together. Either solution creates greater project costs. A design methodology based around a system approach could be utilized within the industry to help educate the design community and increase the use of high tensile strength geosynthetics. Void bridging design methods and system solutions could apply to various applications in civil, environmental and mining engineering. Having the methods available could create the need for future product and polymer refinements to meet the needs of specialty environmental conditions and performance criteria.

Figure 2: Void Bridging Test Section

5.3.3 Pile Supported Structures

The use of geosynthetics for pile or end load bearing support is more widely known than the void bridging application, but has yet to become a common approach for sites where these foundation solutions could be used, even though design methods and supporting research are available (Han and Wayne, 2000; Stewart and Filtz, 2005). Column-supported embankment methodology involves the creation of a load transfer platform (LTP) capable of efficiently carrying and transferring the loads to the piles or columns, Figure 3 (Baillie, 2014). The design of the LTP's involves an in-depth assessment of foundation and platform soils, cover depth, pile loading capabilities, and loadings. The more commonly applied solution is to create a dense matrix of piles to reduce the span required for soil arching or use a binding agent to strengthen the cover soils to facilitate a greater load transfer. Despite available design methodologies and many successful projects, the use of high strength geosynthetics to create pile or column embankments is not widely utilized. Column elements include rigid piles, deep mixed soil columns, stone columns, geosynthetic-encased aggregate columns, and other stiff column elements.

Figure 3: Pile Foundation with Geosynthetic Support

5.4 Conclusion

We will see significant growth in the use of geosynthetics if we, as an industry, create and implement a systems approach and develop and disseminate design methods. To grow and promote the use of geosynthetics, we must take a systems approach to identify and develop solutions for a wide variety of applications. We must create and publish associated design methods, and organize and promote these methods our industry. Doing so will create a stable and trusted source of design solutions that engineering and consulting communities could then utilize. We as an industry can organize, create and implement these system designs. In turn, our industry will grow beyond its current confines, increasing in volume of total geosynthetics sold and while increasing development of new and innovative materials.

6 DO NOT ABANDON THE THRUST ON GEOSYNTHETICS INGENUITY

6.1 The Concept

We will see a significant growth in geosynthetic use if we continue to strive for ingenuity in the development of new products, applications and systems.

6.2 Ingenuity and Creativity

Geosynthetics can now be considered a well-established technology within the portfolio of solutions available for geotechnical engineering projects. Yet, ingenuity continues to be significant in geotechnical projects that involve their use. This is in part because of the ability to tailor the mechanical and hydraulic properties of geosynthetics in a controlled manner to satisfy the needs of all areas of geotechnical engineering. Much of the ingenuity that is brought by geosynthetics to many of the systems that use them is supported by years of research and development invested by geosynthetic manufacturers to advance their products. Yes, the economic model of the geosynthetics industry has focused on product development, which results in proprietary systems that are of course protected. However, the benefits of having geosynthetics as “engineered products” that provide a high technology component to engineering systems significantly outweigh the drawbacks associated with not considering geosynthetics as mere “commodity products” that are simply low-cost components in engineering systems.

A set of 10 ingenuous projects involving geosynthetics was presented by Zornberg (2012), which included recent applications or recent evaluations of old applications in geotechnical projects involving geosynthetics. The discussion of each application identifies specific difficulties in geotechnical design, the creative use of geosynthetics to overcome the difficulties, and a specific case history illustrating the application. Specifically, the series of examples illustrates how geosynthetics provide innovation when adopting the use of geotextiles as filters in earth dams, the use of exposed geomembranes as a promising approach for resistive covers, the use of geotextiles as capillary barrier in unsaturated soil covers, the use of anchored geosynthetic reinforcements in stabilization of steep veneer slopes, the use of geotextile tubes for challenging coastal protection projects, the use of geotextile encased columns to stabilize very soft foundation soils, the use of integral geosynthetic-reinforced bridge abutments to minimize the “bump at the end of the bridge,” the use of geogrids in the design of the highest reinforced soil wall involving geosynthetics, the use of reinforcements with in-plane drainage capabilities in the design of steep slopes, and the use of geosynthetic reinforcements to mitigate the detrimental effect of expansive clays on pavements.

It is not a secret that businesses with an R&D strategy have a greater chance of success than businesses that don't. R&D strategies have clearly led to innovation and increased productivity that boost competitive advantage. Ask the manufacturers in the areas of biomedical engineering and pharmaceutics. Yes, the consumers do have to pay for the R&D that went into developing a new drug or biomedical device. Yet, the benefits to the society at large, which result from the R&D invested by these industries, have largely contributed to a significant increase in our standard of living (and our life expectancy). Eventually, a given drug becomes generic and it turns into a commodity. However, by the time this happens, the biomedical engineering company is probably focusing on the next generation drug. Albeit in a very different way, geosynthetics have also contributed to our increased standard of living, and we probably should expect much more from a geosynthetics industry that continues to focus on research and development.

Overall, geosynthetics play an important role in all geotechnical applications because of their versatility, cost-effectiveness, ease of installation, and good characterization of their mechanical and hydraulic properties. The creative use of geosynthetics in engineering practice is likely to expand as manufacturers develop new and improved materials and as engineers and designers develop analysis methods for new applications. Rather than attempting to decrease the *cost* of geosynthetics by promoting them as "commodity products," we should encourage the geosynthetics industry to focus on demonstrating (or increasing) the *value* of geosynthetics by promoting them as "engineered products."

6.3 Conclusion

Although geosynthetics are now a well-established technology in our portfolio of geotechnical and civil engineering solutions, ingenuity continues to be significant in projects that involve their use. This is probably because of the ability to tailor their mechanical and hydraulic properties to satisfy specific needs in the multiple areas of civil engineering. It is inevitable that a fraction of geosynthetic products become commoditized because of their widely accepted use and plummeted costs and profit margins. However, it is imperative that a good fraction of the geosynthetic products continue to lead innovation. This fraction of specialty products will not only address and solve new problems but, by reminding us that geosynthetics are singular engineered products; their use will bring credibility to the entire geosynthetics industry.

7 FINAL REMARKS

Despite a long history, geosynthetics continue to be underutilized in civil engineering projects. When they are used, their full potential may not be taken full advantage of because designers are not familiar with how the geosynthetics or geosynthetic system behaves or affects the design, construction, or performance of other project elements. To realize the potential of geosynthetics, the geosynthetics industry must collectively educate the next generation of engineers, as well as owners, engineers, other designers, and contractors that use or could benefit from the use of geosynthetics. To increase geosynthetic usage, geosynthetics industry-related manufacturers, suppliers, designers, contractors, and individuals must work together to inform those less knowledgeable of geosynthetics.

The authors' consensus is that we will see a significant growth in geosynthetic use if:

- We significantly increase geosynthetic undergraduate education and exposure for all civil engineers.
- We provide *integrated solutions* that include geosynthetics, instead of continuing the industry focus on selling individual geosynthetic products or product lines.
- We create complete design methods for a broader range of applications than are currently available; take a systems approach with integrated and complete solutions for various applications; and create, organize and promote the necessary associated design methods.

On the other hand, there was no clear consensus on whether we will see a significant growth in geosynthetic use if:

- We provide geosynthetic systems that are less proprietary, are included in national specifications and standards, and change from proprietary products/systems to become more commoditized.

or if:

- We prioritize a continued strive for ingenuity in the development of new geosynthetic products, applications and systems, resulting in highly engineered products that do not focus on commoditization.

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