'96 Geosynthetics Conference / 3 December, 1996 / Seoul / Korea

CURRENT USE AND PROSPECT OF GEOSYNTHETICS IN JAPAN

Toshinobu Akagi
Department of Civil Engineering, Toyo University
Kawagoe, Saitama, Japan

ABSTRACT

The civil engineering use of geosynthetics in Japan is summarized based on the questionnaire surveys of quantities of geosynthetics used in Japan in 1991 and 1993. Replacing conventional materials and methods quite rapidly, the use of various geosynthetics has reached the point where they are considered indispensable for safe, economical construction and maintenance of earth works and other civil engineering structures. Introduction with brief discussions is given to some of the unique methods developed and/or used extensively in Japan including geosynthetic-reinforced soil retaining walls, revegetation bedding reinforced with continuous yarn and prefabricated band-shaped drains.

INTRODUCTION

The Japan Chapter of the International Geosynthetics Society(JC-IGS) conducted questionnaire surveys of quantities of geosynthetics used in Japan in the years 1991 and 1993 (JC-IGS, 1993 and 1995). The results indicate that the geosynthetic products excluding EPS used in Japan totaled roughly 80 million and 91 million square meters, in these years, respectively, as summarized in the following. The numbers shown below are to be multiplied by million square meters and those in parentheses indicate the percentages in each year:

	1991	1993
Wovens	27.00(33.6%)	17.00(18.8%)
Knitted	0.03(0.0%)	0.14(0.2%)
Nonwovens	34.00(42.3%)	43.00(47.6%)
Geonets	2.50(3.1%)	2.40(2.7%)
Geogrids	3.50(4.4%)	7.80(8.6%)
Vertical drains	1.00(1.2%)	2.20(2.4%)
Geomembranes	9.70(12.1%)	14.00(15.5%)
Geocomposites	1.40(1.7%)	2.50(2.8%)
Others	1.20(1.5%)	1.30(1.4%)
Total	80.00(100.%)	91.00(100.%)

The questionnaire surveys were conducted only twice in the past with the third one for the year 1995 currently in progress and will be completed shortly. Although it seems still premature to establish the general trend, the difference between the two totals suggests an annual increase on the order of 7%. Marked increases are noted in the use of nonwovens, geogrids, vertical drains(prefabricated band-shaped drains), geomembranes and geocomposites, while the use of wovens was reduced drastically during the two-year period.

The responses to the questionnaires indicate the following usages of various geosynthetic materials, although the quantity for each usage is undetermined:

Wovens(stabilization of soft ground, prevention of wash-out, prevention of scouring, dike protection, silt fences, underwater mats, reinforcement of embankments)
Knitted fabrics(prevention of scouring, filters, cleaning of contaminated soils)
Nonwovens(prevention of wash-out, prevention of scouring, drainage for embankments, drainage for tunnels, separators, stabilization of soft ground, prevention of grass growth, protection of membranes, shock adsorbers, filters)
Geonets(stabilization of soft ground, hurdles for river dikes, controlling lifts, reinforcements)
Geogrids(reinforcement of embankments, stabilization of soft ground, pavement reinforcement)
Vertical drains(drainage/settlement control, landfills)
Geomembranes(landfill linings and covers, hydraulic barriers for channels, reservoirs, ponds and tunnels, tanks, prevention of scouring)
Geocomposites(drainage/reinforcement, moisture barriers, slope protection)
Others(fabric concrete forms, revegetation, etc.)

The use for pavement reinforcement and landfill linings and enclosures in Japan appears still limited as compared with those in Europe and North America. While the former use is not expected to increase too markedly in the immediate future, the latter will probably grow rapidly as the environmental regulations call for more complete enclosure systems.

The JC-IGS distributed questionnaires to some 90 manufacturers and distributors in Japan dealing with geosynthetic materials for civil engineering uses and obtained 63 and 73 replies, respectively, during the surveys for the years 1991 and 1993. Admittedly some overlaps and missing elements are inevitable, but it is believed the statistics obtained by these surveys are of reasonable accuracy and reliability. The JC-IGS hopes to continue the survey once every two years to grasp the current status and technical needs of the geosynthetic engineering in Japan.

GEOSYNTHETIC-REINFORCED SOIL RETAINING WALL SYSTEM

A unique method of constructing geosynthetic-reinforced walls has been developed in Japan for railway embankments since around 1982. The study on this use of geosynthetics won an IGS Award in 1994 (Tatsuoka, et al 1996a) and suggests considerable future development as an economically attractive, structurally reliable solution that makes full use of geosynthetics. The following introduces briefly the geosynthetic-reinforced soil (abbreviated as GRS hereinafter) retaining wall system(Tatsuoka, et al 1996b).

Figs. 1 (1) through (6) illustrate the standard construction procedure. Firstly, proper foundation treatment is provided if required and a concrete base is cast (1). A sand bag or a gravel-filled gabion is placed at the outer edge (2) and a lift of soil is placed and compacted to a 300 mm thickness on a geosynthetic reinforcement sheet of geotextile or geogrid (3). This procedure is repeated until the intended height of the wall is reached (5). After the constructed wall settles and deforms until a certain state of equilibrium is reached, a cast-in-place lightly reinforced concrete facing is installed directly on the GRS wall (6).

Extensive research and field investigations on a number of full size GRS retaining walls have demonstrated that the stage construction method shown in Fig. 1 minimizes post-construction deformation of the wall system, with practically no differential settlements to take place between the rigid facing and GRS backfill, and also that the full height rigid facing significantly increases the stability of the GRS wall system and enables to reduce the length of reinforcement. Theoretical and experimental studies have been conducted on the effects of facing rigidity and relatively short reinforcement on the performance of GRS retaining walls, which characterize this method and distinguish it from the other types of geosynthetic-reinforced retaining walls having discrete element units for facings (Tatsuoka, 1993 and Helwany, et al 1996).

Since the R & D study has been conducted by the Railway Technical Research Institute in corporation with the University of Tokyo, this scheme has been employed mainly for construction of railway embankments, typically 5 m high (the maximum height is 10 m so far), now totaling approximately 20 km in length at some 80 sites. Since this technique was approved by the Ministry of Transport in 1992, it has found its way to implementation also for highway projects.

The majority of GRS applications implemented so far is in connection with construction of additional railway tracks to the existing ones by installing a vertical GRS retaining wall to widen the existing embankment. As a typical example, Fig. 2 shows a GRS retaining wall constructed in 1992 in Kobe to add a new railway track to the existing four. Being vertical this wall made the maximum use of the available right of way resulting in a great economy. This wall system ranged from 1.5 to 6 m in height and extended to a length of 305 m. The railway alignment runs in the east-west direction roughly along the boundary between the foot of Mt. Rokko on the north and an alluvial fan consisting primarily of sand and gravel on the south. The GRS retaining wall guards the railway embankment on the southern side.

On January 17, 1995, Kobe was hit by a disastrous earthquake. Countless civil engineering structures collapsed or suffered severely; retaining walls of various types were no exception. In the quake-afflicted area, GRS retaining walls had been constructed at 4 sites amounting to a total length of 2 km, 3 of which survived with no damage but the one described in the above showed some signs of distress.

This GRS retaining wall is located in the eastern end of Kobe and the area on the south adjacent to this wall was one of the hardest hit with roughly 80% of the houses totally demolished. The horizontal(E-W) and vertical accelerations recorded were no less than 775 and 379 gals, respectively, at an observation station located about 1 km west of this site.

Relative outward and inward movements with respect to the adjacent rigid facing units of the GRS retaining wall were noted with slips up to 100 mm detected at the top of the wall in the direction perpendicular to the wall face at some of the expansion joints of concrete facings. On its western end where the GRS retaining wall is 6 m high and is in contact with an RC underpass structure, however, the perpendicular slip was about 260 mm at the top and 100 mm at the base.

On its other side the underpass structure is in contact with an L-shaped RC retaining wall, 5.8 m high and 51 m long, supported by massive cast-in-place concrete piles, 1.2 m in diameter, installed to a depth of 6 m on 3 m spacings. It was found that this RC wall had also moved southward 215 mm at the top and 100 mm at the ground level with respect to the RC underpass structure during the quake.

Generally no excessive settlements took place at the top of the GRS backfill near the wall, but the maximum settlement amounted to roughly 150 mm. However, deformations and movements of the GRS were relatively small requiring only minor repair. In contrast with these, the original unreinforced embankment subsided and moved so much that rails on it buckled and distorted badly calling for reconstruction work.

Because of the satisfactory behavior of the GRS retaining walls during the strong motion earthquake, the masonry and concrete retaining walls for railway embankments which were badly damaged or totally destroyed have been replaced by new GRS retaining walls which now total approximately 1.5 km in length in the Kobe area (Tatsuoka, et al 1995).

The GRS retaining wall system is capable of supporting bridge abutments directly. Fig. 3 (a) shows a longitudinal section of such bridge abutments with footings for a bridge girder placed directly on the GRS. This bridge is part of a 110 m railway approach embankment constructed in Tokyo in 1994, ranging from 1.7 to 6.0 m in height, which has a typical cross section, Fig. 3 (b) (Haga, et al 1994). This GRS retaining wall system was heavily instrumented, showing satisfactory performance and stability under actual train loading.

In 1994 a railroad yard was constructed on an embankment with a GRS retaining wall, 2 m high, 100 m wide and 1800 m long on a thick soft clay deposit in Nagano. The fill material was a locally available highly weathered tuff which was a wet clay classified as CH having a natural water content of 32.5% with a plasticity index of 29.2%. The use of woven-nonwoven composites for reinforcement and drainage made it possible to utilize such cohesive material usually considered unsuitable for filling.

A 2.5 m preload was placed on the GRS embankment to induce almost 1 m of settlement before concrete facing was cast on the vertical wall. Although the completed GRS retaining wall is only 2 m high, it has demonstrated that clay backfill may be utilized for a permanent GRS embankment instead of granular backfill which was otherwise to be imported from a distant borrow area. The use of cohesive fill material available at or near the site results in a considerable economy (Tatsuoka, et al 1996b).

The GRS retaining wall system thus 1) is very cost effective, 2) is sufficiently stable and safe as a permanent earth structure, 3) may have a durable, aesthetically acceptable facing, 4) has rigid concrete facing which is capable of supporting relatively light loads such as electric poles, noise barriers, fence, etc., yet requiring no deep foundations, 5) may use not only granular backfill but locally available clayey material with the use of woven-nonwoven geotextile sheets as reinforcement-drainage elements and 6) exhibits only small deformations well within a tolerable limit even during a strong-motion earthquake, should the foundation condition be reasonably good or properly improved.

REVEGETATION BEDDING REINFORCED BY CONTINUOUS THREAD

As an effective means to revegetate slopes and to restore the natural environment, a unique environment-friendly method has been developed to form an artificial vegetation bed reinforced by continuous thread even on steep slopes of hard rocks and lean soils. This method was derived from the Texsol method (Leflaive, 1988) which reinforces sand with continuous yarn and has been known as the Texsol Green method (Yokotsuka, 1991). Slurry of a mixture of grass seeds, cohesive soil and chemicals including a fertilizer, a stabilizer and an aggregation agent is shotcreted with continuous polyester yarn through a nozzle and sprayed on a slope to form a 10 to 100 mm thick bed for vegetation.

Soil mixed in the slurry consists of sand(50-58%) and silt-clay(42-50%). The stabilizer is a special asphaltic emulsion. The seeds are not only of the herbaceous plants but of the arboreous which develop much firmer roots even into cracks in rock slopes and contribute to more perpetual vegetation. The sprayed slurry forms a granulated soil base porous enough to maintain moisture and to ventilate the voids adequately for growth of vegetation.

For slopes steeper than 1 on 1, they are first covered with steel nets or polymeric geogrids anchored by steel pins before the artificial bed is placed. The thread reinforcement makes it possible to keep the bed placed even on slopes as steep as 3 on 1 resistant to erosion due to rainfall and to support the plant life on a permanent basis.

The Texsol Green method has been applied for successful revegetation of steep lean slopes, notably cut slopes along highways in Japan, totaling approximately 7.3 million square meters as of the end of March 1996. This technique won a JSCE technical award in 1989 and an official approval by the Ministry of Construction in 1992.

PREFABRICATED BAND-SHAPED DRAINS

Earlier the writer reported on the problems related to prefabricated band-shaped drains as an example to illustrate the filtration and drainage characteristics of geosynthetics which are in intimate contact with soil (Akagi, 1994). All the problems raised therein seem to stay with us with no significant progress thereafter.

The prefabricated band-shaped drain (abbreviated as PD hereinafter) has to satisfy all the requirements for filtration and drainage as a geocomposite and in addition will have to survive all perils of large deformations and high pressures from the surrounding soil. The hydraulic conductivity and compressibility of the soil in the immediate vicinity are greatly influenced by the installation method and subsequent performance of the geosynthetic drains.

"Filtration" permits porewater in the clay to infiltrate across a band-shaped geotextile filter into continuous small holes, grooves or channels in a plastic core encased by filter fabric and "drainage" allows water to flow vertically through the longitudinal channels in the core to drainage layers of granular soil overlying and/or underlying the soft clay stratum.

The displacement type installation method is by far most popular employing a steel mandrel which penetrates into soft soil by static or vibratory force applied to it. The mandrel encases a PD to protect it during installation and creates the necessary space for the PD by displacing the soft clay. This forced displacement very considerably disturbs the soil in the immediate vicinity of the PD installed creating a smear zone around it. The degree of disturbance and the extent of the smear zone depend upon the size and shape of the mandrel as well as the soil properties, the installation method, etc.

In addition to the basic requirements for filtration and drainage as geocomposites, PD's as vertical drains will have to cope with such problems as: 1) decreases in discharge capacity as confining pressures increase, as a PD deforms badly or bends sharply in the clay which consolidates as much as a few tens of percent, as the length of a PD increases when it is extended down to great depths, and due to other causes, 2) formation of a smear zone around a driven PD and also formation of a transition filter zone around a PD which causes migration of fine particles leading to clogging of filter and flow paths in the core, and 3) evaluation of the equivalent diameter of a band-shaped PD when Barron's formula is applied to the design of a PD installation.

It is apparent that PD's have far superior engineering properties than those of sand drains in terms of hydraulic properties, strength characteristics, durability, reliability, ease of placement and even economy. But PD's are still installed essentially in the same way, disturbing the soil around them and being influenced by the surrounding soil probably to a somewhat less extent but suffering from the same old problems.

In fact it is still difficult to predict or ascertain satisfactory performance of a particular type of PD during the design stage. It is extremely hard, therefore, to select the best type that satisfies the site-specific requirements. Only few large projects have been able to conduct a comparative field study to assure the best choice. There are no well established standard procedures nor testing criteria to compare various PD's which have considerably different characteristics. There have been urgent needs for such, however, and Table 1 gives one such example of the selection criteria specifying proposed values of the properties and capacities that PD's have to possess in order to be considered for a large project in the Southeast Asia (Private communication, 1994).

CONCLUDING REMARKS

This invited lecture briefly summarizes the present and future of the versatile and extensive use of geosynthetics in Japan, as well as some of the unique applications developed and used successfully. The usage in Japan has steadily been growing and is expected to grow at a fairly rapid rate in the future. What follows is the writer's observation and belief of the state of the art of geosynthetics engineering not only in Japan but in various parts of the world.

Recent years have seen a marked progress in practice-oriented knowledge of the properties and behavior of geosynthetics, wide-spread use of index and performance tests both in the laboratory and in the field, and many diversified practical applications of a wide variety of geosynthetic products to various engineering problems. As geosynthetics have replaced conventional materials and methods, we have reached the point where we can no longer construct safer, more economical earth structures without the use of geosynthetics.

As a construction material a geosynthetic may have engineering properties superior to its predecessor, but we should realize that we have neither verified nor defined well enough the properties and performance of a man-made polymer product when it is placed on or buried in the soil as an integral and vital part of an earth structure to last for many years to come. It should be kept in mind, therefore, that it is the soil, the geosynthetic and the interactions between the soil and the geosynthetic that determine the performance of an earth structure under critical conditions.

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 a great future potential of the art of the rapidly growing geosynthetics engineering.

ACKNOWLEDGMENT

Appreciation is due to Mr. M. Tateyama of the Railway Technical Research Institute and to Mr. K. Ozaki of Kumagaigumi, Ltd. for providing the writer generously with the up-to-date information, respectively, on the GRS retaining wall system and on the revegetation bedding method.

REFERENCES

Akagi, T. (1994) "Hydraulic applications of geosynthetics to some filtration and drainage problems - with special reference to prefabricated band-shaped drains," Keynote Lecture, Proc., 5th International Conference on Geotextiles, Geomembranes and Related Products, Singapore, Preprint, 99-119 (to be published in Vol. 4).

Haga, T., Ohira, K., Fuwa, H., Tateyama, M. and Kojima, K. (1994) "Construction of Geosynthetic-reinforced retaining walls for a railway approach embankment," Proc., 49th JSCE Annual Meeting, 1624-1625. (in Japanese)

Helwany, M. B., Tatsuoka, F., Tateyama, M. and Kojima, K. (1996) "Effects of facing rigidity on the performance of geosynthetic-reinforced soil retaining walls," Soils and Foundations, Vol. 36, No. 1, 27-38.

JC-IGS: Japan Chapter of International Geosynthetics Society (1993, 1995) "Geosynthetic Technical Information" Vol. 9, No. 2, 3-9, Vol. 9, No. 3, 8 and Vol. 11, No. 1, 10-14. The results of the 1995 survey will be published in Vol. 13, No. 1 in March, 1997. (all in Japanese).

Leflaive, E. (1988) "TEXSOL: Already more than 50 successful applications," Proc., International Symposium on Theory and Practice of Earth Reinforcement, Balkema, 541-545.

Tatsuoka, F. (1993) "Roles of facing rigidity in soil reinforcing," Proc., International Symposium on Earth Reinforcement Practice, Balkema, Vol. 2, 831-870.

Tatsuoka, F., Koseki, J. and Tateyama, M. (1995) "Performance of geogrid-reinforced walls during the Great Hanshin-Awaji Earthquake, January 17, 1995," Proc., First International Conf. on Earthquake Geotechnical Engineering, Balkema, Vol. 1, 55-62.

Tatsuoka, F., Tateyama, M., Murata, O. and Tarumi, H. (1996a) "Applications of geosynthetic-reinforced soil retaining walls to railway embankments in Japan," IGS News, Vol. 12, No.1, 4-5.

Tatsuoka, F., Tateyama, Uchimura, T. and Koseki, J. (1996b) "Geosynthetic-reinforced soil retaining walls as important permanent structures," Mercer Lecture, Proc., First European Geosynthetics Conf.- EuroGeo 1, Balkema, 3-24.

Yokotsuka, S. (1991) "Re-vegetation method using continuous fibers," IGS News, Vol. 7, No. 3, 13.

SKL9611(22)

Table 1 An example of selection criteria for prefabricated band-shaped drains (Private communication, 1994)

Properties	Test Designation	Proposed Values
Apparent Opening Size, μm	ASTM D4751-87	Less than 90
Grab Tensile Strength, kN	ASTM D4632-91	Greater than 0.35
Trapezoidal Tear Strength, kN	ASTM D4533-91	Greater than 0.10
Puncture Resistance, kN	ASTM D4833-88	Greater than 0.10
Burst Strength, kN	ASTM D3786-80a	Greater than 900
Discharge Capacity @ 7 Days, 200 kPa at Hydraulic Gradient of 1, m^3/yr	ASTM D4716-87	Greater than 500
Discharge Capacity @ 200 kPa and Hydraulic Gradient of 1, m^3/yr	Modified Triaxial (Straight)	Greater than 500
Discharge Capacity @ 200 kPa and Hydraulic Gradient of 1, m^3/yr	Modified Triaxial (20% Compression, Free Bending)	Greater than 500
Discharge Capacity @ 200 kPa and Hydraulic Gradient of 1, m^3/yr	Modified Triaxial (20% Compression, twisted 45 degrees)	Greater than 500
Discharge Capacity @ 200 kPa and Hydraulic Gradient of 1, m^3/yr	Modified Triaxial (20% Compression, One Clamped)	Greater than 500
Equivalent Diameter = (Length + Width)/2		Greater than 50 mm
AOS/D_{85} (Opening Size of Filter/Grain Size of Clay)		Less than 2 to 3
O_{50}/D_{50} (Opening Size of Filter/Grain Size of Clay)		Less than 18 to 24

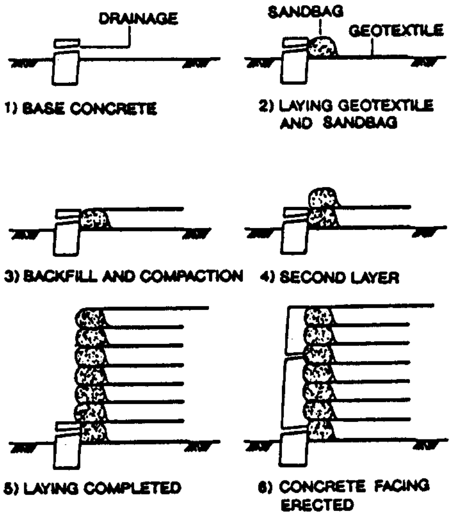


Fig. 1 Standard construction procedure of the GRS retaining wall system (Tatsuoka,· et al 1995)

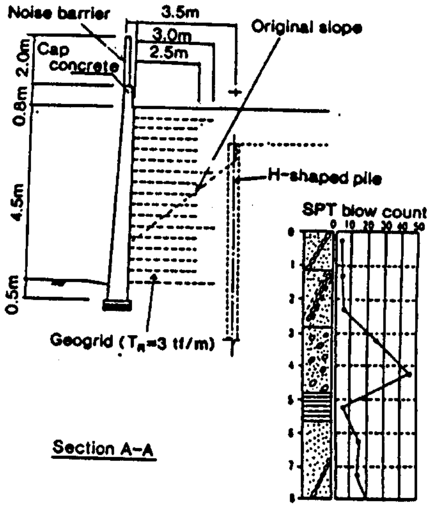
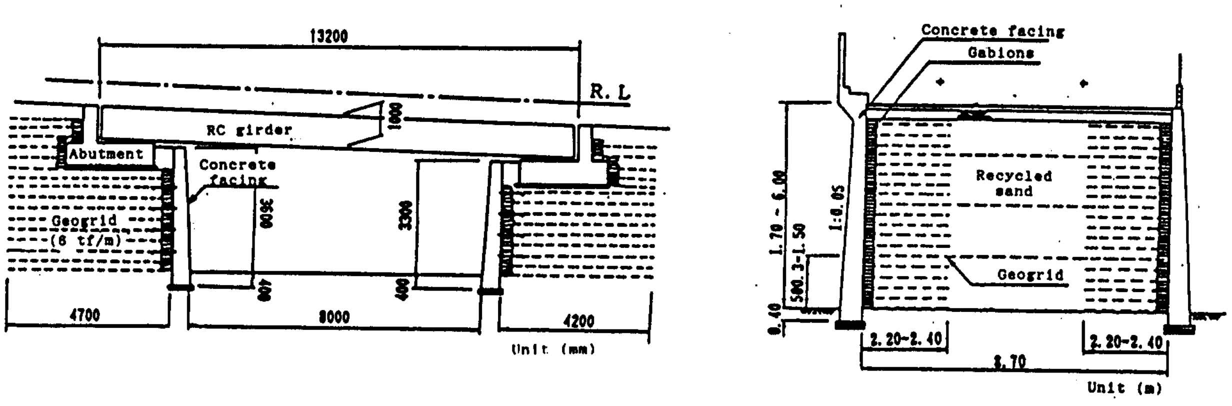


Fig. 2 Typical cross-section of a newly added GRS retaining wall for a railway embankment, Kobe (Tatsuoka, et al 1995)



(a) Bridge abutments with GRS retaining walls

(b) Typical cross-section of GRS retaining walls

Fig. 3 Railway approach embankment with GRS retaining walls, Tokyo (Haga, et al 1994)