GEOSYNTHETICS R&D--THE "EARLY" DAYS (1960s to Circa 1985)

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ABSTRACT

This article summarizes geosynthetics research and development activities from about 1960 to the mid-80s. The primary geotextile applications are used as focal points of the developments that I was personally involved with or have some knowledge about. Some geosynthetic R&D pioneers are also mentioned, as are a few of the early developments that still influence design practice and construction procedures.

INTRODUCTION

The symposium to honor Professor Robert M. Koerner is an opportunity for many of us who have known and admired him to formally thank him for his many contributions to our profession. While our colleague Jean-Pierre Giroud is properly credited for the names geotextiles and geomembranes, Bob Koerner really did the hard work necessary to bring geosynthetics to the forefront of so much of civil engineering practice. Bob applied his many talents and enormous energy to doing research, writing articles and textbooks, teaching short courses, and giving lectures and seminars, all of which were essential for geosynthetics to develop from an exotic curiosity to a real honest-to-goodness civil engineering material.

Much of early history of geosynthetics has been well summarized by Koerner and Welsh (1980), Rankilor (1981), and Veldhuijzen van Zanten (1986). The forewords to the chapters of the IFAI "Design Primer" (Richardson and Koerner, 1990) also describe many of the early developments. When Barry Christopher and I were preparing the FHWA Geotextile Engineering Manual in late 1983, these early books as well as the proceedings of those few early conferences and symposia were very helpful in providing case histories and design procedures. Particularly noteworthy were the International Conference on the Use of Fabrics in Geotechnics, Paris, 1977, ASCE Symposium on Earth Reinforcement, Pittsburgh, 1978, First Canadian Symposium on Geotextiles, Calgary, 1980, a preprint from the ASCE Convention in Portland, Oregon in 1980, and the Second International Conference on Geotextiles, Las Vegas, 1982.

This article then focuses on those early research and development activities that I was personally involved with or have some knowledge about. I also will mention some geosynthetic R&D pioneers that may not have received, in my opinion, proper credit for their groundbreaking work, and I have included a few of the early developments that still influence our design and construction procedures. As the title indicates, I'll limit my remarks to the years from about 1960 to the mid-80s.

The primary geotextile applications will be used as focal points, and to make the length manageable, the article will be stylistically informal and primarily "name-dropping", with very little technical information or detailed references.

FILTRATION, DRAINAGE, AND EROSION CONTROL

A number of us, e.g., Dan Marks in Richardson and Koerner (1990), and Holtz and Christopher (1990) have called Robert J. Barrett the "Father of Geotextiles" because of his pioneering effort in the late 1950s to convince engineers to use geotextiles to replace graded granular filters in erosion control revetments. Barrett himself described some of his early experiences in the foreword to the section on erosion control in Richardson and Koerner (1990). In his first year, he sold only three jobs and only six the following year. Thank goodness Bob Barrett was a persistent man!

Bob Barrett's employer Carthage Mills sponsored some laboratory development work at Soil Testing Services, Inc. of Northbrook, Illinois, starting in 1957. Silvio Polici, a laboratory engineer at STS, developed a soil-fabric permeameter that was later refined and standardized as the Gradient Ratio test by C. C. Calhoun of the US Army Corps of Engineers. About the same time, Barrett convinced the Corps to do some large-scale field tests to really prove the efficacy of geotextile filters under armor stone. The work by Calhoun and the Corp was the basis for the design procedures, testing methods, installation procedures, and material specifications that we use today for geotextile filters in erosion control revetments.

The other US pioneers of geotextiles for drainage and filtration are of course Dan Marks and Bob Carroll, and their work is now classic (see, e.g., Carroll, 1983). One almost forgotten development is the first geocomposite drain, the " Eljendrain", invented by Richard Long and Ken Healy at the University of Connecticut (Healy and Long, 1971). This work was sponsored byh FHWA, and interestingly, the Eljendrain is still being sold. In Europe, pioneering work on geotextile filters during the early 1970s was done by H. J. M. Ogink at the Delft Hydraulics Laboratory in Holland, by H. J. List at the Federal Hydraulics Bureau in Germany, and by Alan McGown and David Sweetland at Strathclyde University in Scotland.

I had to be reminded by Bob Koerner in his Terzaghi Lecture (Koerner, 2000) that Terzaghi had used "plastic membranes" in Mission (now called Terzaghi Dam) in British Columbia in 1957-60. (See also the description in Koerner and Welsh, 1980). Although not what we would call today a geosynthetic, the application was remarkable, especially in a critical structure. Credit for the use of modern geotextiles functioning as filters in dams goes to several French engineers who published interesting case histories in the 1977 Paris Conference.

I also want to mention my former colleague and good friend Oleg Wager in Sweden. He invented the first modern prefabricated geocomposite drain in 1971 as a replacement for conventional sand drains (and Kjellman paper drains) to accelerate the consolidation of soft soils. Wager's first drain had a kraft paper filter surrounding a grooved polyethylene core, but not long after, the manufacturer started using a heatbonded nonwoven geotextile for the filter. This history is recounted by Holtz et al. (1991).

GEOSYNTHETICS IN ROAD AND RAILROADS

As part of a collaboration between the USDA and the USBPR (forerunner of the FHWA), woven cotton textiles were used in the 1930s in test sections in highways in South Carolina, Rhode Island, Montana, and New Jersey. Even though from all accounts, the tests were very successful, this technology was forgotten, probably because the surplus of cotton evaporated after the start of WWII. There probably were other early experiments with geotextiles as roadways, but my first exposure to this technology was in the paper by McGown and Ozelton (1973). They described the successful construction of an unpaved road across a peat bog in Scotland using a heatbonded nonwoven fabric, and they gave a reasonable explanation for how geotextiles probably functioned in roadways.

About the same time, a few nonwoven manufacturers started seriously promoting this technology in North America. Initially, the products were touted as “roadway reinforcing” materials, but after a few full scale road tests, it became apparent that the primary function of these geotextiles was separation. Secondary functions were filtration and drainage, but some reinforcement was also possible, especially on very soft subgrades. One well-documented road test was conducted by the US Forest Service in the Olympic National Forest near Quinault, Washington, using several light to medium weight geotextiles. Important conclusions of the Quinault test were that the geotextiles acted primarily as separators and all performed equally well, provided they were protected by a minimum thickness of aggregate cover; and finally, their use was cost effective.

From this work, John Steward and his colleagues at the USFS in Portland developed a very simple and practical design procedure for unpaved roads (Steward, et al., 1977). In my opinion, this method is still one of the best methods available because it is based on the results of the full scale Quinault road test. It also incorporates sound soil mechanics principles (stress distributions and bearing capacity theory) and uses the results of some model tests on soil-fabric-aggregate systems performed at the University of Illinois by Professor Ernie Barenberg and his students (published as Bender and Barenberg, 1978, and Kinney and Barenberg, 1980). (An interesting footnote: Tom Kinney has continued work on roadway stabilization, most recently with geogrids.)

Other unpaved road design methods have been proposed by Barenberg and his students (referenced above), Giroud and Noiray (1981), and Halliburton and Baron (1983). With the exception of work by Richard Jewell, not much has been done on the design of geosynthetics in roads since the early 1980s.

It became apparent about this time that the size of the unpaved road market was not large, and that the use of geosynthetics in permanent or paved roads could be much more lucrative. Consequently, procedures for this application were developed by some manufactures. However, in no case that I’m aware of was the background data of the research published in the open literature. Although we were often regaled by stories of successful performance and dollars saved, there never seemed to be any control sections provided or field measurements made, and no documentation of these successful applications was ever published in peer-reviewed journals or conferences.

There are two pioneers who used geotextiles as separators in railroads. Jack Newby of the Southern Pacific RR conducted full scale experiments with geotextiles in track subgrades, and Gerry Raymond of Queens University, Kingston, Ontario, performed some rather large-scale model tests of track-ballast-roadbed systems in his laboratory at Queens.

Al Haliburton of Oklahoma State did some mostly conceptual work on geotextiles in airfields for the USAF in the late 1970s. Shortly afterwards, my colleague, Milton Harr at Purdue University, and I also had a project sponsored by the USAF to look at geosynthetics for the rapid repair of runways. We performed model tests of footings on the surface of a dense sand in a large sand box that contained layers of woven geotextiles and biaxial geogrids. This work was unfortunately never published.

Other related geosynthetic applications include Mal Steinberg's use of what were essentially geomembranes to successfully mitigate the action of swelling clays in pavement subgrades. Membrane Encapsulated Soil Layers (MESL) and other subgrade stabilizing techniques for expedient roads and airfield construction have been developed by the US Army. Capillary breaks using geosynthetics to mitigate frost heaving were illustrated by Rankilor (1981). And of course, paving fabrics are often included in this list, even though there is no "geo" in the asphalt overlay.

SOIL REINFORCING

The three primary soil reinforcement applications using geosynthetics are (1) reinforcing the base of embankments constructed on very soft foundations, (2) increasing the stable slope angle of soil slopes, and (3) reducing the earth pressures behind retaining walls and abutments. The design procedures for the latter two applications are traditionally different, although as far as the behavior of the geosynthetic reinforced soil mass is concerned, this difference is quite artificial and arbitrary. To illustrate this point, at what slope angle does a reinforced slope transition into a reinforced soil retaining wall? But as we know traditions are difficult to overcome.

In the first two applications, geosynthetics permit construction that otherwise would be cost prohibitive or not technically feasible. In the case of retaining walls, in comparison with conventional retaining wall construction, GRS walls are significantly cheaper and more flexible, and thus able to tolerate larger foundation settlements and larger seismic events in comparison with conventional retaining wall construction.

Embankments on Soft Foundations

Although bamboo, corduroy, log mats, timber planks, etc. have been used for centuries to support roads and small embankments on soft soils, the first engineered system for this application was developed in 1966-8 by Oleg Wager of the Swedish Geotechnical Institute. Wager used short sheet piles or horizontally lying steel beams under the two crests of the embankment, and tied the sheet piles or beams together by steel tie rods spaced every metre or so (Wager and

Holtz, 1976). An instrumented test embankment on sensitive clays in SW Sweden proved the viability of the concept as well as Wager's method to calculate the stability of the system based on rather simple modifications to the Swedish circle stability analysis. Although expensive, the system had been used about 25-30 times in Sweden and Denmark by the early 1970s at both highway and railroad sites where no other stabilization method was feasible.

It is interesting that Wager, without a formal university education, had a reputation for innovation and creativity. He had tried a number of procedures in his geotechnical practice that worked when they shouldn't have, according to more knowledgeable and better educated geotechnical engineers. He even had used plastic nets and nonwoven fabrics on a couple of projects in the 1960s, apparently with some success. So in 1971, when he was approached by a salesman from a small company that made industrial-grade multifilament woven polyester fabrics, Wager realized that sheets of this material could potentially function as reinforcement for embankments on soft foundations in much the same way as the short sheet piles and tie rods.

A few months later in the late summer of 1971, Wager had an opportunity to try this new reinforcing concept at a pile-supported bridge approach embankment near Nol, in SW Sweden. He and I had a number of discussions that summer about how to design the reinforcing and how we might obtain the material properties for design. The weaving company supplied us with a "theoretical" tensile strength, but we didn't know how to get the soil-fabric friction. Our design was mostly conceptual, largely "by guess and by golly", and we used a very crude inclined plane sliding test to estimate the frictional characteristics of the multifilament woven polyester fabric. The site was instrumented, and in spite of the fact that the reinforcement functioned mostly to take up the horizontal forces imposed by the earthfill, that the design was crude, and we had a very poor knowledge of the relevant properties, the overall embankment performance was highly satisfactory. See Holtz and Massarsch (1976 and 1993) for a description of the project.

The US pioneers of reinforced embankments on soft soils were Jack Fowler of the US Army Corps of Engineers and his major professor at Oklahoma State, Al Haliburton. After a couple of failures (fortunately well documented for us by Fowler and Haliburton), they used multifilament woven geotextiles to reinforce a successful test section and later an embankment constructed to almost 8 m high on foundation soils as soft as 60 kPa. This was at the Corps' dredged disposal site Pinto Pass, Mobil Harbor, Alabama, and the test and construction are described in Fowler and Haliburton, 1980; Haliburton, Fowler, and Langan, 1980; and Fowler, 1981. Pinto Pass was an important case history because the design assumptions and procedures proposed by Haliburton and Fowler were verified, and, most importantly, we learned that proper construction is absolutely essential for successful construction of embankments on ultra soft soils.

Other well-documented case histories of reinforced embankments in Holland from that era are described in the Paris (1977) and the Las Vegas (1982) conference proceedings, and by Veldhuijzen van Zanten (1986).

Steep Slopes and Walls

As mentioned in the introduction to this section, separate treatments of steep slopes and walls is largely artificial and traditional. In fact, in the FHWA Geotextile Engineering Manual (Christopher and Holtz, 1985), we had no case histories for steep reinforced slopes, although we had several for walls and embankments. Yet, we followed the traditional geotechnical approach and treated the design of reinforced slopes differently from walls because that is the way we design unreinforced slopes and conventional structural retaining walls.

A review of the early conference proceedings indicated that there were no papers on reinforced steep slopes at the Paris (1977) conference, and only two at the ASCE symposium in Pittsburgh (1978). Only one of those really involved geotextiles, and that was by Iwasaka and Watanabe; they described using short sheets of nets (1-2 m wide) as compaction aids near the slope face and longer sheets for primary reinforcement of the embankment. The other reinforced steep slope paper was by Ray Forsythe who described a fill slope in California that was successfully reinforced with sidewalls of waste tires tied together with rebar clips.

At the Las Vegas (1982) conference, the only slope paper was by Dick Murray describing a bilinear stability analysis method for fabric-reinforced steep slopes. Almost as an afterthought, he also mentions the first application of geogrids, although is was called a "fabric" in the paper, for the reinstatement of a failed slope.

Although Colin Jones has found several older and similar reinforcing methods, the first modern reinforced soil system was developed and promoted in the mid 1960s by the French architect, Henri Vidal, as *Terre Armeé* or reinforced earth. Vidal used steel strips for the reinforcing elements and this greatly reduced the earth pressure against the wall face. The first Reinforced Earth wall in the US was built in Southern California in 1972, and since then many thousands have been successfully built in the US and throughout the world. Other proprietary reinforcing systems have also been developed using steel bar mats and grids. (Bob Koerner may recall Vidal's appearance at the Third International Conference on Geotextiles in Vienna in 1986, when Vidal claimed to have considered, but then rejected as impractical, the use of geotextiles as reinforcing elements!)

A few years later in the early 1970's, geotextiles were proposed for reinforcing retaining wall backfills because of concern about possible corrosion of metallic reinforcement in backfill soils. At least, this was the reason we started some early experiments with a woven multifilament polyester fabric at the Swedish Geotechnical Institute in 1972. The success of Wager's reinforced embankment project described above persuaded the weaving company, AB Fodervävnader of Borås, Sweden, to sponsor a small research project at the Swedish Geotechnical Institute, and as part of this project we constructed a world's first pullout test device. We learned a lot from these initial experiments, and our work is summarized in a paper to the Paris Conference (Holtz, 1977). This same firm also sponsored research on model GRS walls using their woven multifilament polyester fabric (Holtz and Broms, 1977 and 1978).

We of course weren't the only ones with this idea. It is interesting that the first GRS wall was built in France, the home of *Terre Armeé,* in 1971. As described in the Paris (1977) conference, the wall was 4 m high and used a 300 g/m^2 nonwoven geotextile as the reinforcing. The reason this type of reinforcing system was tried was because the foundation was soft and compressible and the backfill soil was a weathered chalk with a PI = 12 and compacted several percentage points above the Proctor optimum water content. In 1974, John Steward of the US Forest Service along with Professor Dick Bell of Oregon State University designed and constructed the first two US GRS walls in Oregon and Washington. The Oregon wall was about 2 m high while the Washington wall was about 6 m high; both were constructed of lightweight nonwoven geotextiles with a wrapped face.

Interest in this technology developed fairly rapidly, and in 1982, the FHWA and Colorado Department of Highways conducted a major test in Glenwood Canyon, Colorado. Test walls about 4.5 m high were constructed with several lightweight nonwoven geotextiles and using on-site granular backfill materials. All walls had a wrapped face and were monitored; some test sections were subjected to a rather high surcharge fill. Later that same year, NY State Department of Transportation built a GRS wall up to 6 m high with the same wrapped face construction on a state highway near Albany. In both the Colorado and NY walls, the wrapped face was protected from UV radiation by a thin shotcrete layer.

While our Swedish work was with a relatively strong multifilament woven, the early French and US GRS walls were successfully constructed with lightweight nonwoven geotextiles. Yet today, it is rare to find a wall of any significant height built with geotextiles. This state of the practice can be primarily traced to the UK, starting about 1980 with Brian Mercer and Netlon Ltd., developer of Tensar geogrids. Although other grid-type geosynthetics had been developed in Germany by Huesker about the same time, it was Tensar that really promoted the development of geogrids for reinforcing slopes and walls. The man responsible for this development was John Templeman of Netlon, because he successfully got a key public works laboratory and a few universities in the UK to help Netlon develop design methods, properties evaluation, and demonstration projects using geogrids.

One early successful project used Netlon geogrid gabions for a bridge abutment in the south of England. Another involved the Transport and Road Research Laboratory and Dick Murray, mentioned above, who successfully used geogrids for landslide reinstatement using the slide debris on a motorway in central England. Netlon's university R&D was primarily at Strathclyde in Scotland and Cambridge in England. Key players included Alan McGown and his colleague, Kamal Andrawes, at Strathclyde, and Richard Jewel at Cambridge. McGown and Andrawes had been doing considerable research on geotextile properties and applications so they well prepared to work on geogrid reinforcement. Jewel's research was primarily analytical and focused on design methods.

Also in the early 1980s, Netlon contracted with Gulf Canada, who made polyethylene tanks, to develop and promote Tensar geogrids in North America. This soon morphed into the Tensar Corporation in the US, who were very successful in using Netlon's R&D work, some early and successful field projects, and very clever marketing. Soon, Tensar became the dominant geosynthetic reinforcement for both steep slopes and GRS walls.

THE ROLE OF FHWA

In addition to the early work by the US Army Corps of Engineers and the US Forest Service, the Federal Highway Administration also played an important role in the early days of geosynthetics. FHWA sponsored two projects that I think helped promote geosynthetics engineering to state highway engineers:

1. They funded a project at Oregon State University in 1976-80 to identify the test methods and use criteria for what they termed "filter fabrics". The emphasis was on subsurface drainage, erosion control, and soil reinforcement, and the two principal investigators were Professors Dick Bell and Gary Hicks; Bell was the geotechnical specialist while Hicks focused on pavements. They had a review panel consisting of Harry Cedergren, John Steward, and myself; a number of engineers representing various manufacturers also attended the periodic review panel meetings.

The principal findings of the OSU work were that the then-available test methods were more or less adequate, but some tests, especially those for tensile strength, stress-strain, friction, and creep needed improvement. They also found that geotextile permeability could be adequately determined, but the fabric characteristics tests such as the AOS needed improvement. Similarly, durability tests were adequate for control, but could use improvement.

2. In the late 1970s, FHWA realized that for successful utilization of geosynthetics in highway engineering, state highway engineers needed good technical information about the products and their applications. They contracted with Professor Al Haliburton at Oklahoma State to develop course notes (Haliburton, Lawmaster, and McGuffey, 1981) and teach a series of short courses. After only the pilot and two courses, Haliburton's methods and opinions were so controversial that FHWA cancelled their contract, and issued another RFP in late 1982. Barry Christopher and I got the second contract, and because of the controversy, we rewrote the Haliburton course notes into the Geotextile Engineering Manual (Christopher and Holtz, 1985). I think we had more than 70 reviewers, and there were only two that were a bit negative! One thing that helped us greatly was that the AASHTO-AGC-ARTBA Committee on Materials had constituted Task Force 25 with the purpose to develop sample specifications for the more routine geosynthetics applications. We were obligated by our contract to present TF25 specifications, but we did not necessarily have to endorse them in every detail. (Interestingly, our pilot course presentation was in Atlanta in March of 1984, and Bob Koerner was one of our reviewers.) I think it is fair to say that our courses and the GEM along with its successors have had a significant and generally positive influence on the use of geosynthetics by highway engineers throughout the US. Specifications and design practice have greatly improved, and this probably contributed to the increased use of geosynthetics in the years after the mid-1980s.

THE ROLE OF MANUFACTURERS

Discussion of the early days of geosynthetics would be incomplete without at least a few comments about the important role played by many geosynthetic manufacturers. I already mentioned the research sponsored by AB Fodervävnader of Borås, Sweden, which was a fairly small specialty weaving company. Other manufacturers in Europe at that time included Fibertex in Denmark, Nicolon in Holland, Bidim in France, ChemieLinz in Austria, and ICI in the UK. Active US companies included Carthage Mills, DuPont-Typar, Monsanto, Mirafi, Phillips Fibres, Amoco, Netlon-Tensar, Exxon, and probably some others that I have forgotten. Many of these companies sponsored research, some of it proprietary, and theyrelentlessly promoted their products to civil and geotechnical engineers. They also supported their own engineers and sales people to faithfully participate in ASTM, TRB, NAGS-IGS, etc., and they developed a few products specifically for civil engineering applications such as geocomposites and geogrids.

The other side of the story is of course that sometimes the geosynthetics manufacturers' representatives were a bit too competitive, aggressive, and self-serving. They often seemed to go for the short-term advantage, but in my opinion such an approach was detrimental to the long-term health of the entire geosynthetics industry. All of us have stories about some of these early characters, but because most of them are no longer in the geosynthetics industry, these stories are appropriate for happy-hour discussions.

FINAL COMMENTS

I purposely ended the "early days" about the time that work began in earnest on the use of geomembranes for waste containment. That R&D history is more properly told by Bob Koerner and Jean-Pierre Giroud. There were of course earlier uses of geomembranes by the USBR for canal liners and for dam rehabilitation, mostly in Italy. In the waste containment area, however, the EPA was the key sponsor of the development of design procedures and specifications by Bob Koerner, Dave Daniel, Greg Richardson, and others.

Finally, the story would not be complete without at least a mention of the GRI and its strong and continuing positive influence on the development of geosynthetics.

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