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NEW TECHNOLOGIES IN GEOSYNTHETICS

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ABSTRACT: To illustrate potential new technologies in geosynthetics, a few innovative applications of geosynthetics have been selected and summarized. Extraordinary big geotextile bags encapsulating soil including dredged mud, geomembrane lining for a seawater reservoir for pumped-storage power generation, leak detection systems for geomembrane lining and built-in remedial measures, and need for a unified field test procedure are discussed in an attempt to locate a seed of a new technology. It takes a new idea based on the interdisciplinary knowledge and experience to create a new application and to lead it to a cost-effective, environment-friendly new geosynthetic technology.

INTRODUCTION

It seems as though geosynthetics engineering has an unlimited horizon. In fact each of the three main functions of geosynthetics, i. e., reinforcement, separation and drainage, is so vitally important in geotechnical works that there seems to be always a need for geosynthetics. In addition a variety of new geosynthetic products are constantly developed and introduced to the construction market, enhancing the scope of their applications to diversified engineering needs.

Geosynthetics engineering has thus attained a certain level of maturity in a relatively short period of time. This process of development has a resemblance, for instance, to the history of reinforced concrete; concrete and steel had long been there, but the combination of the two well-known materials created a new technology. Synthetics were relatively new, but soil is the oldest construction material; again the combination of the two created a new technology. As compared with reinforced concrete, geosynthetics do not confine themselves to the function of reinforcement alone and soil is much more abundant and cheaper than concrete, suggesting a far greater potentiality in the future.

In the course of the long history, the engineering properties of concrete and reinforcement steels have been improved markedly, but it was not these improvements that led to a breakthrough, e. g., invention of prestressed concrete. The subsequent development has taken full advantage of concrete and steel technology that had advanced, but it was no doubt the human brain that brought a new world of prestressed concrete. It takes a new way of thinking to create a new technology.

A brilliant success comparable to the foregoing breakthrough is yet to be seen in the field of geosynthetics engineering. However, new ideas for innovative uses of geosynthetics are continually brought up and reported in conferences and journals. These lively activities are a healthy indication of progress toward what should and could be achieved and may some day lead to an eye-opening new technology.

New technology is interpreted as such in this theme lecture entitled "New Technologies in Geosynthetics." It presents, therefore, some of the recent topics related principally to innovative ideas and applications of geosynthetics which may, in the observation of the writer, lead at least to a better use of geosynthetics that is cost-effective, environment-friendly and to be widely accepted.

BIG GEOTEXTILE BAGS - GEOTUBES AND GEOCONTAINERS

Big geotextile bags named geotubes and geocontainers, hydraulically or mechanically filled with soil including dredged mud, have been applied in hydraulic and coastal engineering projects. These huge bags can also be used to store and isolate contaminated materials as obtained by harbor dredging and/or to use these units as bunds for reclamation works (Ref. 1).

A geotube is a tube made of permeable but soil-tight geotextile, typically 150 to 180 m long and 4 to 5 m wide, filled to a height of 1.5 to 2 m. The tube is filled with sand or dredged material, which is pumped as a water-soil mixture. Inlet openings on top allow for the attachment of a pipe that transports hydraulic fill into the tubes. If the fill is sandy, these inlets should be spaced closely, e. g., 10 m apart, to assure uniform filling of the tubes. If clayey slurry is used, the inlets can be located as far as 150 m apart (Ref. 2).

The major design considerations include sufficient geotextile and seam strengths in order to resist pressures during filling, compatibility between fabric and soil, and impact of a geocontainer when geotubes are used as protective base on seabed. The conflicting requirements of particles retention and high permeability, combined with high strength, may call for a special composite geotextile. For instance, a nonwoven geotextile can be used as a liner inside to retain the fine particles, while the outside geosynthetic can be a high-strength woven geotextile. Geotubes can be filled on land, e. g., as dikes for land reclamation, bunds, toe protection or groins, or else under water, e. g., offshore breakwaters, sills of perched beaches, dikes for artificial islands or interruption of gullies caused by currents. Also geotubes are often used as a bottom protection for geocontainers.

A geocontainer is a huge pillow-shaped unit made of a permeable, soil-tight geotextile, which could consist of inner and outer liners and subsequently is mechanically filled by a hopper or by a clamshell bucket, Figure 1. Geocontainers are partially prefabricated by sewing sheets of the appropriate length together and placed inside a split-hull bottom-dump barge. The ends are shaped and sewn together to form an elongated "pillow." After being filled with sand or dredged material, the big pillow is closed by sewing machines which provide specially designed seams. The fill capacity of a container could be maximized by increasing the barge opening width and an opening rate to allow the geocontainer to deploy without causing excessive stress and strain in the fabric during placement. The volume of a geocontainer amounts usually from 100 to 1000 cu. m.

Prototype experiments indicate that geocontainers with a volume up to 200 cu m. and dumped in water have frequently been damaged when the depth exceeds 10 m. Failure was caused by a collapse of the seams, when a geotextile with a tensile strength less than 75 kN/m was applied, whereas no damage was observed when the geotextile had a tensile strength greater than 150 kN/m.

Geotubes have been used extensively on the northern shores of The Netherlands for dike construction where fine-grained dredged sands are pumped into a barrier dike for subsequent hydraulic filling behind this dike. Geocontainers have been used for construction of underwater berms and scour protection. Tubes filled with dredged material have been applied as containment dikes in Brazil and France, more recently in The Netherlands for river training structures, and as shoreline protection along the North Sea in Germany. Recently several geotube-geocontainer projects have been designed and constructed in the U. S. A., Malaysia, Taiwan, The Philippines and Japan.

Among quite a few large-scale demonstration projects implemented in the United States, the Marina Del Rey project in the Port of Los Angeles in 1994 encapsulated successfully 42,000 cu. m of contaminated dredged material in geocontainers each holding roughly 1000 cu. m, placed them with split-hull bottom dump barges in a shallow water habitat and capped them with a layer of dredged sand. In the Port of Oakland, California, 3000 cu. m of contaminated dredged material was pumped into geotubes, 15 to 120 m long and 9 to 15 m in circumference, for dewatering and subsequent landfill disposal. The slurry in geotubes was allowed to drain to about 40 to 65% of their original volume prior to opening of the tubes and landfill placement (Ref. 3).

The grand idea of putting big bags of extraordinary sizes to diversified practical use is indeed intriguing and dream-provoking. Such is a method made possible only by the use of a geosynthetic materail and seems indicative of an aspect of the future of geosynthetics engineering.

LINING OF A SEAWATER PUMPED-STORAGE RESERVOIR

Geomembrane was selected as an important element of a very unique pilot project - the world's first seawater pumped-storage power plant. Utilization of seawater was conceived for power generation

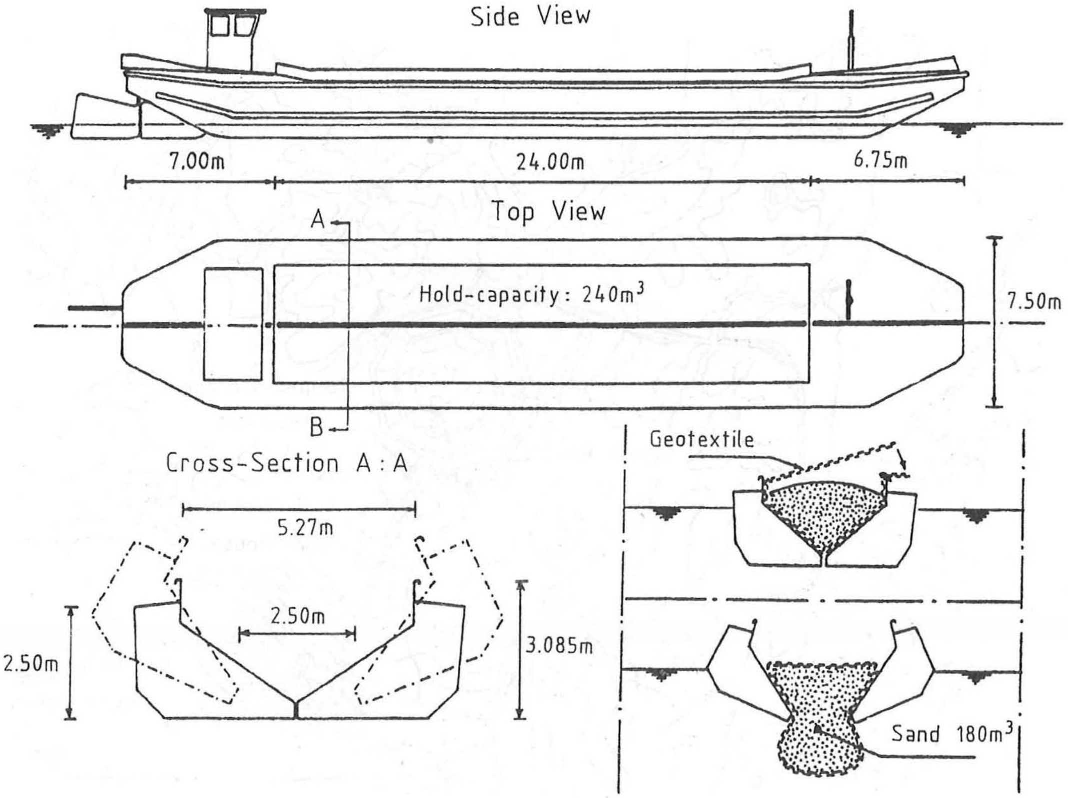


Figure 1: An Example cf Installation of a Geocontainer (Ref. 1)

(30 MW) in Okinawa Island by providing an upper reservoir, 252 m across and with the maximum depth of 25 m, on a plateau 150 m above sea level with the Pacific Ocean nearby serving as its lower reservoir, see Figures 2 and 3 (Ref. 4). It is a pilot project, sponsored by the Ministry of International Trade and Industry of the Japanese Government, exploring the feasibility of such an energy conservation system which makes use of seawater. The purpose of this project also includes evaluation of suitable construction materials, required structures, environmental impacts and operational performance.

The use of geomembrane as a liner of a reservoir is nothing new. The lining in this case, however, has to prevent seawater from seeping into the ground that would contaminate the precious groundwater resource in an island and has to withstand daily cyclic filling and emptying of seawater which may be coupled with violent wind forces due to frequent typhoons attacking this subtropical area. That is, the lining has to be sufficiently stable against strong winds when the reservoir is empty and has to be resistant to deterioration due to marine organisms in addition to the regular requirements such as durability, resistance against ultraviolet rays and ozone, permeability of the material and joints, etc.

After a careful comparative study, a synthetic rubber (EPDM) sheet, 2.0 mm thick, was selected as the most satisfactory, cost-effective lining material. A layer of nonwoven spun-bonded polyester fabric, 800 g/sq.m, was placed as a cushion beneath the EPDM sheet on a layer of crushed rock. This tansition layer, 0.5 m thick, of compacted crusher-run material with a maximum size of 20 mm was laid to dissipate pore pressures of groundwater rising from the underlying relatively impervious subgrade, to release residual air and to drain seawater in the event of leakage through the lining.

The membrane liners covered the slopes, 1 on 2.5, and the flat bottom of the reservoir. Special U-

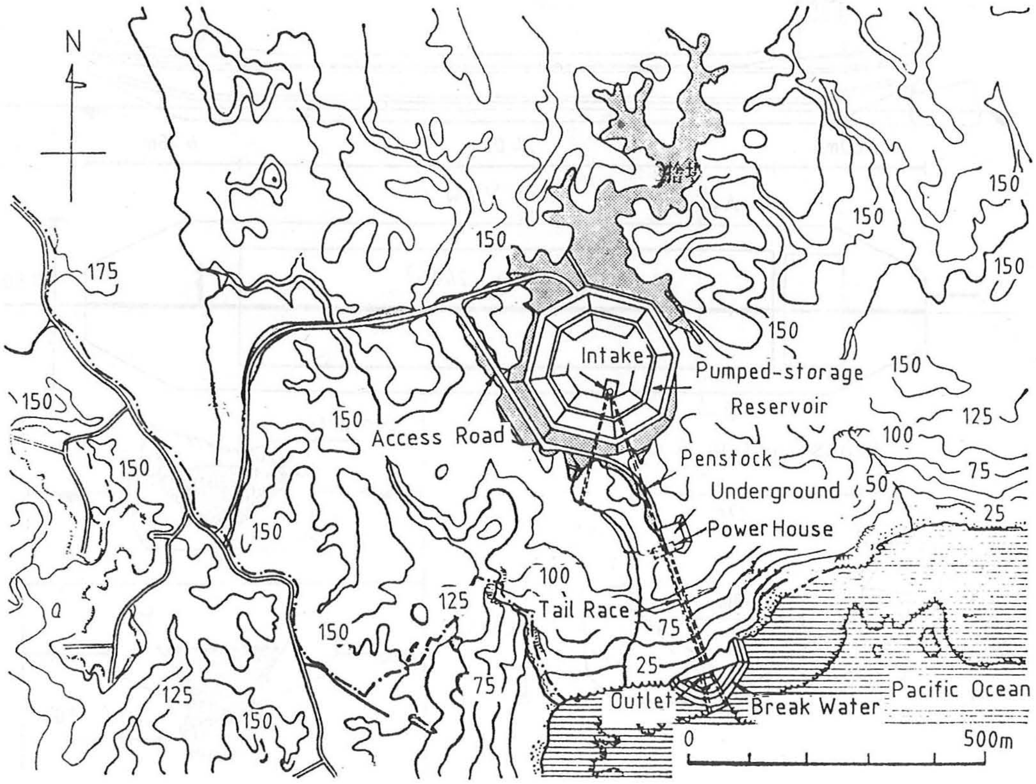


Figure 2: Site Plan of the Sea Water Pumped- Storage Project (Ref. 4)

shaped concrete blocks with PVC pipes built-in for drainage were prepared and installed to anchor the shop-welded geomembranes of limited size. These anchors were placed, therefore, at spacings of 8.5 m on slopes and 17 m at the bottom to avoid on-site welding of the membranes. The U-shaped channel was subsequently filled with concrete and covered by the same EPDM sheet sealed by adhesive tapes. Liner joints were tested wth application of cyclic water pressures as well as the regular vacuum applications. The lining system, when the reservoir was empty, has been attacked by several typhoons and has successfully survived winds up to 49 m/s with no damage.

An inspection gallery has been installed in the bottom of the reservoir along its inside periphery and contain pipelines and pumps to collect leaked seawater, should leakage take place, and to return it to the reservoir. The pipelines are equipped with detectors to sense salinity electrically and to measure leakage flow. The slopes and bottom areas of the reservoir are divided, respectively, into 55 and 9 independent sections, each of which can be monitored and controlld, should lining failure arise. The gallery is also designed to drain groundwater to be led to nearby streams.

Construction of this project started in 1990 and the lining work was completed in 1996. The reservoir has since then been filled with fresh water with the leakage detection system at work. A 5 year test operation will commence in 1999 (Ref. 5).

An idea of providing a pumped-storage dam utilizing seawater may be attractive and may trigger high expection for efficient conservation of clean energy for a highly industrialized area located near the seashore where the source of energy is limited to steam-generated electricity coming from fossil fuel and/or nuclear energy. Geomembrane technology will assure watertightness of the lining of the reservoir required as a satisfactory, cost-effective, environment-friendly solution.

LEAKAGE DETECTION AND REMEDY FOR DAMAGED LINING

Geomembrane lining is a vital part of the enclosure system for waste disposal and liquids. Leakage through lining has to be prevented, but appears to be almost inevitable for one reason or another. Effective, reliable monitoring systems are called for to detect damage and leaks and to pinpoint their locations. Also it is highly desirable to incorporate remedial measures or self healing mechanism into the lining system. Considerable efforts have been made to construct and maintain more complete enclosure systems. A few of them that follow are not entirely new nor have been widely accepted. Yet they seems to indicate a direction for a realistic solution of this problem.

A Leakage Detection System: A new product of double liner geomembrane incorporates an electric detection system. A spiral copper wire is weaved into a woven sheet on 0.6 m spacings. This woven is

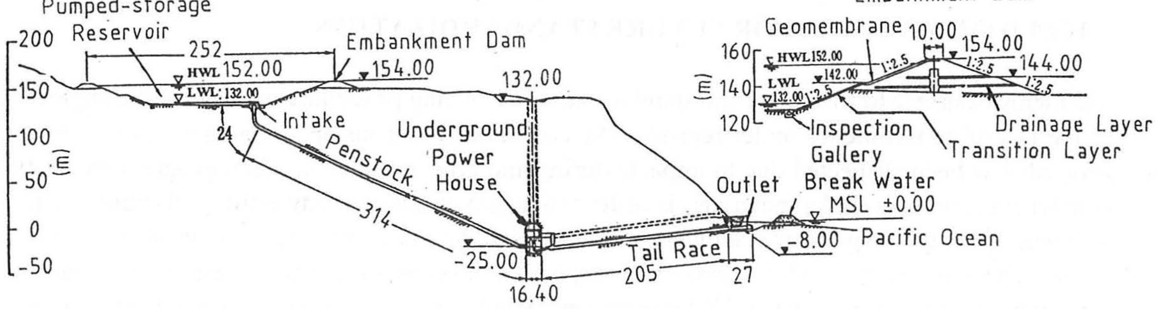
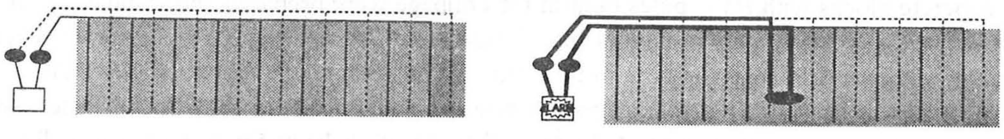


Figure 3: Cross-Section of the Sea Water Pumped-Storage Power Plant (Ref. 4).



(a) No electricity flows between two systems indicated by solid and dotted lines

(b) Leaked liquid produces a closed circuit to give the alarm

Figure 4 An electric leakage detection system (Ref. 6)

sandwiched by geomembrane sheets. Every other wires are connected together as shown in Figure 4. Should damage take place in the membrane and leak result, an electric circuit closes within the inundated woven fabric and the location of the damaged portion may subsequently be determined (Ref.6).

Detection with a Remedial Measure: A double liner enclosure system consists essentially of the upper and lower geomembranes sandwiching highly permeable net-like sheet and area-wise, of independent airtight sections, each 200 to 500 sq. m. Each section can be tested by vacuum application during installation and can be monitored anytime after completion. Each section is connected by a pipe to the central control board. Should leakage be detected in any section, as a quick temporary repair, leaked liquid can be sucked out through the pipe by vacuum or pushed back into enclosed wastes by applying high pressure. As a permanent remedy, grouting can be accomplished into the damaged unit of the lining and can even be repeated if necessary (Ref. 7).

Self Healing Geocomposite: The new geocomposite for lining is composed of four layers having a total thickness of 2.2 mm. The main layer of synthetic rubber containing water-adsorbing resin is sandwiched by the upper and lower rubber (EPDM) geomembranes and the lower sheet is covered by a polyester fabric base. When sharp-edged objects such as nails, pieces of glass, etc, cut into the lining material, holes or cuts close quite tightly due to the highly elastic nature of the core layer. Subsequently its ability to suck water and swell heals the wounds by itself if the damage is not too serious (Ref. 8). The idea is essentially the same as the geosynthetic clay liner that takes advantage of the swelling nature of bentonite when it is exposed to water.

None of the foregoing schemes are dramatically new, but each has its novel practicability. The first two are equipped with a leakage detection system making use of electricity or air pressure, whereas the third one is a care-free self-healing system which requires no monitoring. The products and the systems in the above three have been tested extensively in laboratories and under field conditions so far with satisfactory results. Each appears, therefore, promising depending upon given conditions.

A FIELD IMPACT TEST FOR FUTURE STANDARDIZATION

It is highly desirable to formulate and standardize a field testing procedure to evaluate the engineering properties of geosynthetics under reproducible conditions. For instance, damage to reinforcement geogrids has been suspected due to impacts during and after installation when geogrids are in direct contact with coarse granular materials. In order to assess their survivability in the field condition, a full-size field test employing heavy machinery was conducted by a research organization (Ref. 9) on geogrids which were sandwiched by layers of three types of coarse-grained soils; a) a well-defined sand with fine gravel, b) crusher-run gravel, 37.5 mm maximum size and c) crushed rock, 300 mm max. Geogrid manufacturers generally perform similar impact tests of their own. However, the testing conditions and the soils used vary so widely it is virtually impossible to evaluate the properties under field impact loads.

In the test field, a total of 14 sheets of different geogrids, each 20 to 40 sq. m in area, was tested simultaneously under identical conditions in the following manner: 1) a 300 mm thick granular bed was first placed on the ground and compacted to form a level surface, 2) a geogrid was laid on and pinned to the bed in each test area, 3) a layer of soil was hauled and spread out on the geogrid by a backhoe and rolled by a 21 ton bulldozer, 4) the 300 mm soil cover was compacted by 7 passes of a 9 ton vibratory roller capable of exerting 100 kN dynamic forces, and then 5) the geogrids were exhumed, visually examined and then tested for tensile strength in the laboratory. In addition, 6) the exhumed geogrid specimens were kept immersed in 6 different liquids maintained at 50°C for periods of 250, 500 and 1000 hours, and then tested for tensile strengths. The liquids used were distilled water, 3% NaCl solution and 0.1% solutions of NaOH, $Ca(OH)_2$, H_2SO_4 and HCl. Five specimens each were tested under each condition and later subjected to tensile strength tests with a strain rate of 20 %/min.

No geogrids appeared badly damaged with no visibly fractured strands when excavated out. Losses in strengths due to the field impact test were relatively minor ranging from practically none to less than 20% with most of them retaining their designated strengths. The liquid immersion tests on most of the exhumed specimens resulted in minor effects, but significant reductions in strengths as much as 20 - 30% were noted in some samples.

It appears still premature to establish a standard testing procedure for a field test of this nature in which its practicability and repeatability can be assured, or else to establish a laboratory testing procedure to simulate such field conditions. It is important to note, however, that significant strength losses of some geogrids could result under such test conditions and a unified test procedure is urgently needed, for impact loading during installation could damage geogrids and lower the strength significantly unless due care is taken in the field. By the same token standardized procedures for other field performance tests, notably to determine hydraulic properties under realistic field conditions are urgently needed and it takes more innovative efforts.

CONCLUDING REMARKS

The writer (Ref. 10) earlier commentated the satisfactory performance of a geosynthetic-reinforced retaining wall which had survived the strong-motion earthquake of January 17, 1995 in Kobe, Japan. This wall with rigid facing was designed on the basis of a new concept to which much of the success could be attributed. Another topic discussed was a unique environment-friendly method to revegetate slopes by forming an artificial vegetation bed reinforced by continuous thread even on steep slopes of hard rocks and lean soils. All the topics including these two are just a few examples of the remarkable progress of geosynthetics engineering and at least some of them are in the process of shaping up to a new technology.

The interdisciplinary nature of geosynthetics engineering calls for the knowledge and experience of quite a few well-established disciplines of technologies. It takes textile and polymer engineering to create better products and does take geotechnical and environmental engineering to make use of them wisely. It indeed takes concerted diversified expertise to cultivate an interdisciplinary field like geosynthetics engineering and still takes more efforts to develop new technologies.

As geosynthetics replace conventional materials and methods, the state of the art has reached the point where more economical, safer earth structures may no longer be built without the use of geosynthetics.

As a construction material a geosynthetic may have engineering properties superior to its predecessor, but it should be kept in mind that a geosynthetic should perform satisfactorily when it is buried in soil as an integral and vital part of an earth structure to last for many years to come.

The importance of fundamental understanding of soils and earth structures cannot be overemphasized as well as that of taking the maximum advantage of the knowledge and experience accumulated over the years in the field of geotechnical engineering in particular. The use of geosynthetics has not solved all the problems nor will it be able to. Yet the writer feels he has reasons good enough to believe in new technologies evolving out to realize a great future potential of the art of geosynthetics engineering.

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